NUMERICAL SIMULATION OF
WATERSHED HYDROLOGY

by

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Mathematical Simulation of Rainfall
Runoff Processes

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PREFACE

This research is part of a continuing effort at The University of Texas to develop methods for a numerical simulation of watersheds which will be both operational from the standpoint of engineering usage and realistic from the standpoint of simulating physical processes occurring in the watershed. It is felt that the simulation processes must be closely related to real physical processes if the method is to be useful in predicting the effect of changes that may occur in a particular watershed. It is hoped that in the future efforts can be made to correlate parameters used in the numerical simulation with physical observations made in specific watersheds, and to establish the correspondence between the physical processes occurring in the watershed and the numerical simulation of these processes.

The Stanford Watershed Model was studied as the first generalized watershed model that appeared to be generally available. It soon became apparent that it was difficult to obtain a clear understanding of the inner workings of the model. However, in making a detailed translation of the model into Fortran IV compiler language, a rather complete understanding of the model was achieved and is presented as a part of this report. As the study progressed, it became apparent that the model represented a tremendous breakthrough in hydrologic research. But as with most scientific breakthroughs, its greatest value was the demonstration of what could be done with continuous accounting modeling of a portion of the hydrologic cycle.

Two somewhat conflicting goals emerge as one builds a watershed model. First, the model must give engineering answers to the problem of hydrograph synthesis. The practicing engineer or hydrologist wants a design hydrograph whose accuracy is commensurate with the accuracy of the other variables in the problem. But the research hydrologist wants a model which as closely resembles natural processes as possible. Only with close modeling will he have a tool which will help to understand and explain the complex processes that occur in the natural watershed.

In this study emphasis was continually given to utilizing meaningful parameters for each process, and an attempt was made to model the various physical processes as closely as possible. Hence, evaporation occurs only during daylight hours, transpiration only from the root zone, soil moisture movement in the unsaturated zone is based on the unsaturated form of Darcy's law, etc.

Chapter 1 discusses the general runoff process, identifying the important physical processes. Standard methods of estimating the storm runoff and the hydrograph are reviewed in Chapter 2. An evaluation of the Stanford Watershed Model IV is given in Chapter 3. Chapter 4 contains a discussion of flow through unsaturated porous media, an area unfamiliar to most engineers. A modified watershed model is presented in Chapter 5 with applications reported in Chapter 6. Suggestions for areas of future research are given in Chapter 7.

ABSTRACT

The Stanford Watershed Model has been reviewed and used as a pattern for developing a new watershed simulation model. The new model incorporates considerable flexibility of input data and model time steps which were not available in the Stanford Model. New parameters describing the infiltration, evaporation, and soil water movement processes have been defined and related to physical properties of the watershed where possible. Application to two experimental watersheds are reported.

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Chapter 1

THE RUNOFF PHENOMENON

The runoff portion of the hydrologic cycle embraces those processes by which precipitation, after reaching the watershed with both time and areal distribution, is converted into streamflow at the basin outlet. Observation has led to satisfactory identification of these processes; however, mathematical models of the various processes are not well developed although much effort is currently being expended in this field. The interaction of the various processes is not well understood. In this chapter, each of the processes which affect the conversion of precipitation into streamflow will be examined in a qualitative way. Figure 1.1 identifies these various processes.

Interception Storage

Some of the water falling to the ground is intercepted by vegetation and by man made structures. This water is said to be in interception storage. Interception storage is characterized by fixed maximum volume (with regard to the time scale of one precipitation event, although it varies seasonally). This water never reaches the earth surface, but subsequently evaporates. The storage is filled by the earliest part of the precipitation. Some storage capacity is regained during periods of no rainfall within the storm. The volume of interception storage available is a function of the exposed surface area of intercepting surfaces. This area will change with the growing season, as well as with change in

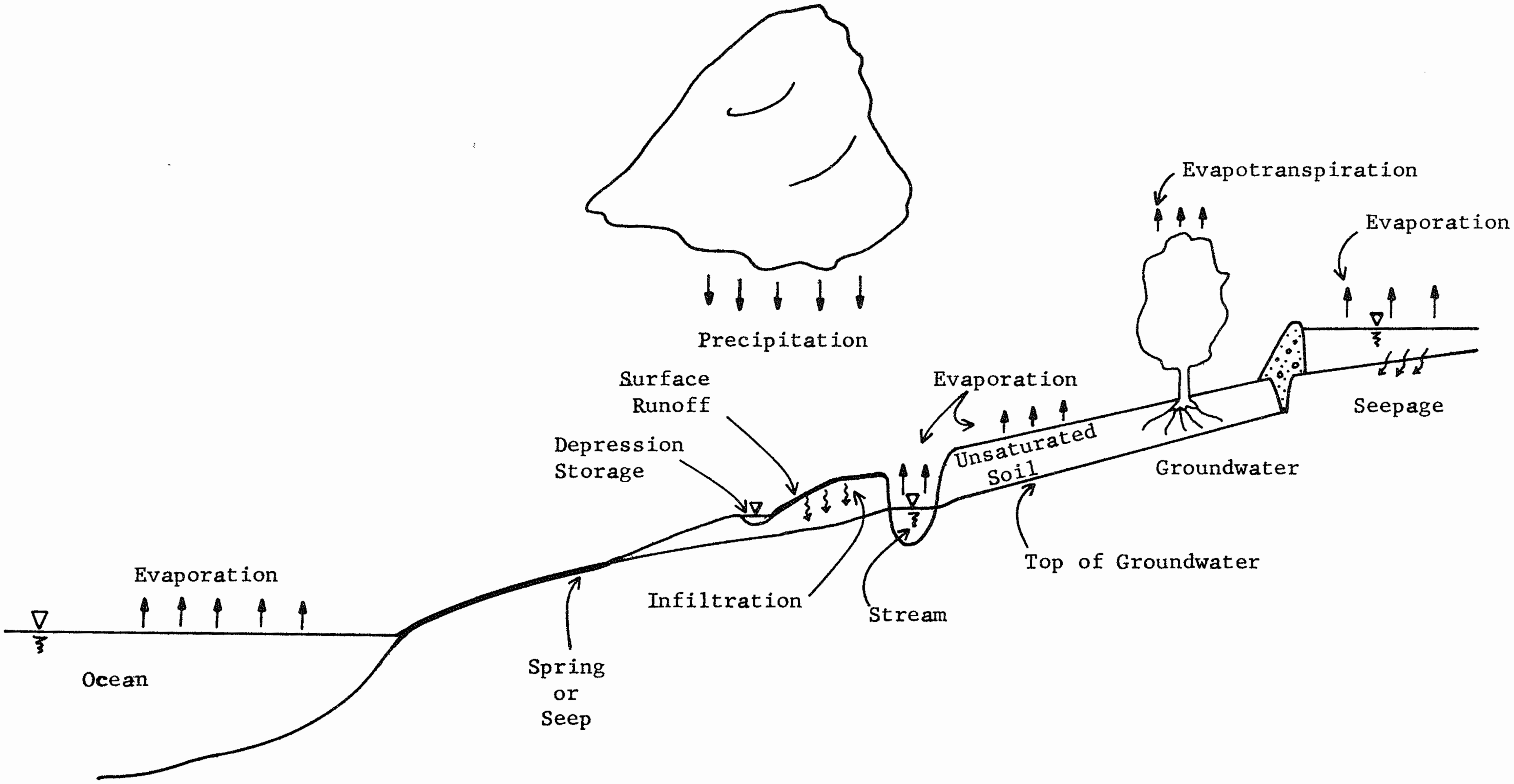


FIGURE 1.1 THE HYDROLOGIC CYCLE

land use.

Surface Depression Storage

This storage consists of cracks, crevices, depressions, and indentations in the earth's surface. If the watershed contains soils which exhibit shrinkage cracks upon drying, the volume of depression storage will decrease as the storm progresses. Water entering depression storage is removed by both the infiltration process and the evaporation process. The volume of surface depression storage available in a particular watershed depends on the nature of the watershed surface. Urban watersheds, in general, have much less depression storage volume than do agricultural lands, particularly agricultural lands where contour plowing and/or farm ponds are present. In agricultural watersheds, the condition of the land throughout the growing season will vary, causing a variation in the total depression storage volume.

Overland Flow and Overland Flow Storage

Overland flow, or sheet flow, is the flow of water at a small depth over the earth's surface. Overland flow provides the conveyance from the point where the water falls to the smallest "channel." It is essentially a two dimensional flow problem; the flow may be either laminar or turbulent. This process has been studied in detail both in theory and experimentally. Overland flow storage is water in transit in the overland flow process. It is a function of the length of the overland flow reach and the flow rate. Overland flow rate is a function of the length, slope, and roughness of the reach.

Evaporation

The process of conversion from liquid or solid state to vapor state occurs continuously at all water-air interfaces. Evaporation is responsible for removal of water from interception storage, from surface depression storage, from both overland flow storage and stream storage, and from the water contained in the soil structure. Water is also removed from plants by transpiration, a form of evaporation.

Evaporation is inversely related to the partial pressure (or humidity) and directly to available energy. Wind may prevent the air adjacent to an air-water interface from becoming saturated, and hence may increase evaporation. In general evaporation increases with increased temperature and wind.

Evapotranspiration varies widely with the plant species, as well as with the temperature.

Infiltration

Infiltration is the entry of water into the pore spaces of the soil. In general, water will infiltrate more rapidly into a dry soil than a wet one, and more rapidly into a sand than a silt. Infiltration rates tend to decrease as the volume of water infiltrated increases. Many empirical formula have been proposed for describing either the instantaneous infiltration rate, or the average infiltration rate. Infiltration occurs continuously from depression storage and overland flow storage, provided water is available for infiltration.

Soil Water Storage and Flow

Water stored in the soil is either in the saturated zone or the unsaturated zone. Storage in and flow through the saturated zone is probably the best understood portion of the hydrologic cycle. Flow is proportional to the driving force and inversely proportional to a resistance factor. Storage consists of the pore space of the soil matrix. Storage in the upper part of the unsaturated zone, commonly called the root zone, has always been of concern to agriculturists. In addition to saturation, these people define two other terms to describe the amount of water in storage in the root zone. Field capacity refers to that volume of water held by capillary forces in the pore spaces against the force of gravity. Wilting point is that volume of water present in the soil when permanent wilting of plants takes place. Water available for plant use is that between field capacity and wilting point. Depth of the root zone may vary; twenty-four to thirty inches is often cited as the range.

Flow through the unsaturated zone has only recently received attention from investigators. Since this process is also the topic of this investigation, discussion of the factors involved will be delayed until Chapter 4.

Stream Flow and Stream Storage

Stream flow is differentiated from overland flow by the presence of a width of stream, i.e., the flow is three dimensional in the stream. The hydraulics of open channel flow are well understood for streams of regular cross section. When inflow becomes a function of length, even these solutions are difficult. With the additional complexity of a natural channel, most investigators have turned to approximations. Best known of these is the unit hydrograph, which assumes a linear flow system. Another commonly used method is channel routing, where the continuity equation is combined with a channel equation. The channel equation describes the relation between the rate of inflow to a reach of the stream, the outflow from this reach, and the storage within the reach. Adequate channel equations do not exist, and approximations must be used.

Each of the processes sketched briefly here has been the subject of investigators in many different fields. An extensive list of references will be found in Chow (1964).

Chapter 2

METHODS OF ESTIMATING STORM RUNOFF

Many engineering design problems require an estimate of the response of a watershed to a "design" storm. Some of the more widely known methods are reviewed briefly in this chapter.

Methods of Estimating Runoff Volume

Soil Conservation Service Method: This method, developed by the Soil Conservation Service as a guide for their field personnel, is probably the most complete, comprehensive method available. It is based on observations made in many parts of the United States. The factors considered are soil type, land use, and land treatment. These are combined to give an index number, which is used in an equation together with rainfall to predict runoff volume. A table is provided for shifting the index to either a dry antecedent moisture condition (Condition I) or near saturated antecedent moisture condition (Condition III). The runoff equation is

$$Q = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \tag{2.1}$$

where Q is the direct runoff, in inches

P is storm rainfall, in inches, and

S is the maximum potential difference between P and Q in inches at time of storm's beginning.

The value of S can be estimated by the relation

$$\text{Index Number} = \frac{1000}{10 + S} . \qquad (2.2)$$

Coaxial Correlation: This method, proposed by Kohler and Linsley (1951), provides a graphical means of determining runoff from rainfall. The parameters used are antecedent precipitation index (API), the date of the storm, the amount of rainfall, and the duration of the storm. The API is an index to soil moisture, and hence, to infiltration. The time of year as reflected by the date is included to reflect the condition of the cover on the watershed, the likelihood of snow, and the condition of the soil surface. Duration provides a measure of average rainfall intensity. Recorded values of rainfall and concurrent storm runoff are required to derive the coaxial plot--in addition to a great deal of patience. The plot thus derived is applicable only to that particular basin. They have been applied, however, with good results to similar basins in the immediate vicinity. This method makes no attempt to model the rainfall runoff process, but rather represents a statistical approach.

Methods of Hydrograph Estimation, The Unit Hydrograph

The most popular method in use today is probably the unit hydrograph proposed by Sherman in 1932. The basic assumption made by Sherman was that the shape of the hydrograph was completely determined, except for a vertical scale factor, by the basin characteristics. Thus, a "characteristic" hydrograph of rainfall excess could be derived for any basin. By changing the ordinates of this graph, the area under the curve, corresponding to runoff, could be made equal to one inch of excess rainfall over the basin. Hence the name, "unit hydrograph." The hydrograph for any other storm of similar duration and areal distribution can be found by adjusting the scale of the ordinate until the runoff volume is correct. It has been pointed out by many investigators that Sherman's assumption is equivalent to assuming a linear response by the basin. However, the natural channel is a nonlinear device. In spite of this departure from basic assumption, the unit hydrograph continues to be used with seemingly satisfactory results by most engineers.

Methods of Estimating Peak Flow

Chow (1962) has described many methods which have been used to estimate peak flow rates for use in determining required waterway openings. Only two methods will be described here, the Rational Method, and a method due to the Soil Conservation Service.

Rational Method: The origin of this widely used method is not known. Chow (1964) traces it to Kuichling in 1889 in American literature and to Lloyd-Davis in English writings. This method assumes that, for a constant rainfall of sufficient duration, called the time of concentration, the runoff rate becomes a fixed fraction of the rainfall rate, or

$$Q = C\ I\ A \tag{2.3}$$

where Q is the runoff rate in c. f. s.,

I is the rainfall rate in inches/hour,

A is the area in acres, and

C is a runoff factor, varying from zero (no runoff) to one (impervious area).

When used for design work, it is necessary to choose the proper value of both the coefficient C and the Intensity, I. The intensity is normally determined by assuming the peak flow will occur when runoff is produced on all the area. Thus, the "time of concentration" (the time necessary for water from the most hydraulically remote part of the watershed to reach the outlet) determines the rainfall duration. This in turn, is used in an intensity-duration relation to determine the value of I. It is sometimes possible to obtain higher rates of runoff by using only a portion of the basin when estimating time of concentration. The shorter time of concentration will yield a higher intensity, which may more than compensate for the loss of area.

Soil Conservation Service: This method is not described because of special merit, but rather as typical of current developments. As described by Kent (1968), the method utilizes the excess runoff determined by the Soil Conservation Service method described earlier in this chapter. It is somewhat similar to the Rational Method, in that a basin lag time is determined from a time of concentration. A chart is provided so that lag time can be estimated from the index number used in the determination of excess rainfall. Thus, the retardedness of the land surface is reflected in the value of the lag time. Other factors involved in the lag time are basin area and average basin slope. Two standard time distributions of rainfall are used, one for the west coast of the United States, the Hawaiian Islands and Alaska; and the other for the remainder of the United States, Puerto Rico, and the Virgin Islands. Both distributions produce a low intensity rainfall during the first ten hours of a twenty-four hour period followed by a period of a very heavy rainfall, and finally another period of low intensity rainfall. The rainfall corresponds approximately to the twenty-five year frequency as shown in the Rainfall Atlases of the United States Weather Bureau. A triangular shaped hydrograph is assumed, with the peak runoff occurring at a time equal to the basin lag time plus one-half the storm duration. Peak discharge may be computed

$$Q_p = \frac{K\ A\ Q}{T_p} \tag{2.4}$$

where Q_p is the estimated peak rate of discharge

A is the area

Q is the storm runoff

K is a conversion factor, and

T_p is time to peak.

Equation 2.4 is for a uniform rain. In order to adapt this to the nonuniform standard rainfall, the equation was modified to

$$\Delta q_p = \frac{484\ A\ \Delta Q}{\frac{\Delta D}{2} + L} \tag{2.5}$$

where A is the area, in square miles,

ΔQ is incremental runoff volume, inches

ΔD is an incremental time, in hours

L is lag, in hours, and

Δq_p is the incremental peak discharge, in c. f. s., i.e. the peak of a triangular hydrograph containing Q volume of runoff.

These incremental hydrographs are combined linearly to produce the design hydrograph. The whole process has been programmed for a digital computer, and charts are included which allow reading of the peak runoff rate directly as a function of drainage area, slope, and basin index number.

Chapter 3

THE STANFORD WATERSHED MODEL IV

The processes discussed in Chapter 1 are interrelated, and to some degree simultaneous in action. Adding to this complexity is the fact that observations are not generally available from controlled experiments, but rather, from random events in nature. This lack of controlled experiments is one of the major obstacles to hydrologic research. The result has been a great many empirical runoff relations. A few of these were discussed in the last chapter.

With the advent of the high speed digital computer, it has become feasible to construct a mathematical model of the entire runoff process. At least three such models have been reported in the literature. Apparently the first embryonic attempt began in 1957 when Professor Ray K. Linsley of Stanford University attempted a very simple rainfall-runoff study with one of his graduate classes in hydrology. From this beginning and with the aid of many other people, notably Dr. Norman H. Crawford, the model to be discussed in this chapter has evolved. This model is not static; Model VI is being tested at Stanford.

A second model, reported by Rockwood (1958), and developed by the Corps of Engineers, and the Portland River Forecast Center for use on the Columbia River Basin, is also undergoing evolution, Kuehl (1967), Schermerhorn and Kuehl (1968), Rockwood (1968). This model lacks detailed simulation of the natural processes; it is in fact, essentially a flood routing model.

A third model has been reported by Boughton (1966) in Australia. This model was constructed with the Stanford model as a guide, and has as its distinguishing feature the use of daily rainfall data, rather than data from a continuous recorder. This, of course, has necessitated a longer scale of time for the model, with the resultant loss of detail. Other models have been reported by Holtan and Lopez (1969), by Dawdy (1969), and by Ayers and Balek (1968).

In addition to the work currently underway at Hydrocomp, Palo Alto, California, on the Stanford Model, and the work reported herein, Dr. L. Douglas James, of the University of Kentucky, has used a translation of the Stanford Watershed Model II, with some modifications from Model IV included. The computer programs written at Stanford were all in SUBALGOL, an extinct version of Burrough's early compiler. This compiler language barrier has, no doubt, limited the availability of the Stanford models to other researchers. Model IV, with the exception of the snowmelt subroutine, has been translated into Fortran IV by the author.

Some terms pecular to the model need to be defined before proceeding to a discussion of the model and of the computer program. A parameter is a constant value associated with a particular basin, e.g., the recession constant for groundwater flow. A variable is the physical quantity determined by the model, e.g., the total evaporation. A flowpoint is the point on a stream where the hydrograph is to be computed by the model. A basin may contain more than one flowpoint. A segment is the working unit of area for application of the runoff processes. A basin may consist of more than one segment.

The Stanford model is a continuous accounting model in the sense that the location of the water within the system is continuously known. The model, in fact, operates on a 15 minute cycle, i.e., adjustments in the location of water in the system are made each 15 minutes.

Figure 3.1 is a diagram of the watershed model as interpreted at the University of Texas. The model consists of storage units with flow between the units prescribed by relationships which approximate the physical phenomenon. Water entering the system in the form of precipitation is subjected, first of all, to the demands of interception storage. The total volume of interception storage is specified by the parameter EPXM. All available interception storage (SCEP) is filled, and the remainder of the precipitation (P3 in the program) proceeds to the surface. Interception storage is decreased each hour from 9:00 a.m. through 8:00 p.m. by the withdrawal of a volume sufficient to satisfy the hourly evapotranspiration potential (EPHRLI), which is calculated as 1/12 of the daily evapotranspiration potential, EP.

The soil is divided into four storage areas. The Upper Zone Storage area includes the depression storage and a shallow depth of the top soil. No physical limitation is given to this zone; however, it is intended to have small storage volume and a fast reaction time. The Lower Zone Storage area is much larger in volume, and apparently embraces the remainder of the unsaturated soil zone. Groundwater Storage is that storage active in causing base flow, while Deep Percolation is that

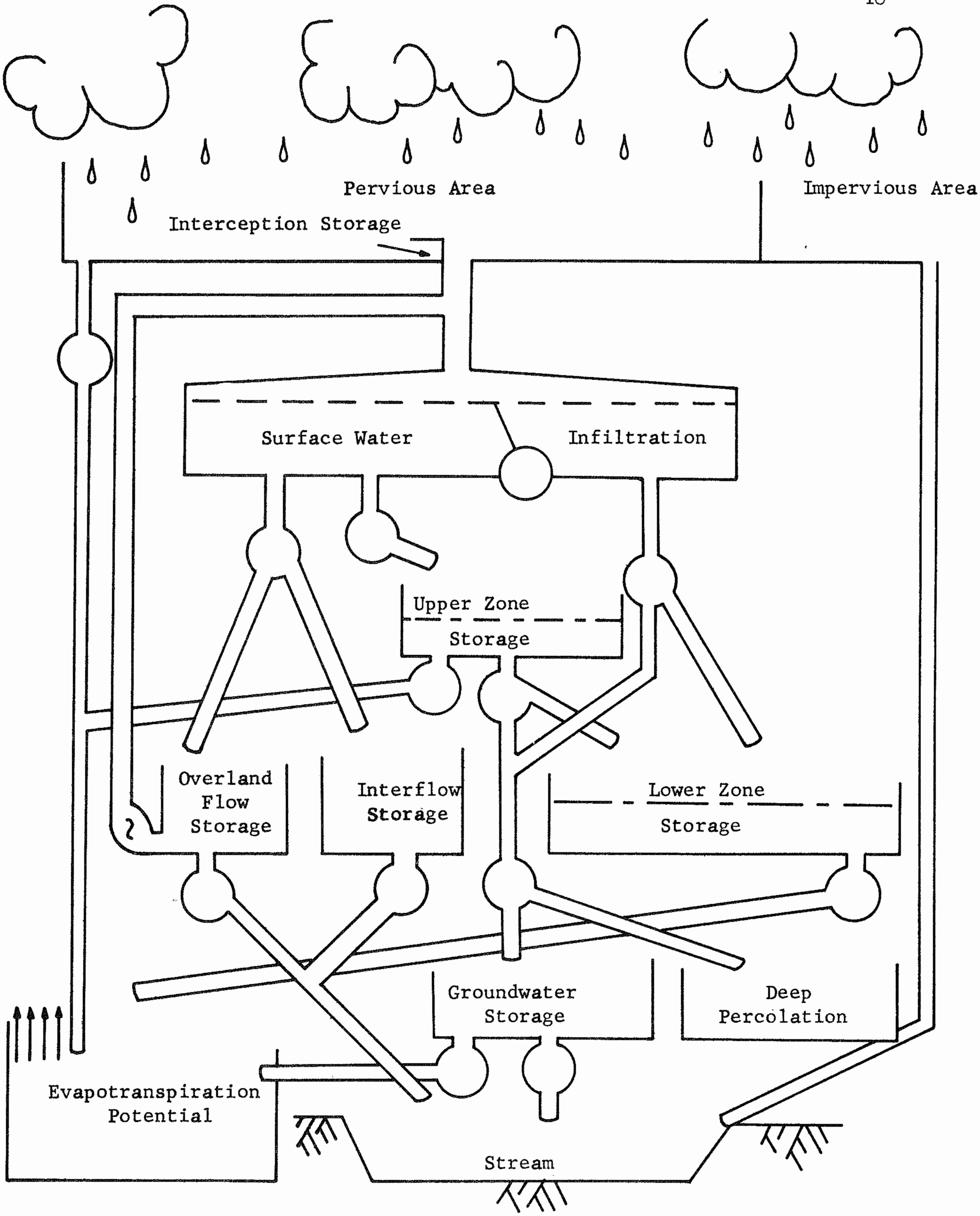


FIGURE 3.1 SCHEMATIC OF STANFORD WATERSHED MODEL IV

storage lost to the system. Both Upper Zone Storage (UZS) and Lower Zone Storage (LZS) have associated nominal storage values, UZSN and LZSN, respectively. Recommended values for LZSN are:

For Seasonal Rainfall. . . . . 4 + .25 (MAR)

For Reasonably Uniform Rainfall. . . 4 + .125 (MAR)

where MAR is mean annual rainfall. UZSN will vary from 0.06 LZSN for steep slopes to 0.14 LZSN for mild slopes.

In addition to the nominal storage parameters, the model requires the use of an infiltration index, CB, and an interflow index CC. CB is related to the soil type; however, this relationship has not been established. A range of 0.3 to 1.2 is suggested. The interflow index does not seem to have a physical meaning.

Water reaching the surface is divided between direct infiltration and surface phenomena. The portion going to each varies during a storm, and is a function of the amount to be divided and the volume of water in Lower Zone Storage. As shown in Figure 3.2, the lower zone storage rating (D4F/CB) is relatively constant when the Lower Zone Storage volume is high, and increases rapidly as the storage becomes less than the nominal. Figure 3.3 shows the manner in which the division between surface water and infiltration is made as a function of the amount of water available and the lower zone storage rating. Thus, early in a storm, Lower Zone Storage will be low, and the Lower Zone Storage rating will be high (Figure 3.2). Whether the intensity of the rainfall is high or low, a relatively large amount of infiltration will occur, with a somewhat smaller amount being associated

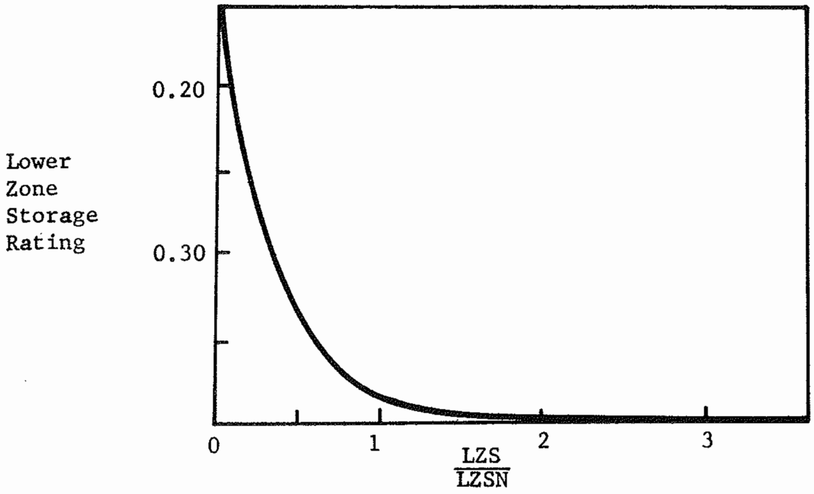


FIGURE 3.2 LOWER ZONE STORAGE RATING vs. LOWER ZONE STORAGE INDEX

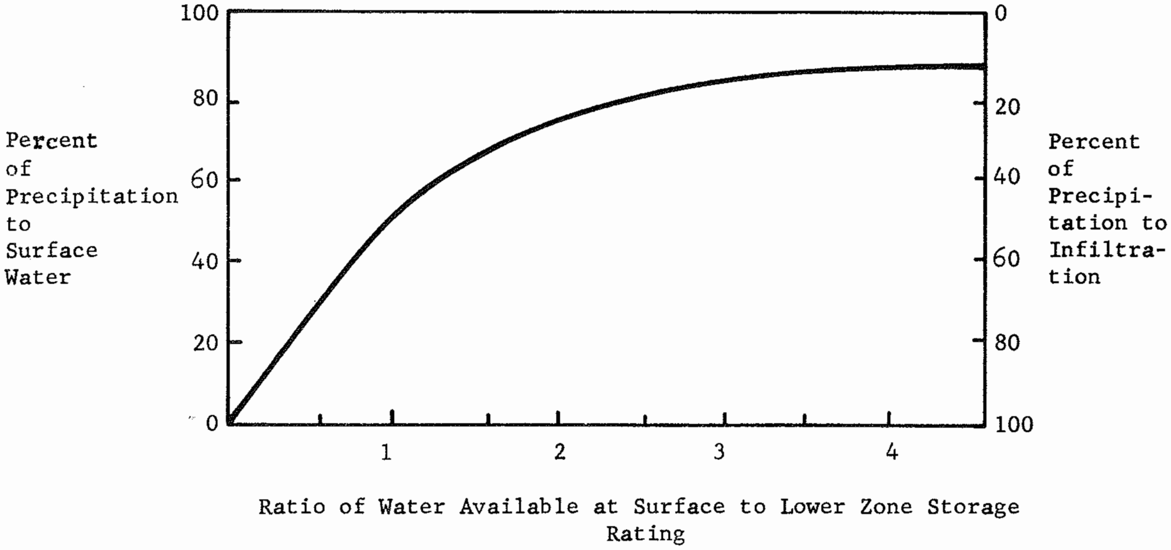


FIGURE 3.3 DIVISION BETWEEN SURFACE WATER AND INFILTRATION

with the larger intensity storm. The curve in Figure 3.2 has the following mathematical representation:

$$\text{Lower Zone Storage Rating} = 2^{-(2 + Z)} \qquad (3.1)$$

where $Z = 4\ \text{LZS/LZSN}$ for $0 < \text{LZS/LZSN} < 1$

or $Z = 2(1 + \text{LZS/LZSN})$ for $1 \le \text{LZS/LZSN} \le 2$

or $Z = 6$ for $2 \le \text{LZS/LZSN}$

Z is called LNRATHM in the watershed model, while the ration LZS/LZSN is called LNRAT. The equation for Figure 3.3 is

$$\text{Infiltration Percent} = [1 - (\text{Available Water/Lower Zone Storage Rating})/(2 \cdot \text{CB})] \cdot 100 \qquad (3.3)$$

for Available Water < CB·Lower Zone Storage Rating and

$$\text{Infiltration Percent} = [\text{CB} \cdot (\text{Lower Zone Storage Rating/Available Water})/2] \cdot 100 \qquad (3.4)$$

for Available Water $\geq$ CB·Lower Zone Storage Rating.

Surface water is next subjected to division between Overland Flow Storage, Interflow Storage, and Upper Zone Storage. The division between the first two and the latter is controlled by the existing Upper Zone Storage, as shown in Figure 3.4.

This curve is represented mathematically by

$$\text{Percent to UZS} = [1 - 1/2\ (\text{UZS/UZSN}) \cdot (1/(1 + \text{UZI})^{\text{UZI}}]100 \qquad (3.5)$$

for $0 \le \text{UZS/UZSN} \le 2$, and with

$$\text{UZI} = 2\ \left|1/2\ (\text{UZS/UZSN} - 1\right| + 1 \qquad (3.6)$$

or by $\text{Percent to UZS} = [\,(1/(1 + \text{UZI}))^{\text{UZI}}]100 \qquad (3.7)$

for $\text{UZS/UZSN} > 2$, and with $\text{UZI} = 2\ \left|\text{UZS/UZSN} - 2\right| + 1. \qquad (3.8)$

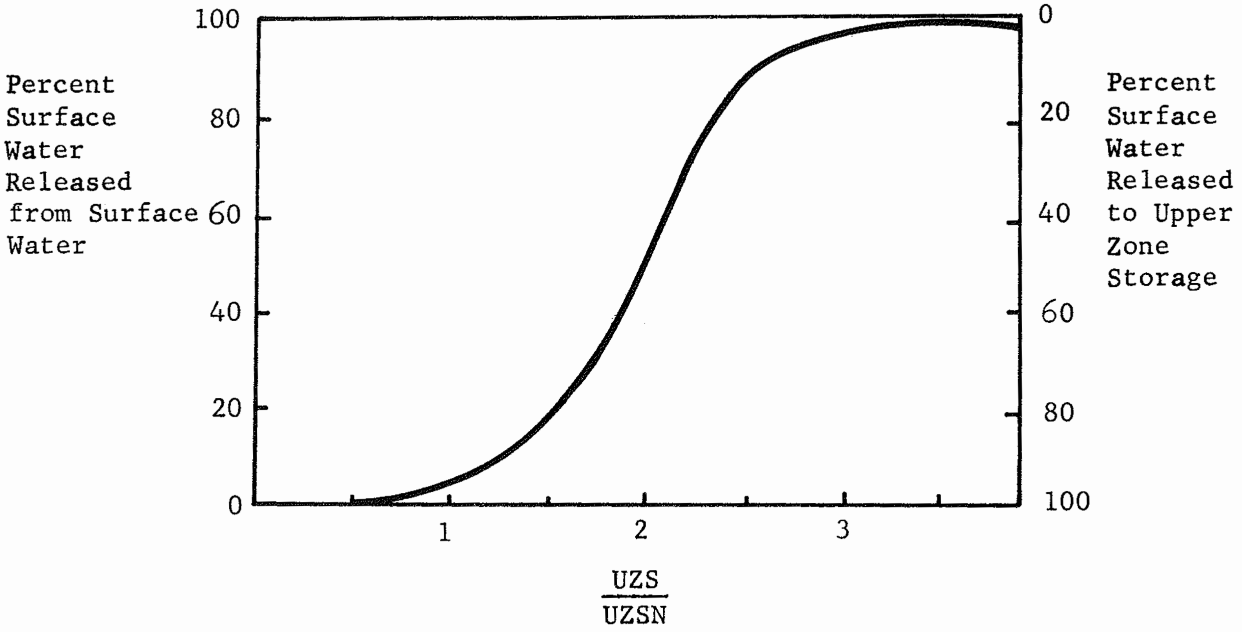


FIGURE 3.4 DIVISION OF WATER BETWEEN UPPER ZONE STORAGE, AND OVERLAND FLOW STORAGE AND INTERFLOW STORAGE

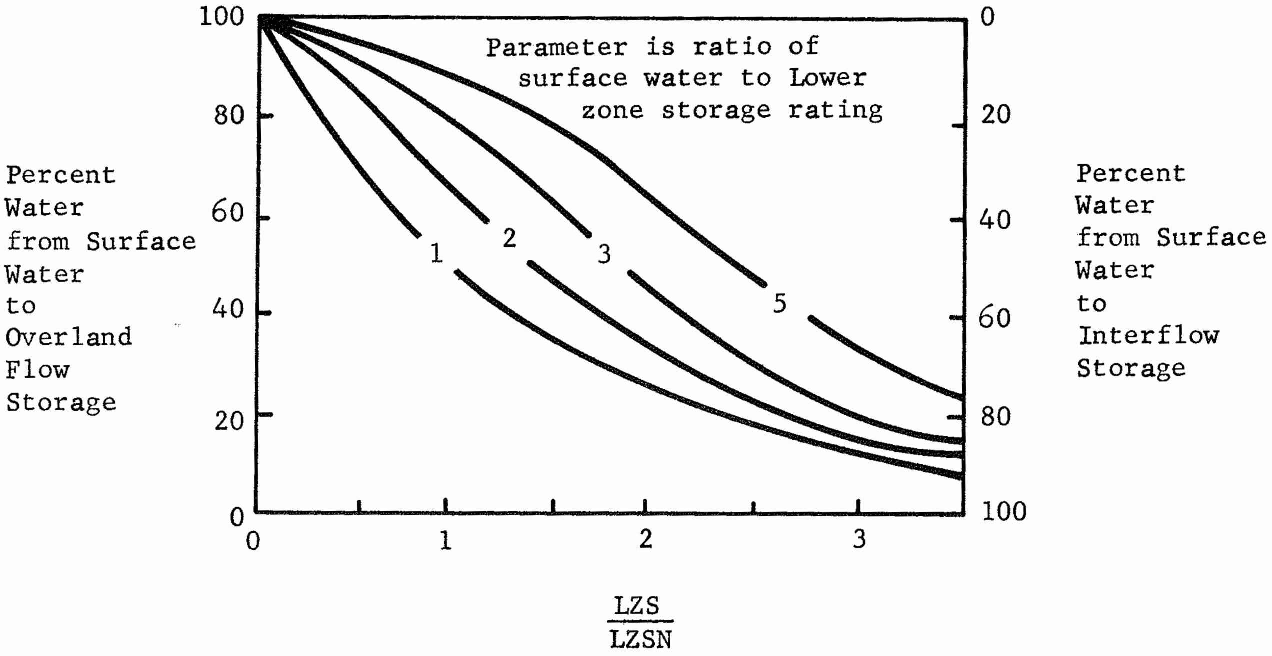


FIGURE 3.5 DIVISION OF WATER BETWEEN OVERLAND FLOW STORAGE AND INTERFLOW STORAGE

The water designated for Overland Flow Storage and for Interflow Storage is divided as shown in Figure 3.5 where both CB and CC equal 1. Decreasing CB causes the curves to drop more rapidly, while decreasing CC has the opposite effect.

Water which infiltrates is also divided three ways. An amount dependent on the volume in Lower Zone Storage is diverted to Lower Zone Storage. This relation is shown in Figure 3.6, where the curve has the mathematical form:

$$\text{Percent to LZS} = [(1/(1 + \text{LZI}))^{\text{LZI}}]100 \qquad (3.9)$$

for LZS/LZSN ≥ 1, or,

$$\text{Percent to LZS} = [1 - (1/(1 + \text{LZI}))^{\text{LZI}}(\text{LZS/LZSN})]100 \qquad (3.10)$$

for LZS/LZSN < 1,

where, in either case, $\text{LZI} = 1.5 \left|\text{LZS/LZSN} - 1\right| + 1.$ (3.11)

A portion of the water diverted to Overland Flow Storage is released as surface runoff to the stream. The amount of overland flow is based on the empirical relation

$$y = D(1 + 0.6(D/D_e)^3)/L \qquad (3.12)$$

for the rising side of the overland flow hydrograph, and

$$y = 1.6\ D/L \qquad (3.13)$$

for the recession side, where

y is the depth of flow at the outfall, in ft.,

D is the volume of storage in $\text{ft.}^3/\text{ft.}$,

L is the length of overland flow, and

D_e is the volume of storage at the equilibrium condition corresponding to the current inflow rate η.

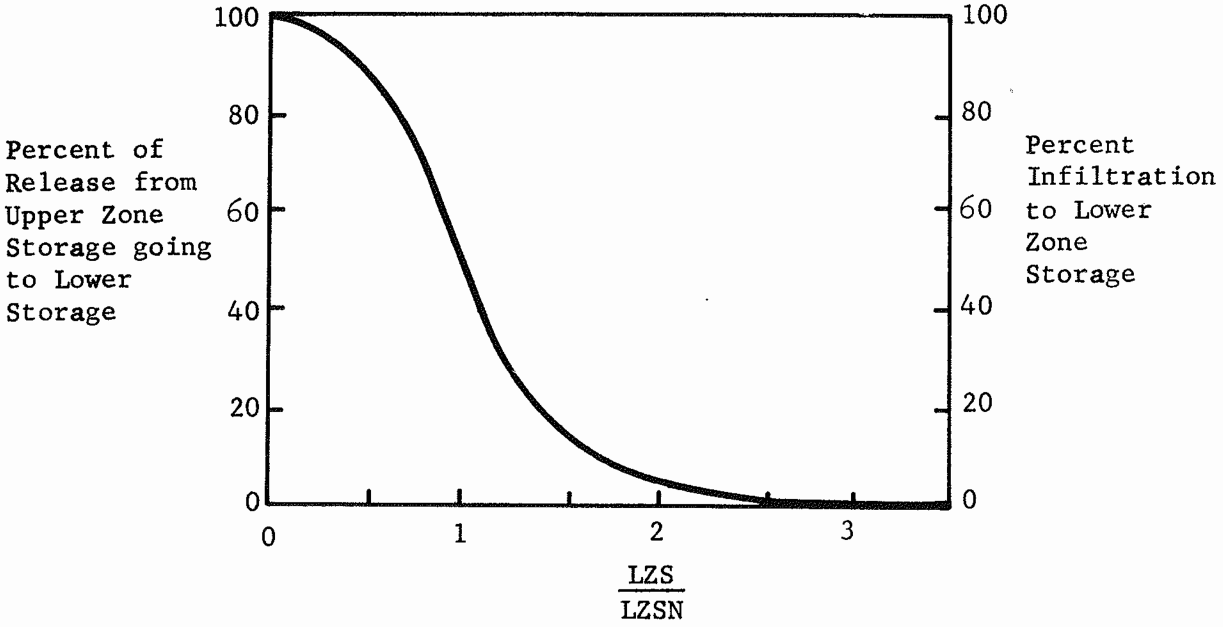


FIGURE 3.6 FLOW INTO LOWER ZONE STORAGE FROM UPPER ZONE STORAGE AND FROM INFILTRATION

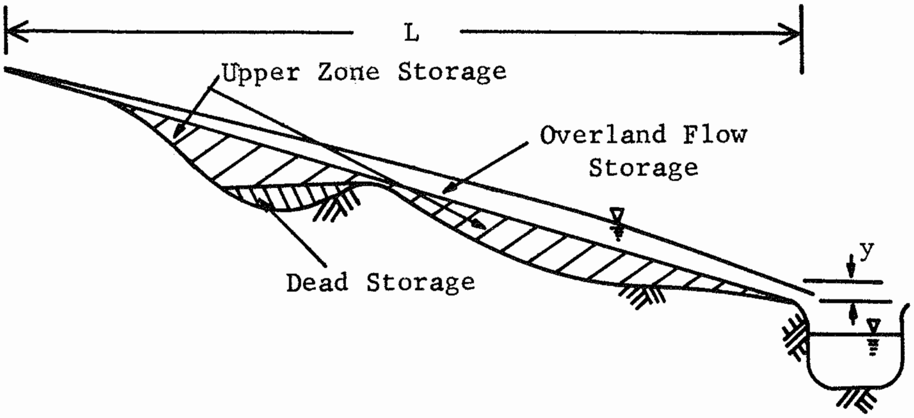


FIGURE 3.7 THE ROLE OF DEAD SURFACE STORAGE IN OVERLAND FLOW

For two dimensional flow, Manning's equation may be written as

$$q = 1.486/n \cdot y^{5/3} \cdot S^{1/2} \tag{3.14}$$

where

q is the flow in cfs per foot of width,

n is Manning's roughness factor, and

S is the slope of the energy gradeline, assumed equal to the bed slope.

When an equilibrium condition is obtained on the slope,

$$q = \eta L \tag{3.15}$$

and

$$q(x) = \eta x. \tag{3.16}$$

The volume of water in Overland Flow Storage at Equilibrium may be found by integrating the expression

$$D_e = \int_0^L y \, dx. \tag{3.17}$$

Solving Equation (3.13) for y, with the value of q(x) from (3.15) used, this reduces to

$$\begin{aligned} D_e &= (n\eta/(1.486\ S^{1/2}))^{3/5} \int_0^L x^{3/5}\, dx \qquad (3.18)\\ &= (n\eta/(1.486\ S^{1/2}))\ 5/8\ L^{8/5}. \end{aligned}$$

With the current inflow rate known, this equation can be solved for D_e, which may be substituted into (3.12) to yield a value of the depth of flow, y, at the outfall. This value of y may then be used in (3.13) to calculate the runoff rate, q.

There is some problem in the model concerning what to use for the inflow rate, η. It is not the total rainfall, since a portion of this is removed by interception, and another portion by infiltration. Still more is used to replenish Upper Zone Storage, and a part is allocated to Interflow Storage. In the watershed, infiltration occurs from Overland Flow Storage, and the "dead" Upper Zone Storage. Consequently, the "dead" Upper Zone Storage must be replenished from overland flow. This difference is illustrated in Figure 3.7, where a part of Upper Zone Storage is shown as "dead" surface storage. No physical counterpart has been discovered for that portion assigned to Interflow Storage. From Figure 3.1, it may be noted that the water subject to the division between Surface Water and Infiltration consists of the precipitation for the quarter hour period, less that trapped by interception and increased by the amount in Overland Flow Storage at the beginning of the time period (RES). Assuming that none of this volume is assigned to Infiltration, Upper Zone Storage, or to Interflow Storage, the portion of the precipitation occurring during this period which reaches Overland Flow Storage will be

$$\eta = RX - RES \tag{3.19}$$

where RX is the volume assigned to Overland Flow Storage at the end of the time period.

The model does not keep the initial volume in Overland Flow Storage separate; however, the foregoing reasoning seems to make plausible the use of (3.19) for defining η so long as $RX > RES$, i.e., the rising side of the overland flow hydrograph.

Water is released from Upper Zone Storage to the lower zones (Lower Zone Storage, Groundwater Storage, and Deep Percolation) only when the Upper Zone Storage is relatively fuller than the Lower Zone

Storage, i.e., when

$$(UZS/UZSN)/(LZS/LZSN) > 1 \; . \tag{3.20}$$

These releases are made on an hourly basis. The percent of Upper Zone Storage releases as a function of the two ratios UZS/UZSN and LZS/LZSN is shown in Figure 3.8. Mathematically, the relation is

$$\text{Percent UZS released} = \left[0.003 \cdot CB(UZS/UZSN)^{-1}(UZS/UZSN - LZS/LZSN)^{3}\right]100 \tag{3.21}$$

The water thus released from the Upper Zone Storage is divided between Lower Zone Storage and lower zones (Groundwater Storage and Deep Percolation) as shown in Figure 3.6.

The volume of water (INTF) released each fifteen minutes from Interflow Storage to become a part of the streamflow is determined by

$$INTF = LIRC4 \cdot SRGX \tag{3.22}$$

where LIRC4 is a quarter hourly interflow recession constant calculated from a daily interflow recession parameter (IRC).

In a similar manner, the contribution from groundwater (GWF) is calculated from

$$GWF = LKK4 \cdot (1 + KV \cdot GWS) \cdot SGW \tag{3.23}$$

in which

LKK4 is a quarter hourly groundwater recession constant calculated from a daily groundwater recession parameter (KK24),

KV is a parameter for the variable component of groundwater recession,

GWS is a groundwater slope index, and

SGW is the current groundwater storage.

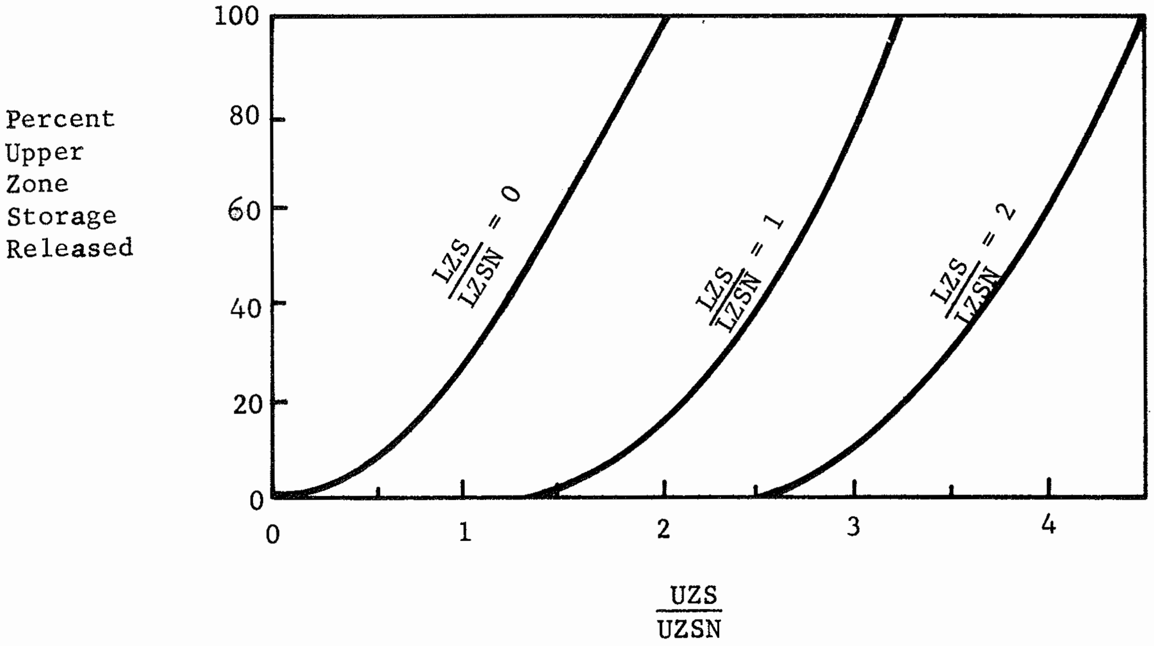


FIGURE 3.8 UPPER ZONE STORAGE RELEASES TO LOWER ZONE STORAGE

As mentioned earlier, water is removed hourly (9:00 a.m. through 8:00 p.m.) from Interception Storage to satisfy the hourly evapotranspiration potential. When the volume available from Interception Storage is less than the hourly evapotranspiration potential, the balance of the potential is removed from Upper Zone Storage. If the hourly evapotranspiration potential is not yet satisfied, the balance is accumulated as the variable REP. At 9:00 p.m. an amount LOS is removed from Groundwater Storage determined by

$$\mathrm{LOS} = \mathrm{REP} \cdot \mathrm{PA} \cdot \mathrm{SGW} \cdot \mathrm{K24EL} \tag{3.24}$$

where PA is the fraction of the total area which is pervious; hence,

REP·PA is the volume of the day's evapotranspiration potential which is unsatisfied,

and K24EL is the fraction of the total area from which evapotranspiration takes place directly, i.e., that part of the watershed where the root zone extends into the groundwater table.

Also at 9:00 p.m., water is removed from Lower Zone Storage according to whether the accumulated unsatisfied evapotranspiration (REP) is greater than or less than K3·LZS/LZSN. K3 is an input parameter determining the value of LZS/LZSN at which the evapotranspiration from Lower Zone Storage becomes limited by the unsatisfied evapotranspiration potential. The relation is shown in Figure 3.9, and has the mathematical description

$$\mathrm{AETR} = \mathrm{REP}(1 - 1/2 \cdot \mathrm{REP}(\mathrm{K3} \cdot \mathrm{LZS}/\mathrm{LZSN})^{-1}) \tag{3.25}$$

for $\mathrm{REP} < \mathrm{K3} \cdot \mathrm{LZS}/\mathrm{LZSN}$, and

$$\mathrm{AETR} = 1/2 \cdot \mathrm{K3} \cdot \mathrm{LZS}/\mathrm{LZSN} \tag{3.26}$$

for REP > K3•LZS/LZSN, where

AETR is the volume of water removed from Lower Zone Storage in order to satisfy the daily evapotranspiration potential.

The computed runoff is based on a unit area whose composition is the same as that of the total segment, i.e., the same fraction of impervious area. The total runoff (R) is obtained by multiplying by the total area. The time distribution of the runoff is accomplished by distributing the water forward in time according to a distribution graph determined by three of the input parameters shown in Table 3.1. The method of deriving these values is similar to that used for determining an instantaneous unit hydrograph. The channels within the segment are divided into reaches, Figure 3.10. The time of travel through each reach is estimated, and cumulative times to each point

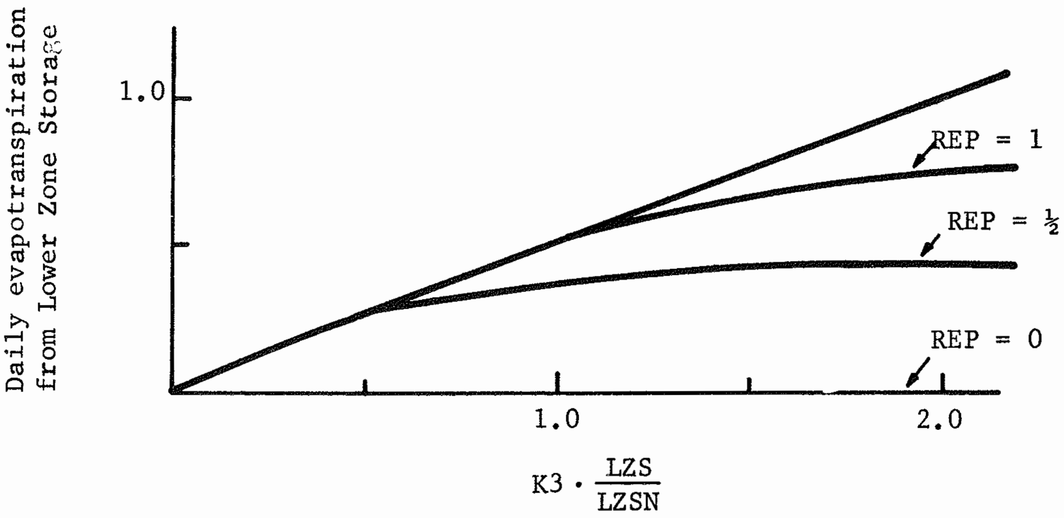
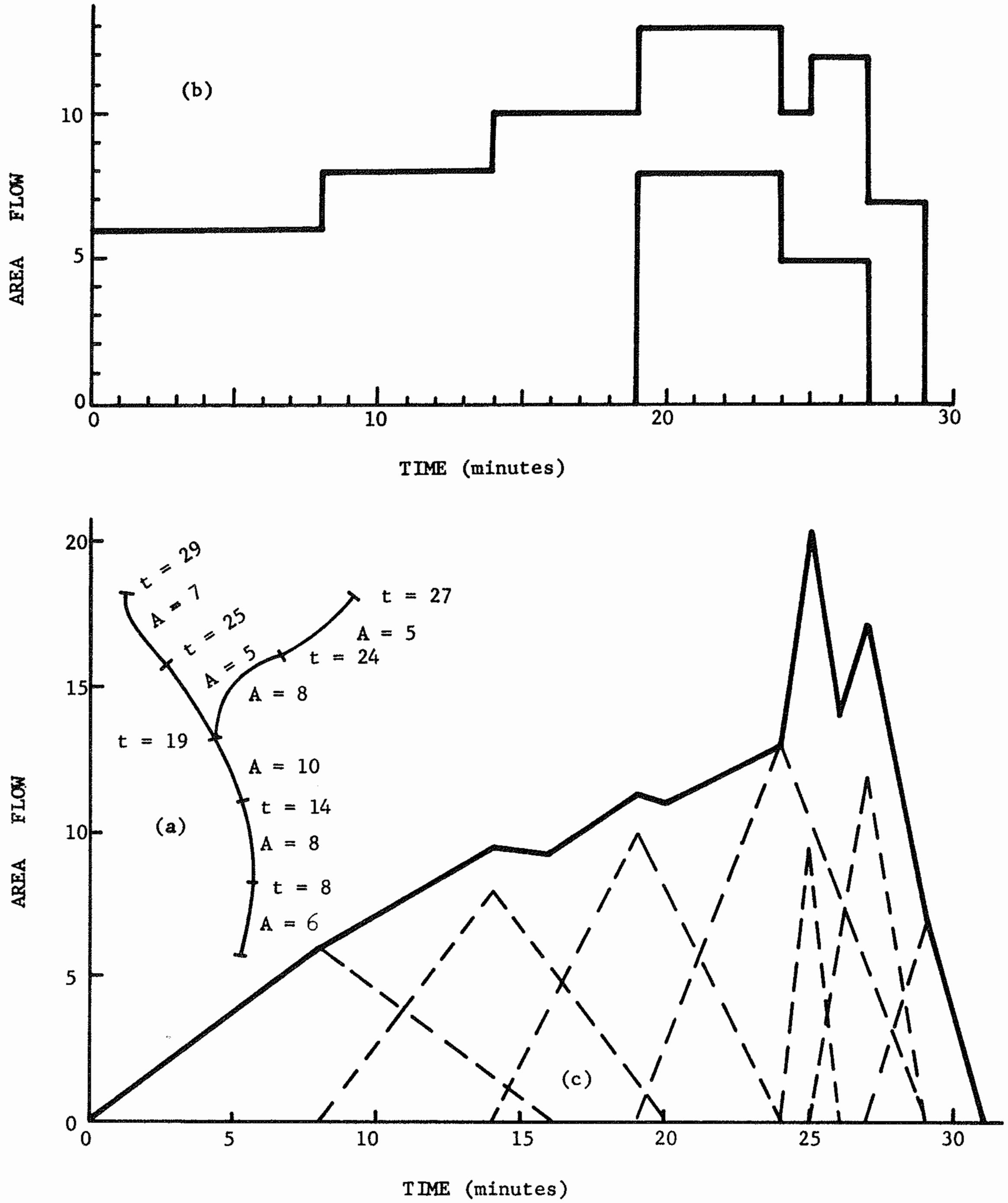


FIGURE 3.9 EVAPORATION FROM LOWER ZONE STORAGE



Time	0-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32
Area	3	8.6	13.8	18.3	19.6	24.0	32.2	10.2
Percent	2.3	6.6	10.7	14.1	15.1	18.5	24.8	7.9

FIGURE 3.10 DERIVATION OF THE ROUTING PARAMETERS

noted, i.e., the time of travel from the point to the outlet. Finally a contributing area is assigned each reach. A histogram is determined by plotting the contributory area against the travel time, as shown in Figure 3.10, (b). The histogram is the response of the watershed to an instantaneous rainfall event. To account for finite duration of rainfall, the response from each reach is assumed to vary in a linear manner from zero at the beginning of response (the travel time for the downstream end of the reach) to a maximum at the time when all of the reach is contributing (the travel time for the upstream end of the reach) and decreases linearly to zero in an equal amount of time. Figure 3.10 (c) shows each of the rectangles of Figure 3.10 (b) replaced by an isosceles triangle. These triangles are then combined to give the heavy line shown. A suitable time increment is chosen--in this case, four minutes, and the channel delay histogram determined as shown in the table in Figure 3.10.

Channel storage and attenuation is accomplished after the outflow hydrograph has been computed. An hourly "stream channel storage recession parameter" is used for this purpose.

The user of the model is required to furnish numerical values for the 16 parameters shown in Table 3.1, in addition to the initial conditions in the watershed. Part of these parameters are, at present, poorly defined. It is usually necessary to make several trials, using different values of the parameters, in order to determine the best set of parameter values. The model computes two sets of statistical data, based on the simulated flow and the actual flow. The first set of data consists of a frequency table based on the recorded flows. The

TABLE 3.1

HYDROLOGICAL PARAMETERS REQUIRED BY STANFORD WATERSHED MODEL IV

Variable	Explanation
CB	Infiltration Index
CC	Interflow Index
EPXM	Maximum Value of Interception Storage
ETL	Evaporation from Stream Surfaces
IRC	Interflow Runoff Recession
KK24	Basic Groundwater Recession Rate
KS1	Stream Channel Storage Recession Parameter
KV	Variable Component of Groundwater Recession
K24EL	Evapotranspiration from Groundwater
K24L	Portion of Groundwater Recharge Assigned to Deep Percolation
K3	Actual Evaporation Loss Index
L	Overland Flow Length
LZSN	Nominal Lower Zone Storage
NN	Manning's n for Overland Flow
SS	Overland Flow Slope
UZSN	Nominal Upper Zone Storage

difference between the simulated mean daily flow and the recorded mean daily flow is called the error (ERR) and for each frequency class the standard deviation of the error is found from

$$SQ_j = \left[\frac{\sum_{i=1}^{n_j} ERR^2_j - \left(\sum_{L=1}^{n_j} ERR_i\right)^2 / n_j}{n_j - 1} \right]^{1/2} \qquad (3.31)$$

where SQ_j is the standard deviation for the j^{th} class and n_j is the number of events in the j^{th} class.

The model also computes the daily correlation coefficient between the simulated and recorded mean daily flows.

$$CORCO = \sum_{i=1}^{N} (FLO_i - \overline{FLO})(DR_i - \overline{DR}) / \left(\sum_{i=1}^{N} (FLO_i - \overline{FLO})^2 \cdot \sum_{i=1}^{N} (DR_i - \overline{DR})^2\right)^{1/2} \qquad (3.32)$$

where

CORCO is the daily correlation coefficient

FLO_i is the recorded mean daily flow on the i^{th} day

$\overline{FLO}$ is the average recorded mean daily flow

DR_i is the simulated mean daily flow on the i^{th} day

$\overline{DR}$ is the average simulated mean daily flow

N is the number of days in the year

The daily correlation coefficient gives a good overall measure of the performance of the model. However, in areas where the number of runoff events is few, the coefficient may be deceptively high, since it is strongly influenced by a large number of near zero events. In all cases, the standard deviation by classes indicates the degree to which the model is capable of reproducing the recorded flows in the different ranges of flow.

Precipitation input is divided into two groups; that data from recording gauges (P1), and that from non-recording gauges (PREC). Only one recording gauge may be used for each segment. The time distribution of the recording gauge is applied to the non-recording gauges to approximate the time distribution of the storm over all the watershed. Each gauge is assigned a weighting factor on the basis of the fraction of the area it is assumed to represent. These factors may be determined by a Theissen network technique, or in any other manner desired by the user. The sum of the weights must equal one.

A single figure is calculated from the recording gauge record and the non-recording gauge records, which is the weighted precipitation for the segment. This data is stored on magnetic tape, and it is not necessary to repeat the calculation for subsequent runs.

The normal run uses hourly precipitation data from the recording gauge. However, an option is provided (DCS(11)) so that the data may be on a 15 minute basis. To exercise this option, four fifteen minute rates are written in the form

WWWXXXYYYZZZ

where WWW is the first quarter hour rate in hundredths of an inch with the decimal omitted, XXX represents the second quarter hour, etc. The program will unpack this data, calculate a 15 minute rainfall rate for the basin, using the non-recording gauges, and re-pack the data before storing on tape.

Chapter 4

UNSATURATED FLOW

When water falls to the ground it becomes subject to the processes of evaporation, infiltration, and runoff, as discussed in Chapter 1. The two processes, surface runoff and infiltration, are interrelated, each being parts of a continuity equation which could be written at the surface. In this chapter, surface runoff will be ignored, and a mathematical model formulated to describe the distribution of water in one dimensional space and time within a column of soil.

Physics of Unsaturated Flow

Water exists as solid, liquid, and gas within the soil. While movement is limited to the latter two states, the presence of ice has a profound effect on the movement of water vapor. The actual mechanics of the flow are discussed at length by Remson (1962). Only the necessary salient features of that discussion will be summarized here.

Motion occurs because of unbalanced forces, and hence, it seems natural to examine the forces acting on water within the soil. These forces are: (1) gravitational force in the vertical direction, and the following forces which may act in any direction, (2) so-called capillarity forces, (3) chemical and osmotic forces, and (4) forces due to partial pressure gradients acting on the water vapor. Chemical and osmotic forces cause relatively slow motion in most soils and will not be included. The volume of water moved in the vapor state is small in comparison to that moved in the liquid state so long as the liquid state is continuous.

Several investigators, beginning with Richards (1931) have shown that Darcy's equation for flow in a saturated porous media,

$$V = - K \frac{\partial h}{\partial y}, \tag{4.1}$$

where V is the bulk velocity in the y direction, (i.e., the flow rate through a unit area, ignoring the area of the soil particles),

K is the permeability of the soil in L/T units,

h is the hydraulic head, usually consisting of a pressure term and a gravitational term, i.e., $p/\gamma + y$,

y is the direction of the flow,

may be used in unsaturated flow. Indeed, Remson (1962) suggests using the equation for flow in both the vapor and liquid state. When h is viewed as the total potential causing motion, Remson's suggestion seems appropriate.

In unsaturated flow, the pressure term is negative due to the "capillary forces"--actually surface tension effects. It is customary to speak of soil moisture tension rather than pressure, and frequently the negative sign is omitted. Considering only the flow in the liquid state, the total head, h, may be defined as

$$h = \psi + y \tag{4.2}$$

where ψ is the soil moisture tension potential, or capillary potential with units of length, and

y is the vertical distance from an arbitrary reference plane, positive upward.

The capillary potential is negative by this definition.

Equation for Unsaturated Flow

Figure 4.1 shows a parallelopiped of the soil matrix. Flow is assumed to occur through only the top and bottom surfaces, which have unit area. Applying the continuity principle to the element

$$\rho V - \rho (V + \frac{\partial V}{\partial y} \cdot \delta y) = \frac{\partial(\rho S \delta y)}{\partial t}$$

$$- \frac{\partial V}{\partial y} \delta y = \delta y \frac{\partial S}{\partial t}$$

$$- \frac{\partial V}{\partial y} = \frac{\partial S}{\partial t} \qquad (4.3)$$

where S is the volume of soilwater per unit soil volume. Substituting 4.2 into 4.1 yields the unsaturated flow form of Darcy's equation

$$V = - K \frac{\partial(\psi + y)}{\partial y} . \qquad (4.4)$$

When this expression of velocity is used in the continuity equation, there results the basic partial differential equation for flow through partially saturated porous media due to capillary and gravitation potentials

$$\frac{\partial S}{\partial t} = \frac{\partial}{\partial y} [K \frac{\partial(\psi + y)}{\partial y}]$$

or

$$\frac{\partial S}{\partial t} = \frac{\partial}{\partial y} [K(\frac{\partial \psi}{\partial y} + 1)] \qquad (4.5)$$

The soil moisture, S, the permeability, K, and the capillary potential are related, and the relationship is a soil property which does not change as long as the geometry of the soil matrix does not change. Typical curves of these relations are shown in Figure 4.2. Unfortunately,

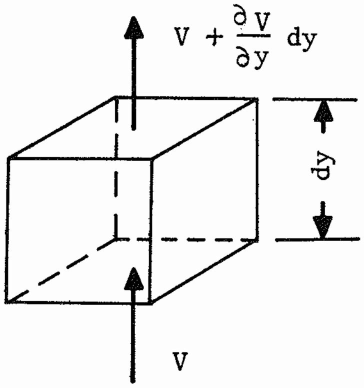


FIGURE 4.1 CONTINUITY FOR UNSATURATED ONE-DIMENSIONAL FLOW

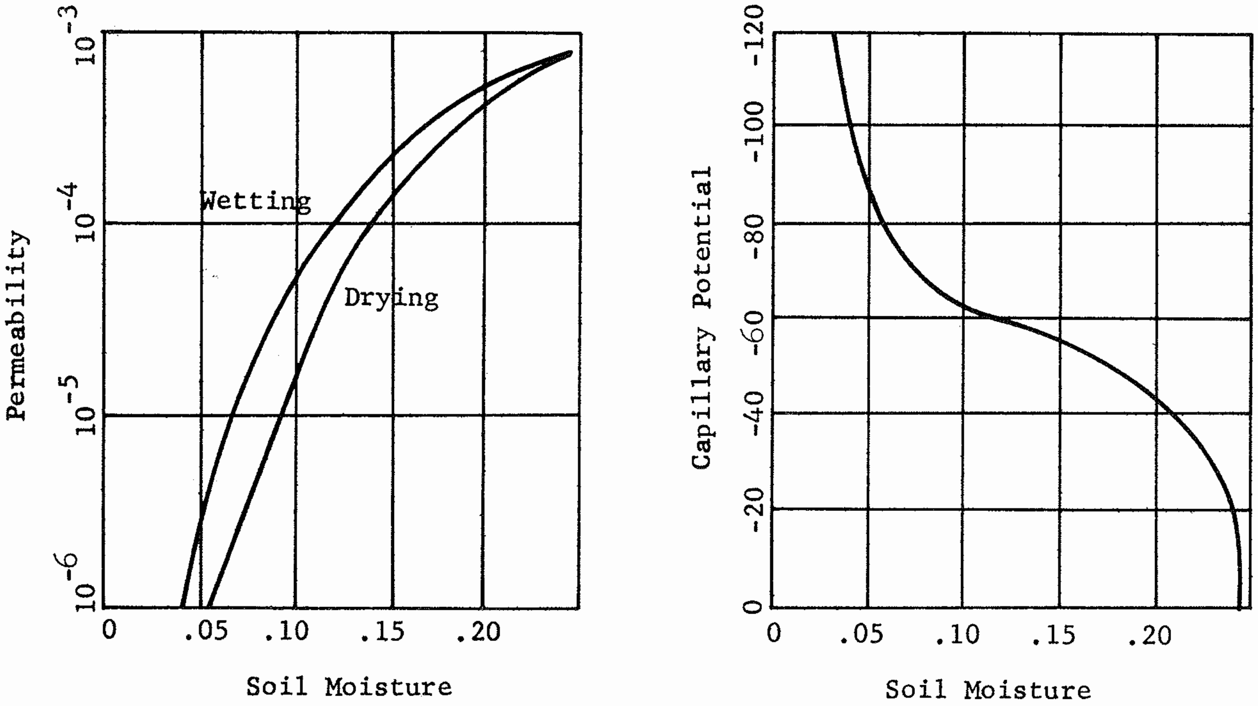


FIGURE 4.2 TYPICAL RELATION BETWEEN SOIL MOISTURE, PERMEABILITY AND CAPILLARY POTENTIAL

there is a hystersis effect in both the soil moisture-permeability relation and the soil moisture-capillary potential relation. Recently, the suggestion of Poulovassilis (1962) was implemented by Ibrahim and Brutsert (1968). Poulovassilis had shown a method he called the "independent domain concept" to be applicable to the hysteresis problem. Essentially, this method reduces both the soil moisture-permeability and the soil moisture-capillary potential functions to single valued functions. Consequently, the analysis will be based on the assumption of a single valued, laboratory determined relationship for both permeability and capillary potential as a function of soil moisture.

If these two relationships could be expressed in a mathematical form, the next step would be to choose one variable as the dependent variable and express the other two variables as a function of this variable. Rubin (1966) has recognized solutions using both the soil moisture and the capillary potential as the dependent variable. He has suggested the use of a combination of these properties. While any of the three variablescould be chosen, there is an advantage in choosing the capillary potential as the basic variable. The advantage consists of being able to express both permeability and soil moisture as uniquely defined functions of capillary potential. There are certain soils for which the soil moisture and the permeability do not change over some range of values of the capillary potential function. See Figure 4.3. Such soils have an air entry value different from zero, i.e., these soils will sustain some tension before the soil moisture is decreased below saturation.

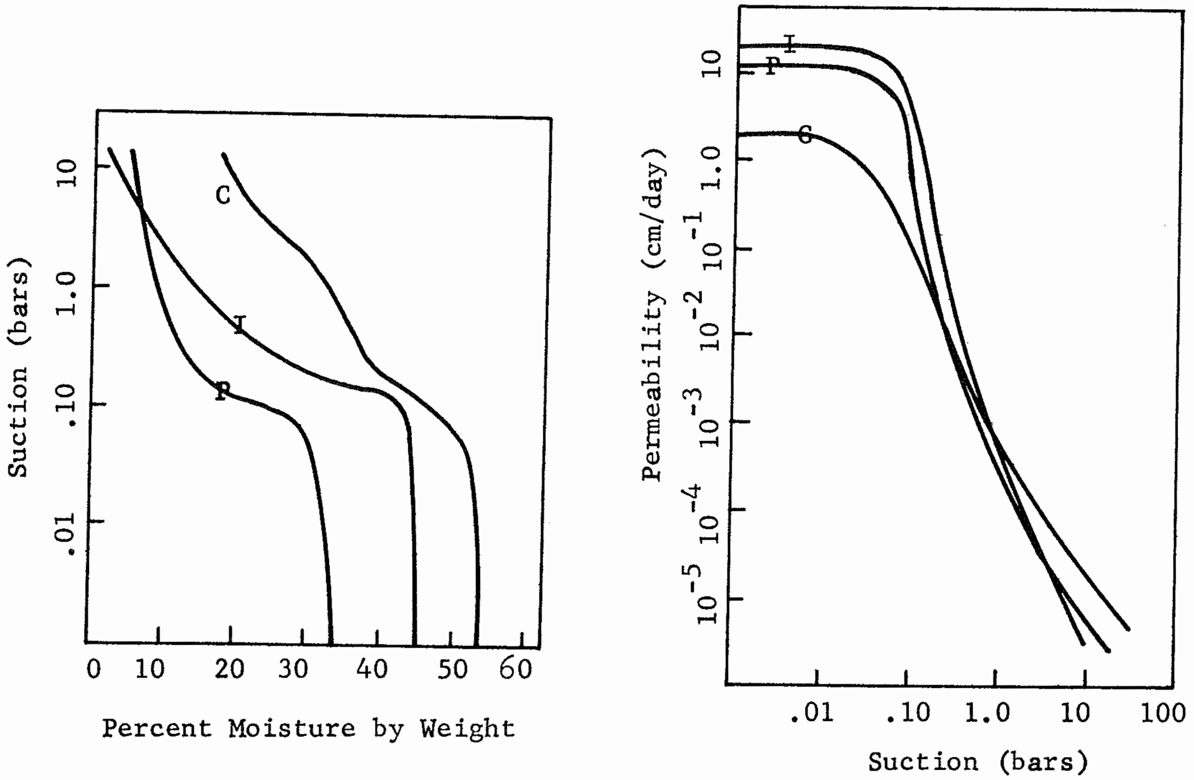


FIGURE 4.3 VARIATION OF PERMEABILITY AND WATER CONTENT WITH CAPILLARY POTENTIAL FOR

I	Indio Loam
P	Pachappa Sandy Loam
C	Chino Clay

(After Gardner (1958)

Then

$$K = K(\psi), \text{ and}$$

$$S = S(\psi).$$

Using the chain rule, 4.5 may be rewritten

$$\frac{\partial S}{\partial \psi} \frac{\partial \psi}{\partial t} = \frac{\partial}{\partial y}\left[K\left(\frac{\partial \psi}{\partial y} + 1\right)\right] \tag{4.6}$$

$$\frac{\partial \psi}{\partial t} = \frac{d\psi}{dS}\left[\frac{\partial K}{\partial y}\left(\frac{\partial \psi}{\partial y} + 1\right) + K\frac{\partial^2 \psi}{\partial y^2}\right] \tag{4.7}$$

$$\frac{\partial \psi}{\partial t} = \left[\frac{d\psi}{dS} \frac{dK}{d\psi}\frac{\partial \psi}{\partial y}\left(\frac{\partial \psi}{\partial y} + 1\right) + K\frac{\partial^2 \psi}{\partial y^2}\right] \tag{4.8}$$

Equation 4.8 is a quasi-linear second order parabolic partial differential equation. Boundary conditions are of the form

$$\text{for } t = 0,\ \psi(y,0) = \psi(y)$$

$$\text{for } t > 0,\ \psi(0,t) = G_1(t)$$

$$\psi(Y,t) = G_2(t)$$

where Y is the thickness of the soil column. Phillip (1957) has obtained a series solution for the special case of $\psi(y)$, $G_1(t)$, and $G_2(t)$ all constant. Other investigators have resorted to a finite difference representation of the partial differential equation.

In general these investigators have been interested in some special aspect of the unsaturated flow phenomina. Gardner and Fireman (1958) and Liakopoulos (1966) investigated evaporation from the soil surface. Gardner and Fireman included a saturated zone (a water table). Gardner (1959), Nielsen, et al. (1961) and Biswas, et al. (1966) all considered the redistribution of water within the soil column. Youngs (1957) considered the soil water profile with the surface maintained at saturation. Rubin (1966) studied infiltration into initially air dry Rehovat sand. He recognized three types of infiltration:

(a) Infiltration controlled by the rate of rainfall; occurs only when rainfall rate is less than saturated permeability of soil.

(b) Preponding which occurs immediately when rainfall rate exceeds saturated permeability and lasts until ponding occurs.

(c) Surface ponding when a saturated zone occurs at the soil surface.

For a given soil, the time to incipient ponding (i.e., the time of preponding) decreases as the rainfall intensity increases and increases with increasing initial dryness of the soil. Figure 4.4 shows the infiltration rate as a function of time for a hypothetical soil.

The finite difference solutions have used various representations of the derivatives. A common approximation of the first derivative

$$\frac{\partial \psi}{\partial y} \doteq \frac{\psi_2 - \psi_1}{\Delta y} \tag{4.9}$$

is sometimes used. Here Δy is the distance between the points 1 and 2. The approximation possesses various degrees of error depending on the position of the point within the interval where the derivative is to be evaluated. Thus, if the derivative is to be evaluated at the midpoint of the interval, the error has order $(\Delta y)^2$. However, use of 4.9 to evaluate the derivative at either end of the interval may introduce errors of the order of magnitude of Δy. Since in finite difference schemes, the Δy value is normally less than unity, evaluation at the midpoint is usually more accurate. The difficulty of using 4.4 in finite difference form to evalute the infiltration rate may now be examined.

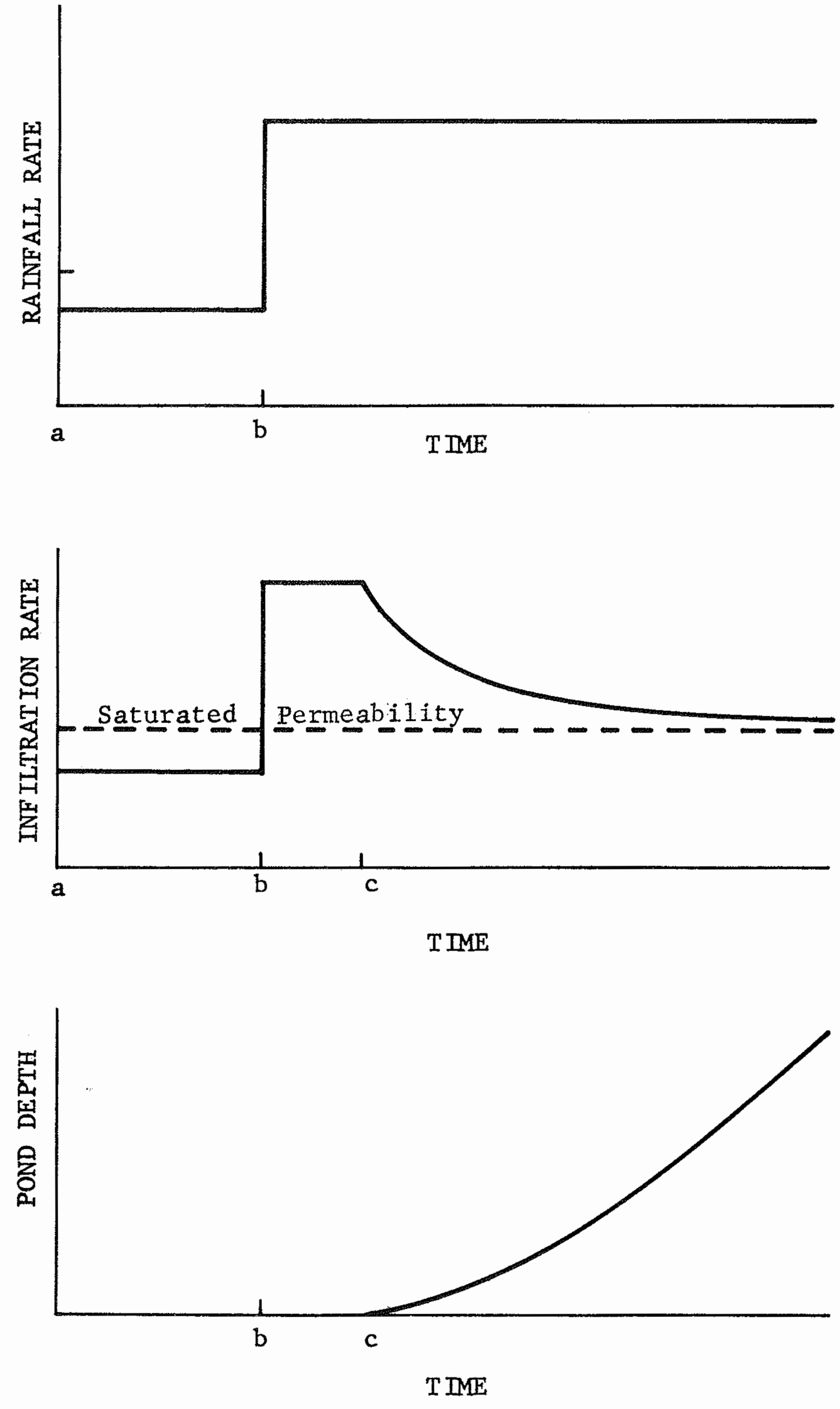


FIGURE 4.4 INFILTRATION RATES FOR THE THREE RAINFALL CONDITIONS

a - b Supply control
b - c Incipient ponding
c - Ponding

Substituting 4.9 into 4.4 with the evaluation occurring at the surface.

$$[V]_{y = 0} = - [K]_{y = 0} \left(\frac{\psi_1 - \psi_0}{\Delta y} + 1\right) \qquad (4.10)$$

where the subscripts 0 and 1 on the ψ term indicate the value of ψ at the surface and at a distance Δy below the surface respectively. When 4.10 is used to describe the infiltration rate, the error is of the order Δy. Since Δy is necessarily finite, it is impossible to predict precisely the infiltration rate from finite difference analysis. However, the use of a very small value for Δy gives a good approximation. More serious objections to the use of 4.4 to describe infiltration rates are based on the inadequacy of that equation itself. In particular, two phenomena which may strongly influence the infiltration rate are the rainfall impact effect and the flow of air out of the soil as it is being replaced by the water. The effect of the displaced air is probably very small except for extreme rainfall rates. Extreme rainfall rates may produce almost instantaneous flooding of the surface, trapping large quantities of air within the soil horizon. The effects of this air on the infiltration rate has not been studied.

The energy of the raindrop at impact causes some penetration of the water into the soil matrix, a phenomenon which might be termed "forced infiltration." This phenomenon has been observed, primarily by those interested in the erosion effects of such impacts.

The inclusion of either of these phenomenon in a mathematical model may be extremely difficult until more theoretical work has been accomplished. The movement of air and water simultaneously within the soil matrix will involve the concepts of two phase flow systems. Some restructuring of the soil matrix occurs due to the impact of the raindrop; the problem of describing this mathematically seems insurmountable.

Movement of water beneath the soil surface may be described by 4.10

$$[V]_{y=\alpha} = -[K]_{y=\alpha}\left(\frac{\psi_i - \psi_{i-1}}{\Delta y} + 1\right) \qquad (4.11)$$

where the point y equal α is between the nodes i and i-1. The velocity V may be viewed as the velocity of the water leaving the area of node i-1 and entering the area of node i. This equation will be used in Chapter 5 to describe the movement of water after infiltration has occurred.

Related Investigations

Some time was spent during this investigation studying the behavior of a finite difference model of a soil column. The model was obtained by substituting 4.11 in the continuity equation, 4.3. The resulting equation related the values of the capillary potential at three node points at one time step to the values at the same three nodes at the previous time step. The resulting system of nonlinear algebraic equations were solved by an iterative technique which assured the use of the proper values of permeability and soil moisture when the solution was reached. Boundary conditions at the surface consisted of a period of no flow at the surface, a period of rainfall, followed by a period of evaporation. An impervious layer was assumed to exist at the bottom, with the water removed from any saturated zone formed at the bottom at a rate proportional to the thickness of the saturated zone. As may be seen from 4.8, and as noted by Rubin (1966), the finite difference equations are inadequate for saturated flow because of the presence of the $d\psi/dS$ term which is undefined in the saturated zone. Consequently the location of the interface between a saturated zone and an unsaturated zone must be obtained as part of the solution, with the proper form of Darcy's law applied in each zone. Finite difference solutions provide values of the dependent variable only at the node points. When the interface occurred between nodes, some interpolation scheme had to be used to locate the interface. Both linear and quadratic interpolation were tried. However, the soil moisture appears to approach the saturated value in an asymptotic manner, producing large errors in the interpolation process. The result of these difficulties within the computer model was instability of the location of the interface. This led to abandoment of this line of inquiry. Some method which does not require differing forms of Darcy's law for the saturated and unsaturated zones will avoid these difficulties. Rubin (1966) asserts his combination of permeability, soil moisture and capillary potential accomplishes this feat. Almost certainly such a model can be used to ascertain an infiltration model somewhat better than the one presented in Chapter 5. However, such a study was considered outside the scope of the present investigation.

Chapter 5

A MODIFIED WATERSHED MODEL

The Stanford Watershed Model, as described in Chapter 3, has not received widespread use to date. This is due, in part, to the computer language used. A second cause is the inability to associate the computer program directly with the steps in the physical process. A third restriction on the use of the Stanford Model is the inability to deal with time units shorter than one hour*. On small watersheds this is a serious limitation. In this chapter a modified watershed model is presented which attempts to deal with these last two problems. Extensive use has been made of the processes of the Stanford Model, particularly relating to overland flow and stream routing. The material reviewed in Chapter 4 has been used as a guide to the unsaturated flow process. A schematic of the watershed model is shown in Figure 5.1; each phase will be discussed in detail.

The computer program which has been written to implement the modified watershed model is given in Appendix 1. It has been written to accommodate rainfall measured at irregular intervals in either accumulated form as from a weighing gauge or as a rate from a tipping bucket gauge. Either of these records is converted to a record with the average rate for the specified time period. This period may be as short as one minute,

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*Although the model operates on a 15 minute cycle, the routing period must be in units of whole hours, and this effectively removed the quarter-hour variations.

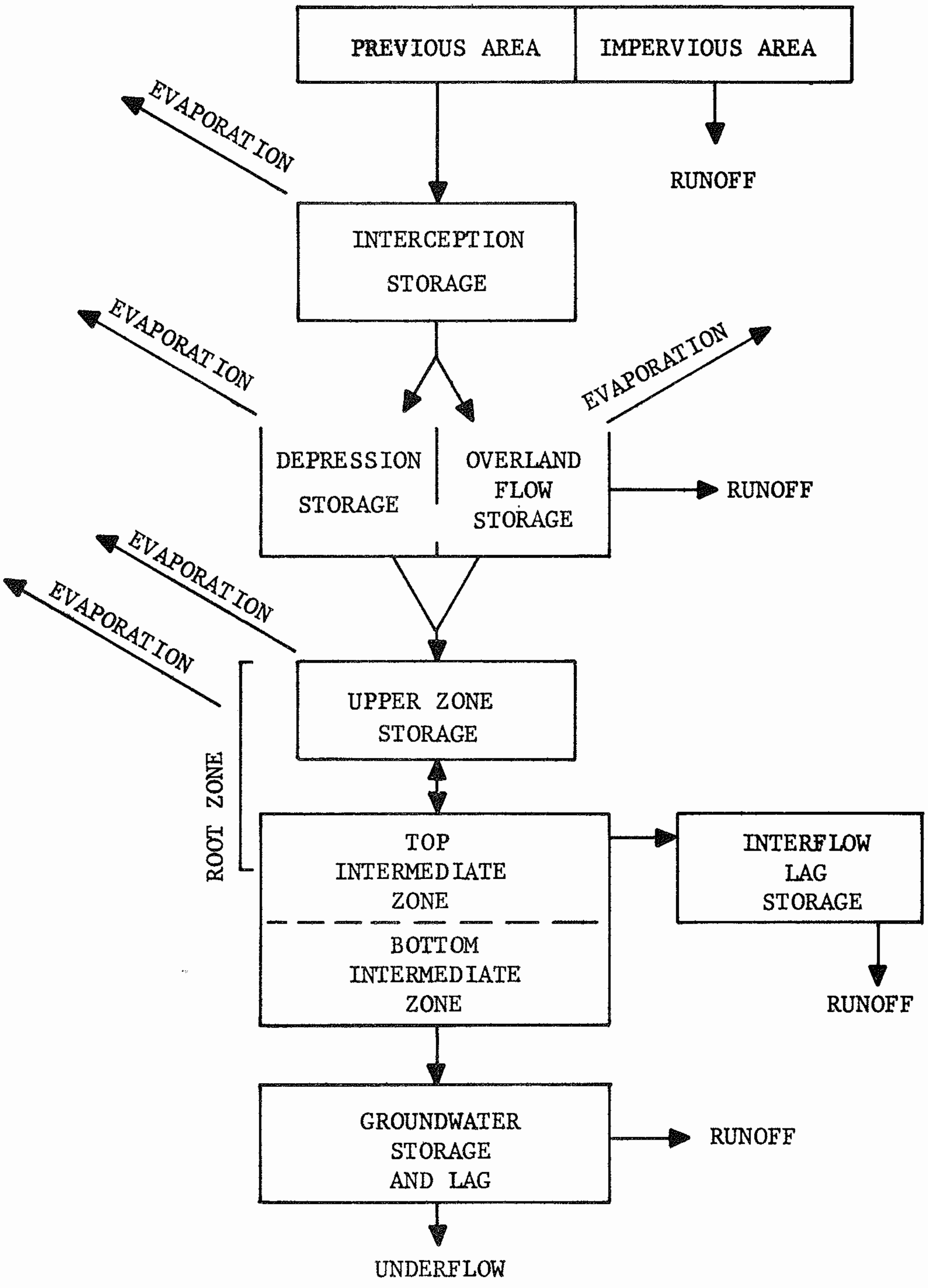


FIGURE 5.1 SCHEMATIC OF UNIVERSITY OF TEXAS WATERSHED MODEL

or as long as one day. A similar record is prepared from the measured streamflow when this is available. The maximum length of the basic accounting cycle is set at fifteen minutes. A full discussion of the input variables and the output available is found in Appendix 1.

Interception Storage

All precipitation falling on the pervious area is routed through interception storage. The volume of water in interception storage in inches at any time is limited by an input parameter, VINSTM, which may vary monthly. This parameter may be estimated as a function of the type and density of material above ground. In agricultural areas, the maximum interception storage may be very small early in the year, increasing to a maximum as the crops mature in the fall, and then drop sharply as the fields are prepared for the winter. On the other hand, in forest or urban areas, the maximum volume may be relatively constant over the annual cycle.

Surface Storage

Water passing through interception storage arrives at the ground surface. It may fall into one of two types of storage: depression storage or overland flow storage. Depression storage, or dead storage, is that volume of storage within depressions of all sizes in the watershed. A depression is defined as a hole or low area with no outlet. Within the pervious area of the watershed, three types of areas are delineated as shown in Figure 5.2. These areas are characterized as (A) areas from which overland flow proceeds directly to the stream: (B)

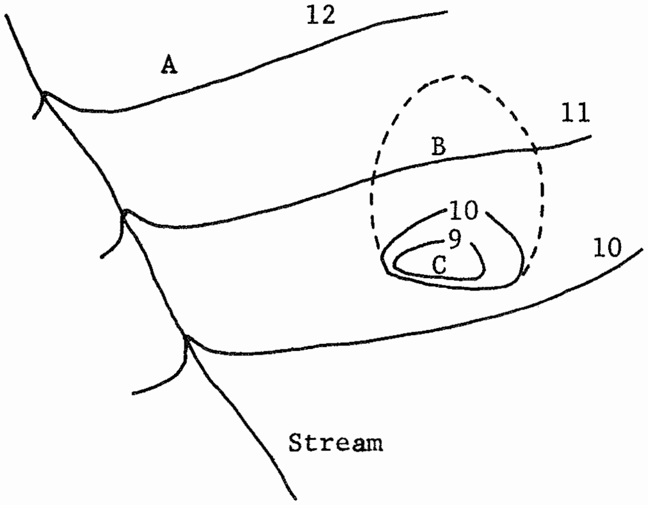


FIGURE 5.2 THREE TYPES OF AREAS WITHIN WATERSHED
A) OVERLAND FLOW DIRECTLY TO STREAM
B) OVERLAND FLOW TO DEPRESSION STORAGE
C) DEPRESSION STORAGE

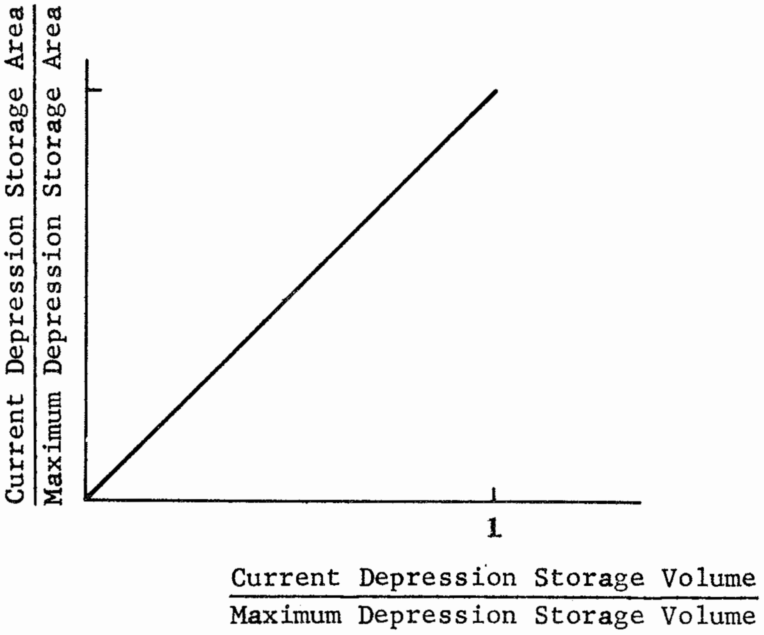


FIGURE 5.3 ASSUMED RELATION BETWEEN SURFACE AREA AND VOLUME OF DEPRESSION STORAGE

areas from which overland flow proceeds into a depression; and (C) areas of depression storage. The areas of depression storage vary from the hole caused by a woman's shoe to farm ponds and other flow retarding structures. The surface area of the water in depression storage at any time is assumed to vary linearly with the volume of depression storage, Figure 5.3. Rainfall reaching the land surface is divided between overland flow storage (OLS) and depression storage (DS) on the basis of the surface area of each type of storage. Overland flow storage is further divided between that flow going directly to the stream and the flow going into depression storage. Infiltration and evaporation, also surface phenomena, are based on the surface area of each type of storage.

The overland flow model used is taken from the Stanford Model. It is a quasi-turbulent form of Izzard's overland flow equations

$$\mathrm{OLF} = \frac{64200\ S^{0.5}}{nL} \left(\frac{D}{L}\right)^{5/3} \left(1 + 0.6 \left(\frac{D}{De}\right)^{3}\right)^{5/3} \qquad (5.1)$$

where OLF is the rate of runoff in inches per hour per unit area,

n is the Manning roughness factor for overland flow (ROUGH),

L is the length of the overland flow reach in feet (VLENGH),

S is the slope of the overland flow surface (SLOPE),

D is the storage in ft.^{3}/ft. and is defined as the average of the storage at the beginning of the time period and the storage at the end of the time period (OFSAVG),

D_e is the storage in ft.^{3}/ft. for an equilibrium condition (OFSEQU), and is defined by

$$\mathrm{OFSEQU} = \frac{0.000818\ i^{0.6}\ n^{0.6}\ L^{1.6}}{S^{0.3}} \qquad (5.2)$$

where i is the precipitation rate, in inches per hour (XI). This model is based on the following empirical relationship between outflow depth and storage

$$y = \frac{D}{L}\left[1 + 0.6 \left(\frac{D}{D_e}\right)^3\right] \qquad (5.3)$$

where y is the depth, in feet, at the lower edge of the flow plane.

These equations were developed by Linsley and Crawford (1966), and plots showing quite good agreement with a finite difference solution of the partial differential equation of varied flow were presented.

Overland flow generated on that portion of the watershed classified as contributing directly to streamflow is added to the variable RO. That part of overland flow originating on the area contributing to depression storage is added to depression storage. Some of the smaller depression storage areas will fill rapidly and surface runoff from areas originally designated as depression areas will commence when these areas are filled. For small indentions of the soil this will occur early in the storm, while for larger storage areas the runoff will not occur until much later. A typical relationship between area producing runoff through depression storage and the volume in depression storage is shown in Figure 5.4. The curve is assumed to be a parabolic with vertex at the origin and may be written as

$$X_a = \left(\frac{1}{C}\,\frac{DS}{DSMAX}\right)^{0.5} \qquad (5.4)$$

where X_a is the fraction of the pervious area which originally was designated as depression storage, or an area contributing flow to depression storage, but is now producing runoff,

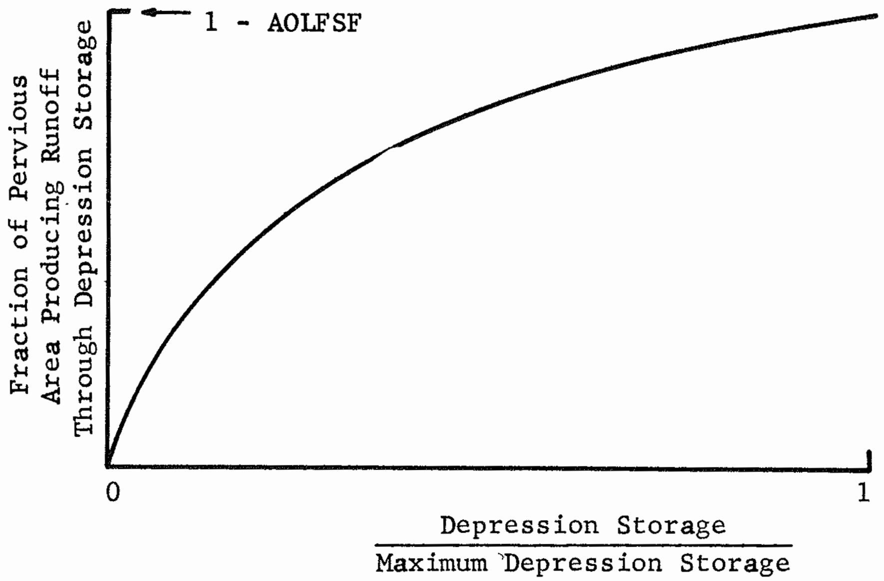


FIGURE 5.4 ASSUMED RELATION BETWEEN VOLUME OF DEPRESSION STORAGE, AND SURFACE RUNOFF FROM DEPRESSION STORAGE

DS is the actual depression storage volume, in inches of depth,

DSMAX is the maximum depression storage volume in inches of depth, and

C is a constant, normally with a value of 1.

The actual shape of this relation will vary from one basin to the next. However, it is felt that the parabola is adequate for most basins, based on the following preliminary investigation. The depression storage of a basin is the sum of the storage of many different depressions. Figure 5.5 shows several normalized volume-area distribution curves which might characterize different basins. The area under any curve is one, i.e., all of the depression storage within the basin. The basins labeled a and b have a significant proportion of their depression storage in shallow depressions. Basin b_1 has a uniform distribution--equal volume in shallow, intermediate, and deep basins; while both c and d possess considerable amounts of storage in deep depressions. If one assumes that the area producing runoff into a depression is approximately linearly related to the area of the depression storage (that is, the surface area of the depression when full), the relation between fraction of depression storage volume (DS/DSMAX) and the fraction of area which was originally classified as depression storage oriented but is now producing runoff to the stream may be derived. This relation is shown in Figure 5.6. The relation of equation 5.4 is also shown. The fit is reasonably good, except for that portion of the curve generated by deep ponds, i.e., basins with the characteristics of c or d. However, type d basins can be fitted with equation 5.4 provided C is chosen so

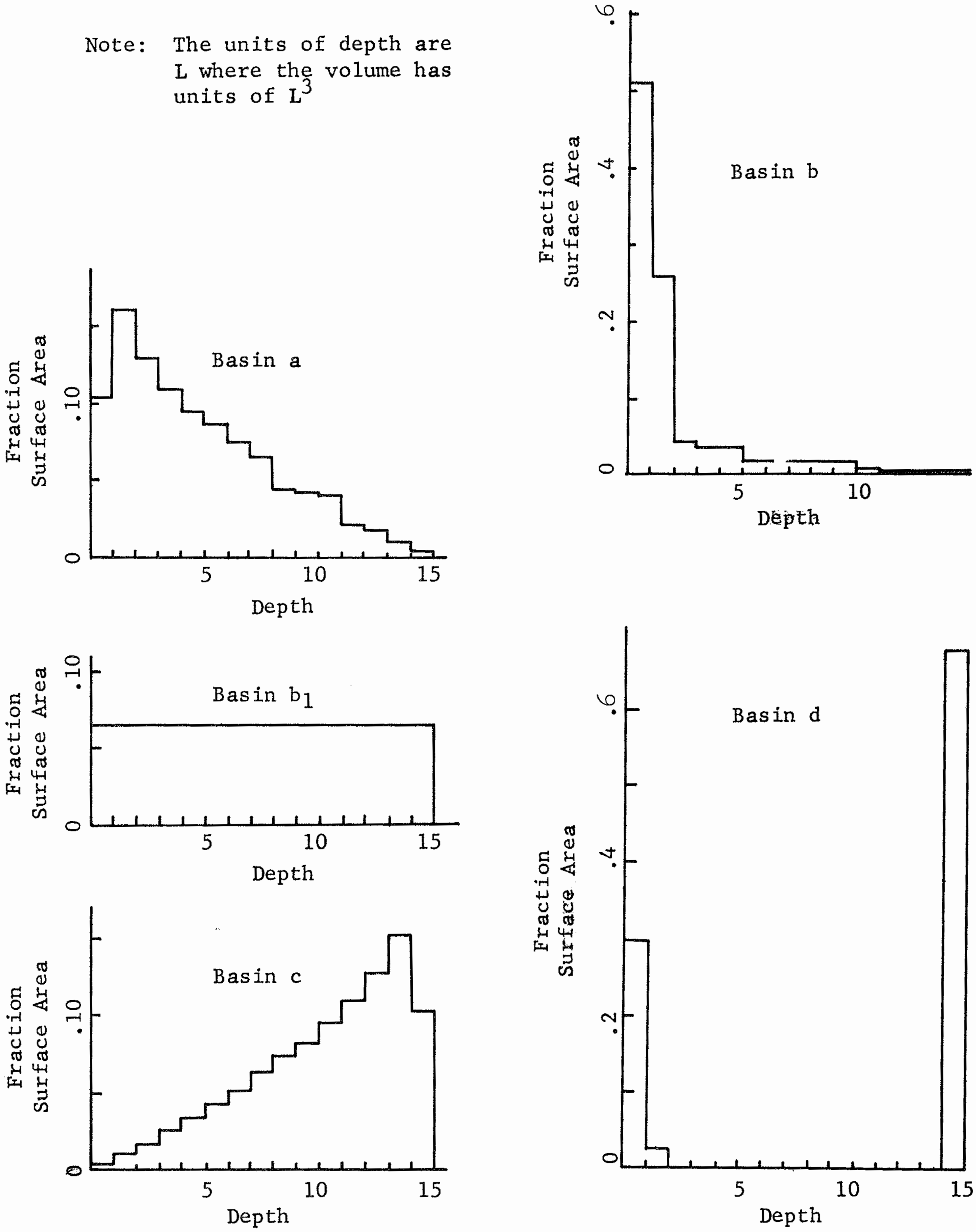

Note: The units of depth are L where the volume has units of L^3

FIGURE 5.5 NORMALIZED AREA-VOLUME HISTOGRAMS

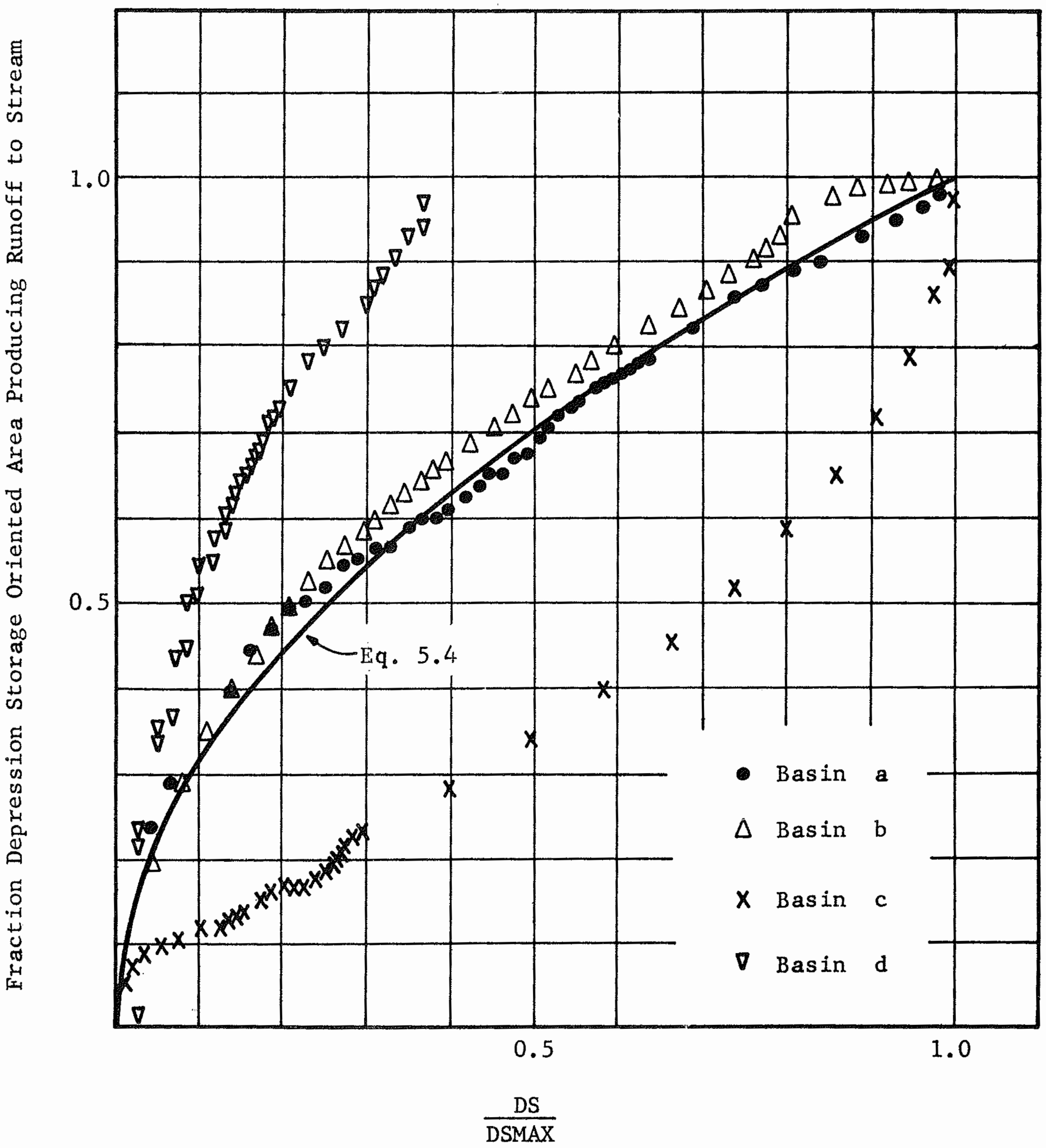


FIGURE 5.6 INFLUENCE OF DEPRESSION STORAGE CHARACTERISTICS ON FRACTION OF AREA PRODUCING RUNOFF

as to cause the curve to pass through the point defined by subtracting the pond storage from the total basin depression storage, and subtracting the pond area (and associated drainage area) from the total area. It is doubtful if natural basins of type c exist, although this might be the distribution for a basin after several "stock pond" type improvements have been made. In such a case, equation 5.4 should probably be replaced by an expotential curve of the form

$$X_a = C \quad \left(\frac{DS}{DSMAX}\right)^z \tag{5.5}$$

where C and z are parameters needed to obtain adequate fit.

Infiltration

The infiltration rate was given in Chapter 4 as being dependent on (a) the available water, i.e., the rainfall rate; or (b) the ability of the soil to conduct the water through the soil in its unsaturated condition, i.e., Rubin's preponding condition, or (c) the ponded depth, the thickness of the saturated zone, and the saturated permeability. Ponding of water occurs only for the third condition. The first is characterized by a rainfall rate less than the saturated permeability of the soil, and the second by a rainfall rate greater than the saturated permeability. Equation 4.4 may be rewritten as

$$V_o = -(K)_{y=0} \left[\left(\frac{d\psi}{dS}\right) \left(\frac{\partial S}{\partial y}\right)_{y=0} + 1\right] \tag{5.6}$$

where V_o is the infiltration rate. This equation is applicable to both conditions (a) and (b) and $\partial S/\partial y$ should be viewed as the dependent variable.

Referring to Figure 5.7, the infiltration rate of ponded rainfall is given by

$$V_o = -K_{sat}\left[\frac{POND - \psi_{ae}}{SATDPH} + 1\right] \qquad (5.7)$$

where POND and SATDPH have the meanings shown in the figure, and

ψ_{ae} is the value of soil tension at air entry.

Holtan (1961) proposed an infiltration equation

$$f = a\ F_p^n + f_c \qquad (5.8)$$

where f is the infiltration rate when supply is not the limiting factor,

f_c is the constant infiltration rate, the saturated permeability of the soil,

F_p is the total volume which can be infiltrated before a constant rate of infiltration is reached,

a and n are constants.

Holtan recommends a be taken as 0.62 and n as 1.387. F_p is a measure of the voids remaining in the soil column at any time, and hence is also a measure of the water in storage in the column. Since Holtan's equation is for the period when rainfall excess exists, i.e., ponding,

$$-[K]_{y=0} = -K_{sat} = -f_c \qquad (5.9)$$

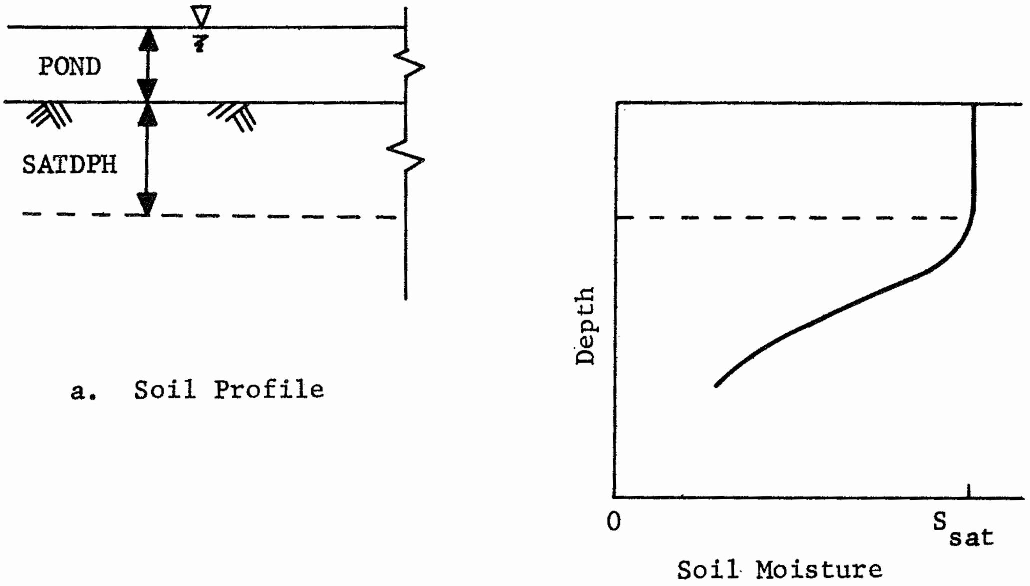
where the minus sign is a matter of convention. Then to the extent that

$$K_{sat}\left[\frac{POND - \psi_{ae}}{SATDPH}\right] = a\ F_p^n \qquad (5.10)$$

Holtan's equation approximates equation 5.7. Holtan found from experimental data that F_p could be expressed as

$$[F_p]_0 = K\ S_0 \qquad (5.11)$$

where the zero subscript indicates evaluation at time zero,



a. Soil Profile

b. Moisture Profile

FIGURE 5.7 INFILTRATION WITH PONDED RAINFALL

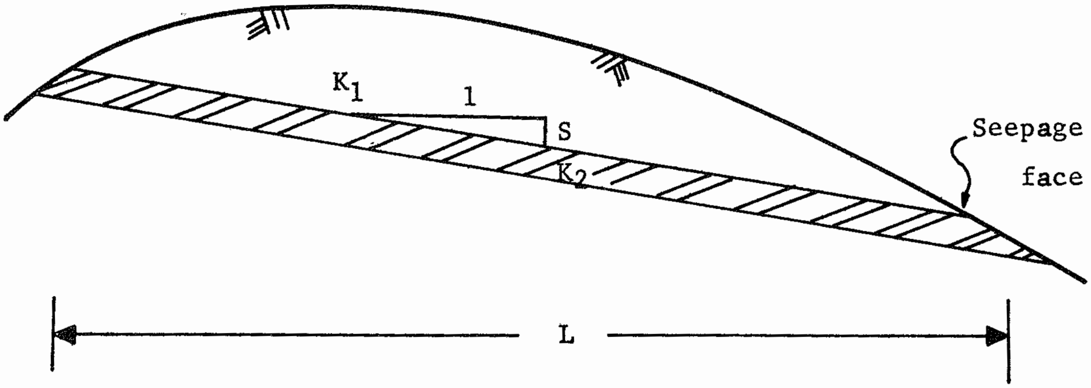


FIGURE 5.8 IDEALIZED INTERFLOW MODEL

K is a vegetative factor given in Table 5.1, and S is the available pore space in the 0-21 inch depth.

TABLE 5.1

HOLTAN'S VEGETATIVE FACTOR

Cover	Value of Vegetative Factor K
Bluegrass	1.00
Crabgrass and Alfalfa	.70
Lespedeza and Timothy	.45
Alfalfa	.35
Weeds	.30

Holtan's equation is particularly suited to a continuous accounting type watershed model, since the independent variable is the unsaturated pore space within the top layer of soil. Defining this layer to be the Upper Zone, equation 5.8 may be written

$$\begin{aligned} f &= a(UZST - UZS)^{n} + SATPRM \\ &= C1\ (UZST - UZS)^{C2} + SATPRM \qquad (5.12) \end{aligned}$$

where UZST is the total pore space in the Upper Zone, porosity times thickness in inches^3/inch^2.

UZS is the current volume of water in the Upper Zone in inches^3/inch^2.

SATPRM is the saturated permeability of the Upper Zone, in inches per hour.

C1 and C2 are input constants, corresponding to Holtan's $a \cdot K$ and n.

No allowance was made by Holtan for water leaving the Upper Zone, i.e., the volume of the pore space remaining at any time t after the storm began was computed as the pore space available at t_o less the volume of water infiltrated from t_o to time t. The watershed model will reflect more accurately the actual volume of water in storage within the Upper Zone. Consequently, the Upper Zone can be thinner than Holtan's twenty-one inches. In agricultural lands, the depth to which cultivation takes place seems a reasonable thickness, while in uncultivated areas, the thickness may vary from one-half inch for very tight soils to several inches for sandy soils. The presence of any less permeable zone should terminate the Upper Zone. Equation 5.12 gives the infiltration rate for the period when supply is not the limiting factor, i.e., the potential infiltration. When the rainfall rate is less than this potential infiltration, all of the rainfall is infiltrated. This decreases the pore space available, and consequently decreases the infiltration potential for the next time period. Rubin (1966) pointed out that for a uniform supply less than the potential infiltration rate, the soil column eventually reaches an equilibrium state in its upper reaches where the gradient $\frac{\partial[K(\psi + y)]}{\partial y}$ is just adequate to transfer the supply. This may also occur in the model, as the flow into the Upper Zone may be exactly equal to the flow out of the Upper Zone. Holtan's equation, while not exact, does seem to offer a good approximation to the infiltration process, both in the situation of infiltration limited by supply, and infiltration limited by the soil condition.

Flow Through The Unsaturated Zone

Ideally, one would describe flow through the unsaturated zone using some form of equation 4.4. However, in a watershed model this will have to be approximated. In the continuous accounting model, the volume of water within each interval of depth can be obtained. However, as the number of these intervals increases, the time to perform the calculations also increases, and soon reaches an economic limit. The number of such zones must be limited. The independent variables in equation 4.4 may be written as functions of the soil moisture, S.

$$\psi = f(S) \tag{5.13a}$$

$$K = g(S) \tag{5.13b}$$

Solution of equation 4.4 must yield

$$V = h(S) \tag{5.14}$$

Several forms of the functions f(S) and g(S) have been proposed. Ibrahim and Brutsaert (1968) proposed

$$g(S) = K_{sat} \left(\frac{S - S^*}{S_{sat} - S^*}\right)^n \tag{5.15}$$

where n varies from 2 to 5 and depends on the pore size distribution, assuming the smaller value for pore size distributions with small variances,

S^* is the soil moisture at which the permeability is "negligibly small," and

K_{sat} is the saturated permeability.

An attempt was made to fit the data for the soil described by Watson (1967), for Geary Silt Loam, and for Sarpy Loam by a least squares technique. In each case, the value of S^* needed to minimize the square of the error, E, using the model

$$g(S) = K_i = K_{sat} \left(\frac{S_i - S^*}{S_{sat} - S^*}\right)^n + E_i \qquad (5.16)$$

became greater than the smallest value of S. This required raising a negative number to a power. The definition of S^* seems arbitrary; a strict interpretation of the definition would require S^* to be zero for each soil.

Gardner (1958) proposed

$$g(S) = K = \frac{a}{\psi^{\tau} + b}$$

which was subsequently modified to

$$g(S) = K = \frac{K_{sat}}{\left(\frac{\psi}{\psi^*}\right)^{\tau} + b} \qquad (5.17)$$

by King (1965) to obtain dimensional homogeneity. The constant b is approximately 1 for soils with an air entry capillary potential of zero. An estimate of τ may be obtained by evaluating $\frac{d(\log K)}{d(\log \psi)}$ as ψ approaches $-\infty$. King shows good agreement for four soils, ranging from a sand through a clay. King also gives

$$f(S) = e\left(\frac{\cosh[(\frac{\psi}{\psi^*})^{\beta} + \alpha] - \gamma}{\cosh[(\frac{\psi}{\psi^*})^{\beta} + \alpha] + \gamma}\right) \qquad (5.18)$$

where e is the porosity of the soil, and

ψ^*, β, γ, and α are "parameters depending on the liquid, the soil, and the capillary pressure history."

The following restrictions on the parameters exist:

$$\psi^* > 0$$

$$\beta < 0$$

$$\alpha \geq 0$$

$$0 < \gamma < \cosh \alpha$$

The complexity of equation 5.17 and 5.18 makes curve fitting a prohibitive task.

A somewhat simpler set of functions has been used in the model

$$K = A_1 (S + B_1)^{C_1} + D_1 \quad (5.19)$$

and

$$-\psi = A_2 (S + B_2)^{C_2} + D_2 \quad (5.20)$$

Values of the coefficients for the various soils tested are shown in Table 5.2 (a and b), which may be used as a guide in assigning the coefficients. The program moves moisture from one zone to another using equation 4.4 rewritten as

$$V = K \left(\frac{\partial\psi}{\partial y} + 1\right) \quad (5.21)$$

The value of permeability is the weighted average of the permeability in each zone as determined by equation 5.19. The value of $\frac{\partial\psi}{\partial y}$ is found from

$$\frac{\partial\psi}{\partial y} \doteq \frac{\psi_1 - \psi_2}{y_1 - y_2} \quad (5.22)$$

where subscripts 1 and 2 refer to the two zones. The value of ψ is found using equation 5.20. The value of S for each zone is found by dividing the total moisture in the zone by the zone thickness.

Interflow

The phenomenon of interflow, while frequently observed in nature has not been studied in detail. A simplified interflow model is shown in Figure 5.8. The occurrence of water at the seepage face is dependent on the slope of the less permeable zone, S, the permeability of this

Description and Source	Permeability						
	A	B	C	D	Max. R.E.	Avg. R.E.	R^2
Geary Silt Loam Hanks and Bowers (1962)	797.7	-0.114	7.75	$2.9 \cdot 10^{-9}$	0.400	0.139	0.949
Yolo Light Clay Phillip (1957), Gardner (1958)	3.37	-0.103	6.01	$-3.0 \cdot 10^{-7}$	0.372	0.147	0.936
Watson (1967)	206.8	0.002	4.06	$-6.9 \cdot 10^{-4}$	0.231	0.091	0.919
Sarpy Loam Hanks and Bowers (1962)	1677.2	0.044	8.70	$-1.6 \cdot 10^{-6}$	0.652	0.284	0.936
Del Monte Sand (drying) Liakopoulos (1966)	1.689	0.026	2.45	$2.4 \cdot 10^{-3}$	0.233	0.079	0.899
Del Monte Sand (wetting) Liskopoulos (1966)	1.983	-0.00585	2.66	$2.2 \cdot 10^{-5}$	0.312	0.188	0.915
Vachaud (1966)	117.32	-0.1185	5.69	$7.1 \cdot 10^{-4}$	0.187	0.068	0.954
Remson (1965)	$1.6 \cdot 10^{4}$	0.087	25.16	$1.0 \cdot 10^{-9}$	1.790	1.179	0.883

TABLE 5.2a COEFFICIENTS FOR PERMEABILITY AND CAPILLARY POTENTIAL APPROXIMATIONS

Description and Source	Capillary Potential						
	A	B	C	D	Max. R.E.	Avg. R.E.	R^2
Geary Silt Loam	0.061	0.063	-7.67	-8.11	0.014	0.004	0.963
Yolo Light Clay	Data given in equation form: $\psi = -7.87 \ 10^{-7}/12.2 \cdot K - 1^{\,0.5}$						
Watson	-47.6	-0.047	-0.033	33.74	0.008	0.001	0.923
Sarpy Loam	26.20	.7745	-23.91	0.965	2.68	0.753	0.898
Del Monte Sand (drying)	225.3	1.0	-11.35	3.64	0.59	0.239	0.900
Del Monte Sand (wetting)	4.8788	-0.0219	-9.8626	-2.888	0.25	0.119	0.911
Vachaud	9.937	0.6555	-21.28	1.207	1.765	0.478	0.894
Remson	249.76	0.816	-30.89	-2.653	0.480	0.167	0.909

TABLE 5.2b COEFFICIENTS FOR PERMEABILITY AND CAPILLARY POTENTIAL APPROXIMATIONS

zone in relation to the permeability of the zone above it, the depth to the less permeable zone, and the area contributing water to the interflow process, i.e., the length L in Figure 5.8. These variables and perhaps others combine to change a portion of the infiltration hydrograph into the interflow hydrograph. The simplest mathematical formulation of the process would seem to be one which determines the volume of the interflow and produces the interflow hydrograph by lagging this volume. This method is used in the watershed model. The volume of interflow from the top level of the Intermediate Zone is determined by

$$\text{VINFLO} = C_{16}\ (\text{TIZS} - C_{10} \cdot \text{VINST})\ \Delta t \tag{5.23}$$

where VINFLO	is the volume of water added to the interflow process during the time period Δt,
TIZS	is the volume of water stored in the top half of the Intermediate Zone,
VINST	is the total volume of the Intermediate Zone, and
C_{10}, C_{16}	are the input parameters which must reflect the difference in permeability between the two zones.

When the quantity

$$\text{TIZS} - C_{10} \cdot \text{VIST} \leq 0,$$

VINFLO is set to zero. C_{10} is seen to be a parameter which sets a lower limit on the volume of water which must be present before interflow can occur. The interflow hydrograph shape is determined by a lag function

$$X = (C_{14} \cdot \text{DELINF} + C_{15})\ \Delta t \tag{5.24}$$

where X is the volume of water discharged to the stream from interflow storage in time Δt,

DELINF is the volume of water in interflow storage, and C_{14}, C_{15} are input parameters.

No rationale can be given for Equation 5.24. Probably the parameter C_{15} can be taken as zero. By analogy to routing equations for stream, the outflow should be related to the volume in storage.

Groundwater Flow

Much of what was said about the difficulties of mathematically modeling the interflow process also applies to the flow of groundwater. The watershed model makes provision for groundwater flow to occur into the stream and also to flow out of the basin. The latter is termed "underflow," and is determined as a function of the water stored in the saturated portion of the soil profile

$$Y = C_{13} \cdot GWS \cdot \Delta t \tag{5.25}$$

where Y is the volume of water leaving the basin as underflow in the period Δt,

GWS is the volume of water in groundwater storage, and

C_{13} is an input parameter.

The flow into the stream is determined in a similar manner

$$X = (GWS - C_{11}) \cdot C_{12} \cdot \Delta t \tag{5.26}$$

where X is the volume of water flowing from the groundwater system into the stream during time Δt,

C_{11} is the volume of water in groundwater storage below which no flow into the stream occurs. (A slight modification here would allow influent streams to be modeled.)

C_{12} is an input parameter.

For the base flow period of the stream hydrograph, equation 5.26 is analogous to the commonly used decay equation

$$q_i = k \cdot q_{i-1} = k^i \cdot q_0 \tag{5.27}$$

where q_i is the flow for the i^{th} time period,

q_{i-1} is the flow for the $(i-1)^{st}$ time period,

q_0 is the flow at the beginning of the first time period, and

k is the recession constant.

For equation 5.26,

$$k = \frac{1}{1 - C_{12} \Delta t \dfrac{GWS + C_{11}}{GWS - C_{11}}} \tag{5.28}$$

It is seen that k is not constant, but approaches zero as the groundwater storage approaches the input parameter C_{11}. The result of the variable recession constant is a steeper and shorter recession than given by equation 5.27. This is further accentuated by the removal of a volume of water from groundwater storage for underflow.

Evaporation and Evapotranspiration

The evaporation process is highly dependent on the energy received in the form of sunlight. The amount of energy received is reflected in both the total evaporation and in the time distribution of the evaporation. Other important climatic factors in the evaporation process are wind and humidity. The average effect of all three factors will be reflected in the amount of evaporation from an evaporation pan. Accordingly, the model makes use of monthly pan evaporation to establish potential monthly evaporation for the basin. An average daily potential is determined from the monthly potential, using a second order interpolating equation, and finally an instantaneous potential evaporation rate is determined. Potential evaporation is assumed to occur from thirty minutes past surrise until one hour after sunset, and to reach a peak when three-fourths of this time has elapsed. A skewed sine curve fitted to these three points is used for estimating the instantaneous potential evaporation rate. The time distribution of the evaporation potential agrees well with data reported by van Bavel (1966) as shown in Figure 5.9.

Evaporation occurs first from Interception Storage. If there is insufficient water stored in Interception Storage to satisfy the potential evaporation for this period, additional water is removed, in order, from Overland Flow Storage, Depression Storage, and Upper Zone Storage. Evaporation is assumed to occur at the potential rate from Overland Flow Storage and from Depression Storage. It will also occur at the potential rate from the Upper Zone Storage when the Upper Zone is saturated. However, as the water content of the Upper Zone decreases, the evaporation also decreases because of the difficulty of the soil to deliver the necessary moisture to the surface. This is approximated in the model by using

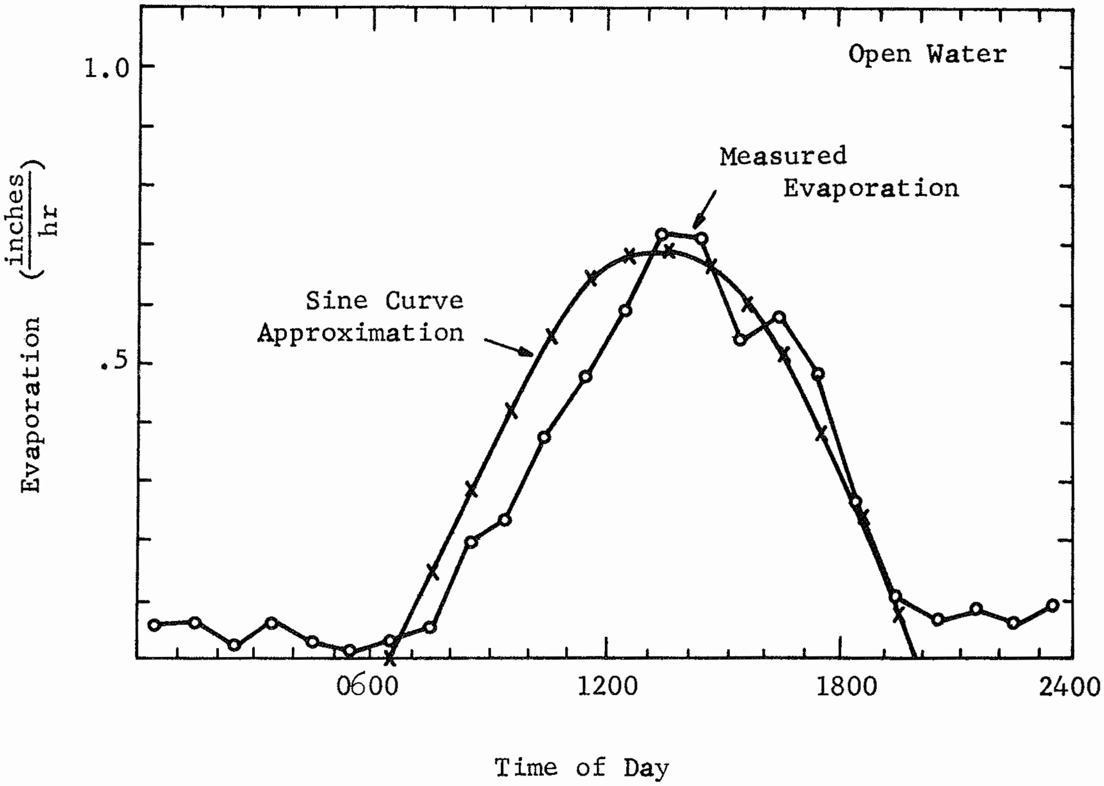
$$E = EVAPOT \cdot \left(\frac{UZS - UZMIN}{UZST - UZMIN}\right)^{\alpha} \qquad (5.29)$$

where E is the actual evaporation rate from the soil surface,

EVAPOT is the potential evaporation,

UZS is the current volume of water stored in the Upper Zone,

UZMIN is the minimum volume allowed in the Upper Zone (evaporation



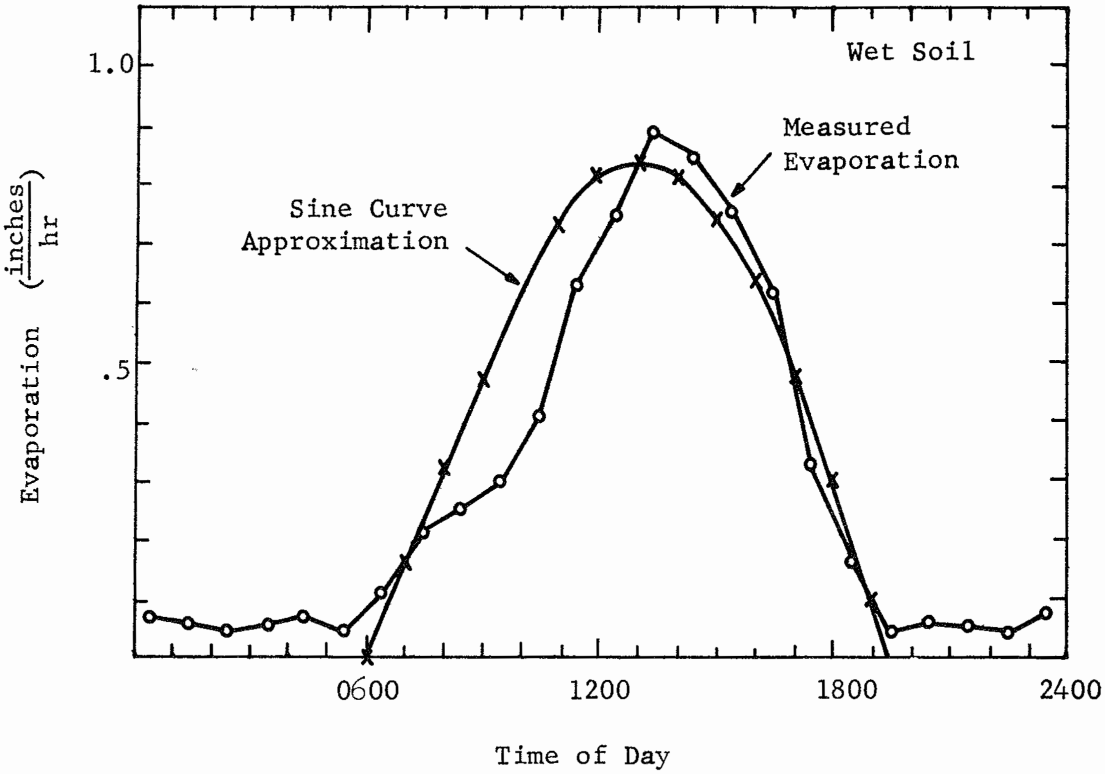


FIGURE 5.9 SINE CURVE APPROXIMATION OF van Bavel's (1966) EVAPORATION MEASUREMENTS

will not remove the chemically bonded water from the soil particles),

UZST is the total volume allowed in the Upper Zone, and

α is a parameter describing the soil's ability to deliver water to the surface.

The ratio, E/EVAPOT is shown plotted against the moisture values for various levels of the parameter α in Figure 5.10.

Transpiration of water from the soil by plant life seems to be independent of the soil moisture content when the content is above the wilting point. Consequently, during the months when transpiration is a factor, water is removed from the root zone (RTZONE) in addition to the evaporation. This removal is limited by the wilting point moisture content, assumed equal to the minimum volume for each zone. The root zone thickness does not necessarily coincide with the Upper Zone--for deep rooted trees and such crops as alfalfa it should be larger. The monthly evaporation as measured by the pan evaporation is augmented by the monthly consumptive use (TRANPO).

Stream Flow Routing

The runoff for any time period as calculated by the model thus far described must be routed through the basin in order to produce the hydrograph of stream flow. As in the Stanford Model, a distribution graph technique is used. (Figure 3.10) The flow generated during this period is distributed according to input parameters into future runoff intervals,

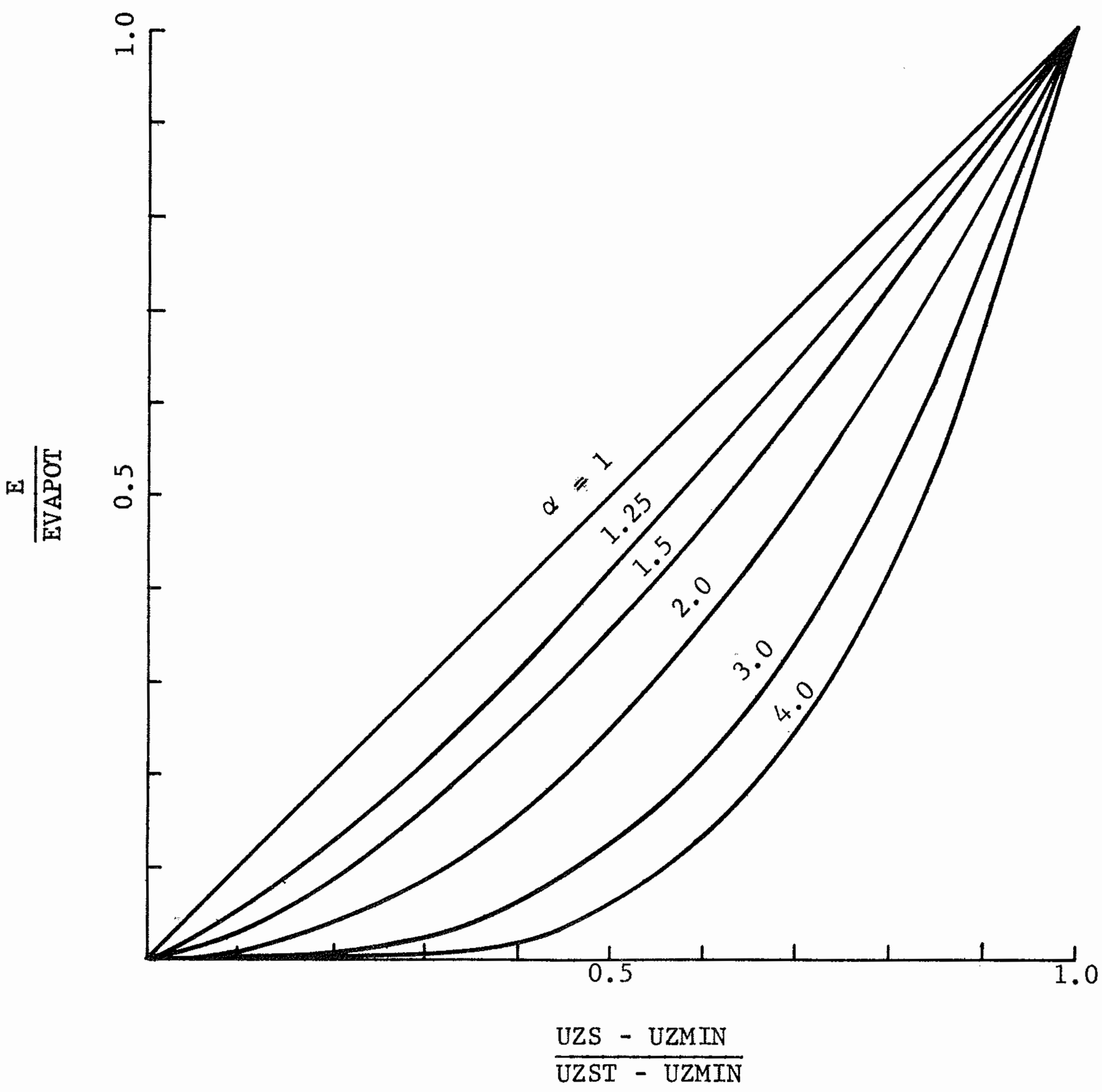


FIGURE 5.10 VARIATION OF TRANSPIRATION WITH MOISTURE CONTENT

i.e., the flow reaching the stream during the present time interval will appear at the gauging point distributed in time.

Watersheds with Multiple Segments

The program will simulate a watershed composed of several subwatersheds or segments. The order in which the segments are simulated must be from upstream to downstream, and the precipitation tape must be prepared in this same sequence. The program processes the segments sequentially; segment numbering must conform to the above usage.

Program Options

The program written to implement this model provides several options which the user may exercise to obtain output which meets his needs. The program will provide detailed storm analysis, printing the stream flow for each time period, or plotting this data on the printer. Options are also available for statistical analyses of several types when measured stream flow is supplied. The correlation coefficient for each storm is provided with the detailed storm analysis. The correlation coefficient is defined as

$$\text{CORRE} = \frac{\Sigma X_i \, Y_i - (\Sigma X_i \, \Sigma Y_i)/n}{[(\Sigma X_i^2 - (\Sigma X_i)^2/n) \cdot (\Sigma Y_i^2 - (\Sigma Y_i)^2/n)]^{0.5}} \qquad (5.30)$$

The correlation coefficient, defined in the same way, is also provided for the total yearly period. However, this coefficient can be extremely deceiving since each of the time intervals is counted. If the flow rate is zero for a large portion of the time, the correlation coefficient will be unrealistically high. A second measure of the goodness of fit is provided by classifying the flows into several flow ranges, and analyzing each range individually. The ranges are the same as used by the Stanford Model; the logarithm of the interval size is constant. Twenty-five ranges are provided; for each class the total number of cases in that class, the average error of these events, the average absolute error, and, when possible, the standard deviation of the errors is presented. This table allows the user to judge whether the model is doing an equally good job on all magnitude of flows. A third statistic which is provided is the coefficient of weighted absolute errors defined by

$$\text{COEFF} = \frac{\Sigma A_i \left| X_i \right|}{\Sigma A_j f_j \cdot \bar{x}} \tag{5.31}$$

where A_i is the weighting factor, defined by

$$A_i = \ln \left(\frac{Y_1 + Y_2}{2}\right) + 1$$

Y_1 and Y_2 are the two end points of the flow interval as described above which contain the ith flow rate

X_i is the error, i.e., the difference between the simulated and the recorded flow for the i^{th} time period

f_j is the number of events in the j^{th} class

$\bar{x}$ is the average flow for the time interval.

This coefficient eliminates the time intervals of no flow and provides a logarithmic weighting factor. In general, the smaller it becomes, the better the overall fit.

The adequacy of each part of the proposed model must be tested on existing basins. Two such tests have been performed and are reported in Chapter 6.

With further testing and with more analytical work performed, some aspects of the model are sure to change. For example, a two dimensional finite-difference analysis of the phenomenon of interflow will surely result in a better mathematical model to use in the simulation process. However, the model, as presented in this chapter, contains the basic framework to support improved mathematical statements of the various components of water transfer without destroying the model. This feature, it is believed, will make the basic model structure extremely usable and durable.

Chapter 6

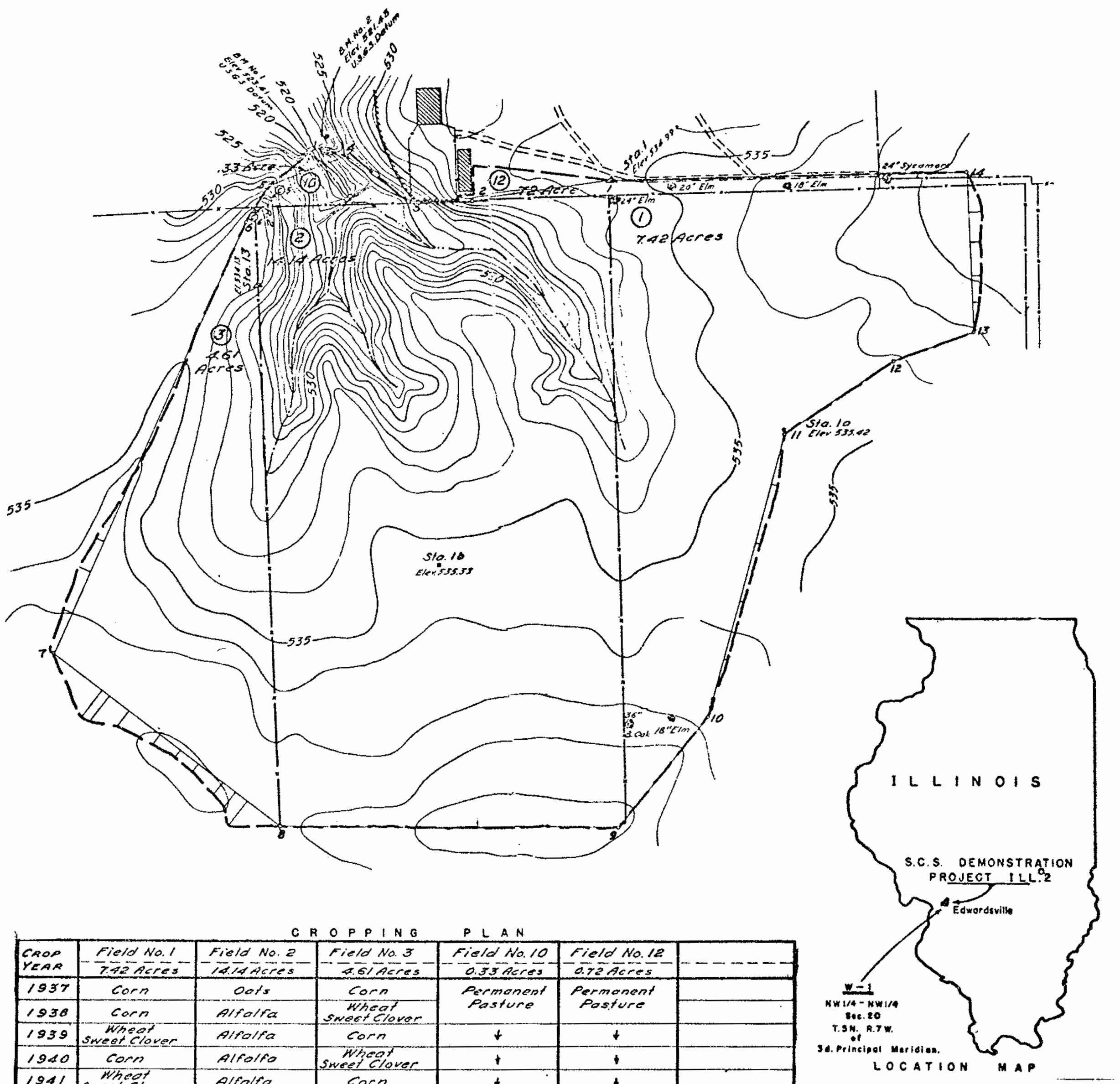
APPLICATIONS OF THE WATERSHED MODEL

The algorithms used to describe the various components of the hydrological cycle within the watershed model have been described in Chapter 5. The use of the model on two small watersheds is described in this chapter.

The Edwardsville, Illinois Watershed

Holtan and Minshall (1968) have presented comprehensive precipation and streamflow data for watersheds WI and WII at the Soil Conservation Service experimential area near Edwardsville, Illinois, for the period July, 1941, through June, 1943. The description of the watershed is complete enough to allow estimation of most of the parameters needed for the model. Watershed WI was chosen because it is the smaller (27.22 acres) and appears to be the more homogeneous. Figure 6.1 shows the contour map of the watershed, together with some land use data as furnished by the Agricultural Research Service. The precipitation records are from weighting type recorders; the watershed contains four recorders. There was little or no variation in the four records--so little, in fact, that only one recorder record is given by Holtan and Minshall for many of the storms. Consequently, a composite precipitation record was constructed relying heavily on recorders R9 and R11, Figure 6.2. Runoff was measured by a triangular weir; runoff rate was reported.

Several small plot infiltration studies were conducted within the experimential watershed. Rather complete descriptions of these are given,



CROPPING PLAN

Crop Year	Field No. 1 7.42 Acres	Field No. 2 14.14 Acres	Field No. 3 4.61 Acres	Field No. 10 0.33 Acres	Field No. 12 0.72 Acres	
1937	Corn	Oats	Corn	Permanent Pasture	Permanent Pasture	
1938	Corn	Alfalfa	Wheat Sweet Clover			
1939	Wheat Sweet Clover	Alfalfa	Corn	↓	↓	
1940	Corn	Alfalfa	Wheat Sweet Clover	↓	↓	
1941	Wheat Sweet Clover	Alfalfa	Corn	↓	↓	
1942	Corn	Alfalfa	Wheat Sweet Clover	↓	↓	
1943						

100 50 0 100 200 300 400

Scale in Feet

Contour Interval: 1 Feet

WATERSHED CHARACTERISTIC

1. Size.............27.22.........Acres ....0.0425..........Sq. miles
2. Range in Elevation (approx. M.S.L.) from 520.0 ft. to 540.0 ft.
3. Prevailing Land Slope..............1.0...........%
4. Range in Land Slopes from 0.4 % to 10 %
5. Length of Principal Waterway....785........ft.
6. Average Slope of Principal Waterway.....1.8........%
7. Total Number of Waterways.....3..............................
8. Number of Acres per Waterway.......9.07......................
9. Total Length of Waterways.........1650 feet...............
10. Drainage Density (Length of waterways per acre)....61.......ft/acre
11. Form Factor A/L^2..........0.77.....................................

L E G E N D

Field Boundary.......................................—x—
Field Number..⑫
Runoff Measuring Station..........................
Diversion Terrace....................................
Drop Structure...
Rainfall Measuring Station and Number...............R2
Secondary Traverse Station..........................□ Sta 1a
Watershed Boundary Traverse Station................○ 9
Camera Station and View Number..................5
Watershed Boundary..................................— — —

NOTE: All other Symbols are those adopted by the U.S. Board of Surveys and Maps.

FIGURE 6.1 DATA FOR WATERSHED WI

VIEW NEGATIVE NUMBER

View No 5 Negative No. Ill. - R.S. - 30
View No. 6 Negative No. Ill. - R.S. - 31

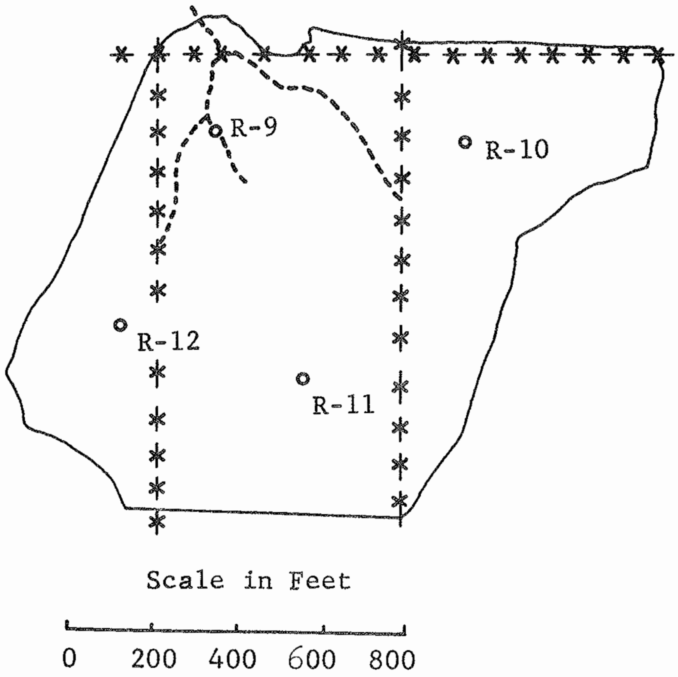


FIGURE 6.2 LOCATION OF RECORDING RAIN GAUGES IN WATERSHED WI

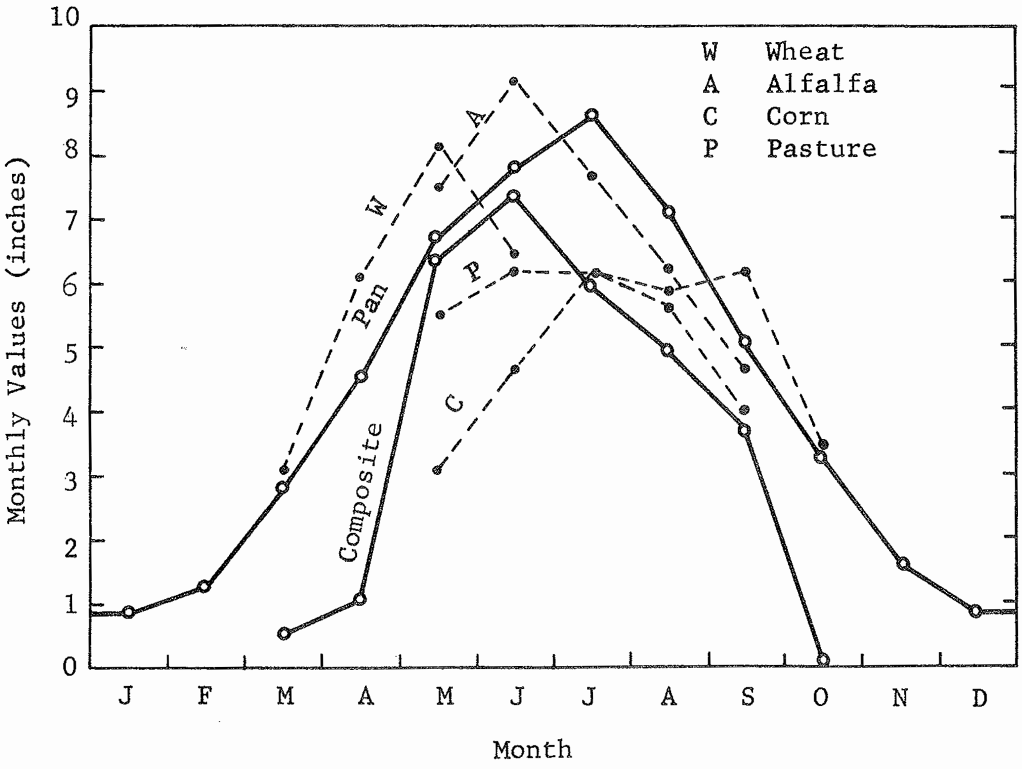


FIGURE 6.3 MONTHLY VARIATION OF PAN EVAPORATION AND CONSUMPTIVE USE

together with soil types and depths. As a result of these experiments, Holtan and Minshall divided the watershed into four areas, based on the average permeability in a three-hour test as shown in Table 6.1.

Pan evaporation rates were secured from the United States Weather Bureau records. Monthly values are shown on Figure 6.3. As shown on Figure 6.1, crops for 1942 consisted of corn, alfalfa, wheat and sweet clover, in addition to a small amount of permanent pasture. The consumptive use of these crops was estimated by the Blaney-Criddle method (Chow, 1964). These monthly values are plotted on Figure 6.3. Also shown on Figure 6.3 is the monthly transpiration potential used by the model.

TABLE 6.1

DISTRIBUTION OF EQUILIBRIUM INFILTRATION RATES FOR WATERSHED WI

Percent of Total Area	Infiltration Rate (inch/hour)
12.06	0 - 0.53
20.99	0.53 - 0.67
19.63	0.67 - 0.83
47.32	over 0.83

Holtan and Minshall indicate no groundwater contribution to streamflow from WI. There was some, however, from WII, of which WI is a part. It seems logical then to suppose that some amount of "underflow" was occurring.

Selecting the Parameters

One goal of the watershed model is to have physically meaningful and physically determined parameters. The parameters and the basis of the selected value will be discussed.

Impervious Area: Figure 6.1 shows no impervious area, assume a value of zero.

Division of Pervious Area: No benching or contouring is evident from Figure 6.1. Consequently 0.8 of the total area was used as producing runoff directly to the stream, 0.15 as producing runoff directly to depression storage, and 0.05 as depression storage, except for the months of October and May. Values for October were 0.4, 0.5, and 0.1 while 0.3, 0.55, and 0.15 were used for May. These changes were necessary to account for the land preparation prior to planting winter wheat on 4.61 acres in October and corn on 7.42 acres in May.

Infiltration Parameters: From equation 5.12, three parameters are needed in the infiltration equation: C1, C2, and SATPRM. C1 was found using Holtan's recommended value of 0.62 times a vegetative factor of 0.35 from Table 5.1. C2 is also Holtan's recommended value. The saturated permeability was originally taken as 0.15 inches/hour. However, after studying the storms of October 30-31, 1941, when the soil was saturated, this value was revised to 0.05.

Unsaturated Permeability and Capillary Potential Parameters: At the present stage of development, these parameters are difficult to assign. Holtan and Minshall give soil horizon descriptions at four sites within WI. Bogota silt loam is the predominate soil type, which they describe as "highly permeable." Chow (1964), quoting from the United States Soil Conservation Service, classifies the Bogota series as group C--slow infiltration rates generally with impeding layer.

The soils listed in Table 5.2, for which the parameters have been found by a curve fitting technique, are not well described in the literature from which the data were taken. In fact, all are laboratory results from reconstituted soils. The values of Geary Silt Loam were used initially. However, the value of saturated permeability as computed by equation 5.19 did not agree with the value used in the infiltration equation. Reference to the table in Chow (1964) showed that this soil is in group B, a group with somewhat more permeability than group C. Consequently, the parameters were changed to describe a less permeable soil. Final values are given in Table 6.2.

Routing Parameters: A basic time interval of 10 minutes was chosen as corresponding reasonably well with the size of the watershed without causing the program to consume an excess amount of time for execution. The contour map, Figure 6.1, was examined, and the following velocities assigned:

areas below el. 530	1.63 ft/sec
areas between el. 530 and 535	1.13 ft/sec
areas above el. 535	0.67 ft/sec

Travel times and areas were estimated as shown in Figure 6.4 in which the travel times in minutes are underlined and the contributing areas, in acres, are indicated along the stream reach. The time distribution of runoff corresponding to an instantaneous rainfall is shown in Figure 6.5. The resulting routing elements were

0.12 0.42 0.40 0.06.

TABLE 6.2 PARAMETER VALUES

Parameter	Values
XLAT	38.8
XLONG	90.0
CORTZ	0
Monthly Pan Evaporation	0.84 1.28 2.72 4.54 6.64 7.80 8.70 7.16 5.10 3.32 1.63 0.84
TRANPO	0.0 0.0 0.52 1.03 6.28 7.33 5.91 4.97 3.66 0.31 0.0 0.0
NEWVAL	0 0 0 0 1 1 0 0 0 1 1 0
KSEGMT	1
JRINT	10
ISEG1	0
ISEG2	0
NRELEM	4
LAG	0
C	0.12 0.42 0.40 0.06
PANFAC	0.8
ALPHA	3.5
RTZONE	15.
ATOTAL	27.22
APERVS	1.0
AOLFSF	Oct: 0.4, Nov-Apr: 0.8, May: 0.55, Jun-Sep: 0.8
AOLFDS	Oct: 0.5, Nov-Apr: 0.15, May: 0.25, Jun-Sep: 0.15
DSMAX	0.25
VINSTM	0.005
DEPTHI	12.
DEPTHU	0.75
CHANLG	0.55
C1	0.20
C2	1.387

TABLE 6.2 (continued)

Parameter	Values
C3	186.
C4	-0.114
C5	7.745
C6	$0.2026 \cdot 10^{-6}$
C7	-10.
C8	0.2
C9	-3.0
C10	0.9
C11	0
C12	0
C13	0.001
C14	0.995
C15	0
ROUGH	0.065
SLOPE	0.0175
VLENGH	75.
SATPRM	0.05
UZST	4.14
VIZST	67.44
C16	0.001
SMMIN	0.15

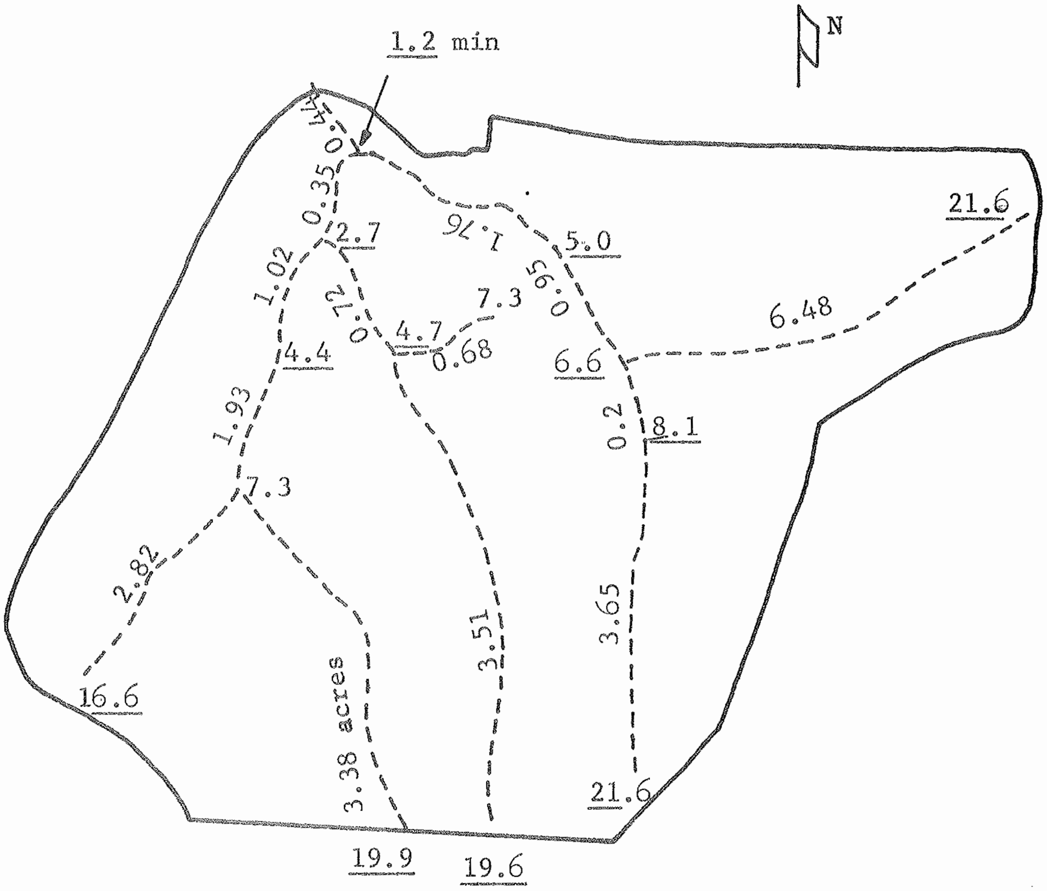


FIGURE 6.4 TRAVEL TIMES AND CONTRIBUTING AREAS FOR WATERSHED WI

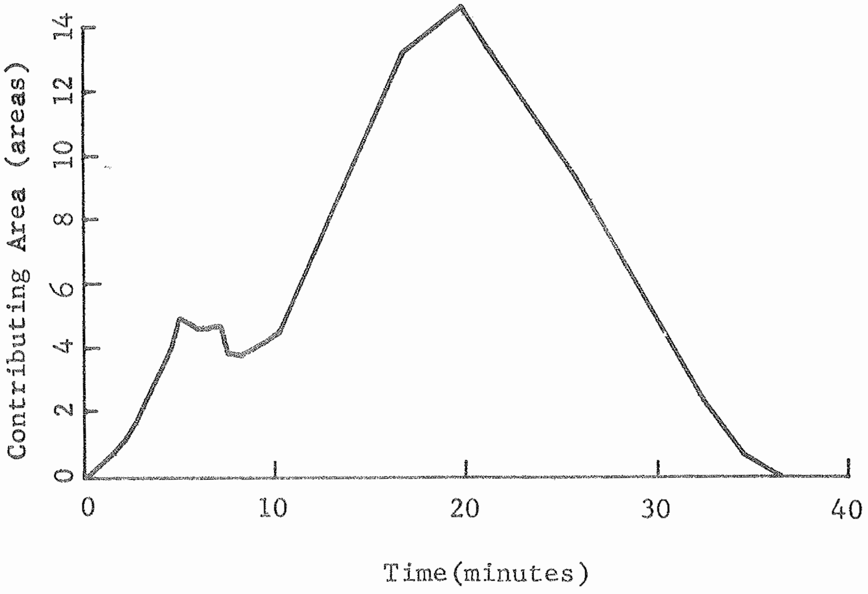


FIGURE 6.5 CONTRIBUTING AREAS OF WATERSHED WI TO AN INSTANTANEOUS INPUT

Upper Zone: A depth of nine inches was chosen for the Upper Zone Storage. This figure was selected as the probable depth of cultivation during the 1940 era. A maximum moisture content of 0.46 (by volume) was used because of the silt loam classification. A wilting point of 0.15 was used.

Intermediate Zone: No data is available on the soil below about 60 inches. An Intermediate Zone depth of 12 feet was selected as being adequate to prevent any groundwater flow being significant in the model. The same soil moisture limits were used in this zone as in the Upper Zone.

Interflow: The soil descriptions given by Holtan and Minshall indicate a restrictive clay layer at the 18 inch level on the portion of the watershed above elevation 530. Quite probably interflow does occur due to this clay layer. Transfer to interflow from the top portion of the Intermediate Zone is allowed when this zone is 0.9 full. The amount transferred is 0.001 of that volume above 0.9. The volumetric recession constant for the interflow storage is 0.99.

Results of Computer Run

The results of this choice of parameters is presented in Tables 6.3 and 6.4 and in the hydrographs of Figure 6.6 through 6.9. The hydrographs presented where chosen before the computer run as typical of the various conditions encountered by the model.

The model has not been as successful as was expected using the parameters assigned on the basis of available data. The most serious discrepancy is in generating the proper volume of runoff for each storm.

TABLE 6.3 SUMMARY OF MONTHLY SIMULATED AND MEASURED VALUES

Month	Rainfall (inches)	Measured Runoff (inches)	Simulated Runoff (inches)	Simulated Evaporation (inches)
Oct	8.10	1.01	1.04	0.10
Nov	2.87	0.77	0.24	0
Dec	1.59	T	0	0
Jan	1.23	0.01	0	0
Feb	2.59	0.90	0.03	0
Mar	2.01	0.10	0.01	0.43
Apr	2.22	0.34	0.03	0.83
May	5.25	0.10	0.57	5.09
Jun	7.56	1.31	2.16	6.00
Jul	8.20	3.46	3.57	4.75
Aug	3.49	0.46	0.94	3.94
Sep	1.43	T	0.01	2.91
Annual	46.54	8.58	8.59	24.04

TABLE 6.4 COMPARISON OF SIMULATED AND MEASURED VALUES FOR EACH STORM

Date	Rainfall (inches)	Runoff (inches)		Correlation Coefficient
		Measured	Simulated	
10- 2-41	0.30			
10- 4-41	0.20			
10- 5-41	0.36	0.0084	0.0404	0.9484
10- 7-41	0.24		0.0007	0
10- 9-41	0.86	0.0025	0.1996	0.7560
10-14-41	0.42	0.0103	0.0490	0.9453
10-17-41	1.44	0.1729	0.2302	0.8557
10-20-41	1.89	0.3322	0.3866	0.8020
10-22-41				
10-26-41	0.37	0.0031	0	0
10-30-41	2.02	0.3898	0.0941	0.8701
10-31-41				
11- 5-41	2.04	0.7495	0.2308	0.8747
11- 6-41				
11-10-41	0.01			
11-17-41	0.01			
11-19-41	0.29			
11-20-41				
11-22-41	0.35	0.0031		
11-23-41	0.05			
11-24-41	0.12	0.0255		
12-12-41	0.30			
12-22-41	0.28			
12-23-41	0.44	0.0007		
12-25-41	0.28	0.0050		
12-26-41	0.29			
1- 1-42	0.28			
1-18-42	0.05			
1-30-42	0.90	0.0102		
1-31-42				
2- 3-42	1.40	0.5999	0.0271	0.7963
2- 6-42				
2- 9-42	0.21			
2-15-42	0.55	0.0851		
2-16-42				
2-23-42	0.35			
2-26-42	0.05			
2-27-42		0.0157		
2-28-42		0.0082		

TABLE 6.4 (continued)

Date	Rainfall	Runoff (inches)		Correlation
	(inches)	Measured	Simulated	Coefficient
3- 4-42	0.03			
3- 5-42				
3- 7-42	0.71	0.1365		
3- 8-42				
3-12-42	0.65	0.0874	0.0073	0.4577
3-13-42				
3-20-42	0.07			
3-25-42	0.25			
3-26-42				
3-27-42	0.23			
3-30-42	0.07			
4- 6-42	1.16	0.0199	0.0215	0.9712
4- 7-42				
4- 8-42	1.17	0.3211	0.0019	0.5257
4-10-42				
4-24-42	0.02			
5- 2-42	0.17			
5- 3-42	1.05	0.0107	0.1629	0.3763
5- 5-42	1.11	0.0465	0.2928	0.8658
5- 6-42				
5-11-42	0.03			
5-13-42	0.60	0.0047	0.0792	0.6288
5-15-42	0.96	0.0288	0.1080	0.9270
5-17-42	0.10			
5-18-42	0.59	0.0098		
5-23-42	0.16			
5-26-42	0.07			
5-31-42	0.41		0.0002	0
6- 1-42	0.59	0.0058	0.1051	0.7161
6- 6-42	0.12			
6- 9-42	0.31			
6-10-42	0.07			
6-11-42	0.18			
6-13-42	1.35	0.1442	0.5503	0.9823
6-15-42	0.31			
6-18-42	0.52	0.0033	0.0322	0.0768
6-19-42	0.10			
6-20-42	0.03			
6-21-42	1.69	0.0275	0.6521	0.9685
6-25-42	0.50			
6-26-42	1.79	0.8281	0.8110	0.9064

TABLE 6.4 (continued)

Date	Rainfall (inches)	Runoff (inches) Measured	Runoff (inches) Simulated	Correlation Coefficient
7- 7-42 7-10-42	6.97	3.2982	3.3998	0.9164
7-12-42	0.45	0.0703	0.1111	0.9463
7-14-42	0.51	0.0598	0.0274	0.5551
7-19-42	0.09			
7-21-42	0.63	0.0174	0.0662	0.9378
7-26-42	0.31			
8- 2-42	0.18			
8- 3-42	0.20			
8- 6-42 8- 7-42	2.21	0.2157	0.5390	0.9014
8-14-42 8-15-42	0.90	0.0024		
9- 7-42 9- 8-42	0.82	0.0020	0.0027	0.1332
9-19-42	0.46			
9-26-42	0.15			

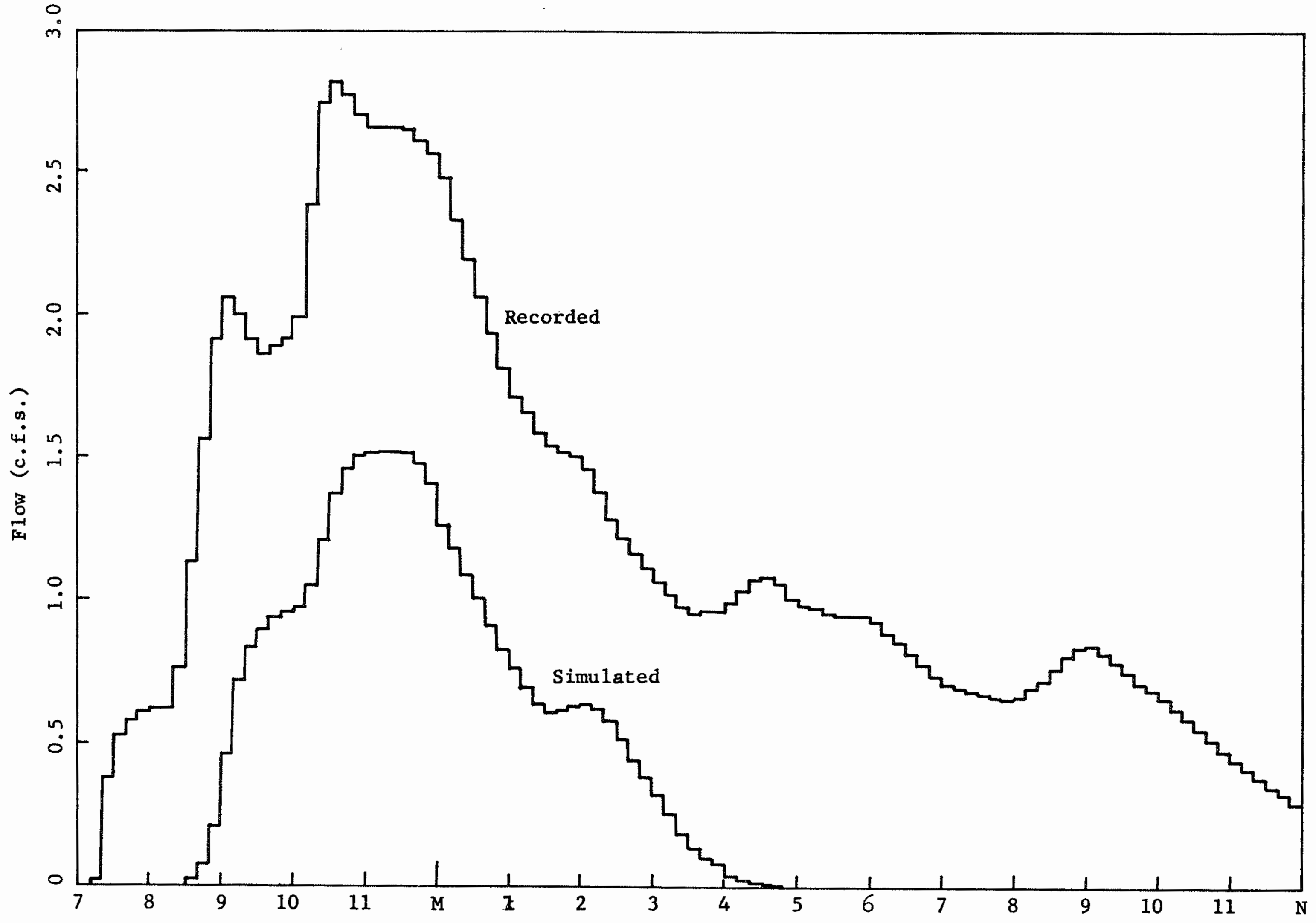


FIGURE 6.6 COMPARISON OF MEASURED AND SIMULATED FLOW FOR STORM OF NOV. 5-6, 1941

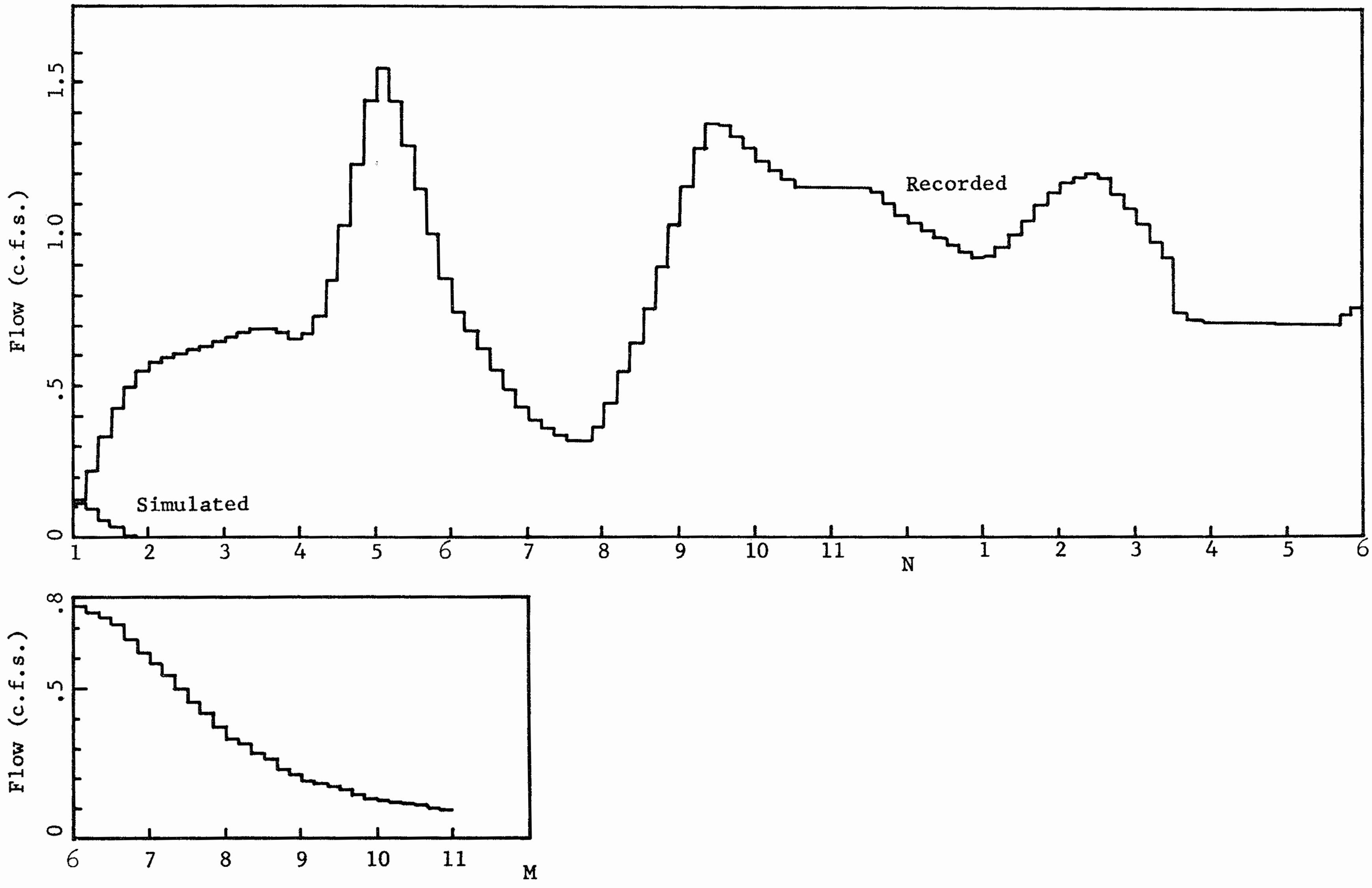


FIGURE 6.7 COMPARISON OF MEASURED AND SIMULATED FLOW FOR STORM OF FEB. 6, 1942

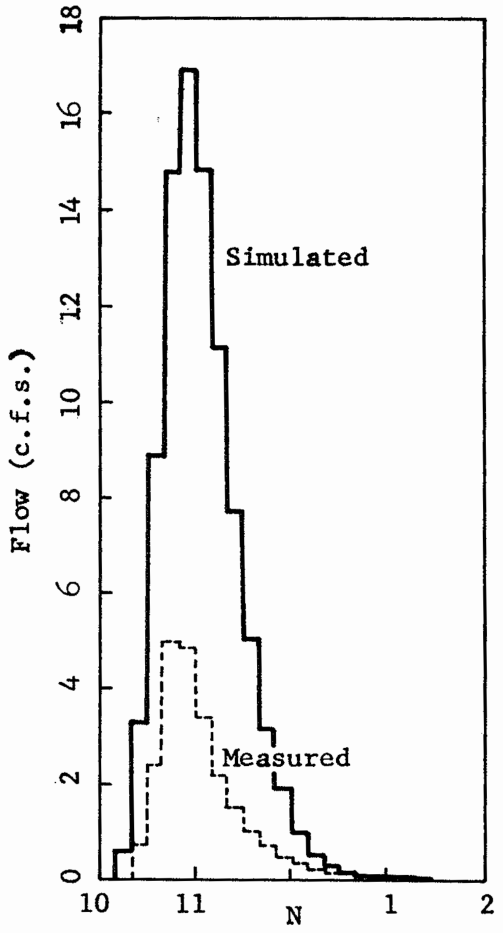


FIGURE 6.8 COMPARISON OF MEASURED AND SIMULATED FLOW FOR STORM OF JUNE 13, 1942

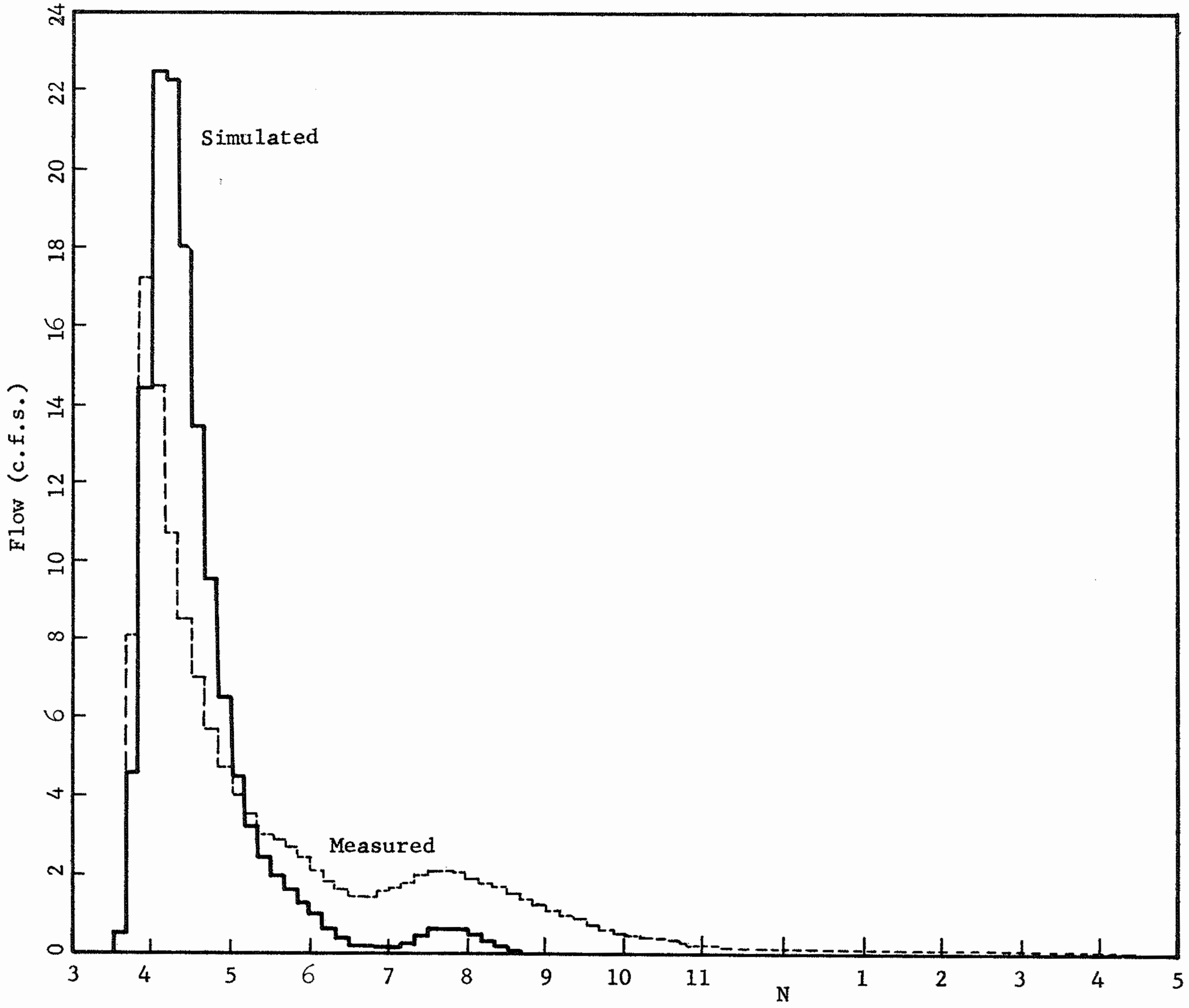


FIGURE 6.9 COMPARISON OF MEASURED AND SIMULATED FLOW FOR STORM OF JUNE 26, 1942

Part of this failure is attributable to the lack of a frozen soil facility within the model. Holtan and Minshall state that infiltrometer tests were discontinued during the winter because the soil was saturated. Figure 6.10 shows the daily maximum and minimum temperatures recorded at Greenville, Illinois, for the period November, 1941, through March, 1942. Greenville is about 30 miles east of Edwardsville. Clearly the ground was frozen throughout much of February. Fluker (1958) found soil temperature extremes to lag air temperature extremes by one month. Quite possibly the period of frozen ground extended well into March. If the ground is frozen and near saturation, virtually no infiltration, soil moisture movement, or evaporation will occur. The complexity of including the affects of temperature in the model are much greater than simply the problem of securing the daily temperatures (although this is a data preparation chore not to be overlooked). Rather the problem is in modeling the head flow process. The thermal characteristics of soils vary with the soil type and with moisture content. Also, the soil moisture freezes from the surface down; there may be no infiltration or evaporation at the surface because it is frozen while moisture transfer occurs a few inches beneath the surface below the frost line. Almost certainly some simple model such as "no evaporation, infiltration, or soil moisture movement while the air temperature is below 30° F." would improve the performance of the model, particularly during February.

Application to Mukewater Creek Watershed

Coskun and Moore (1969) reported the results of application of the Stanford Model to the Mukewater Creek watershed in central Texas. Using

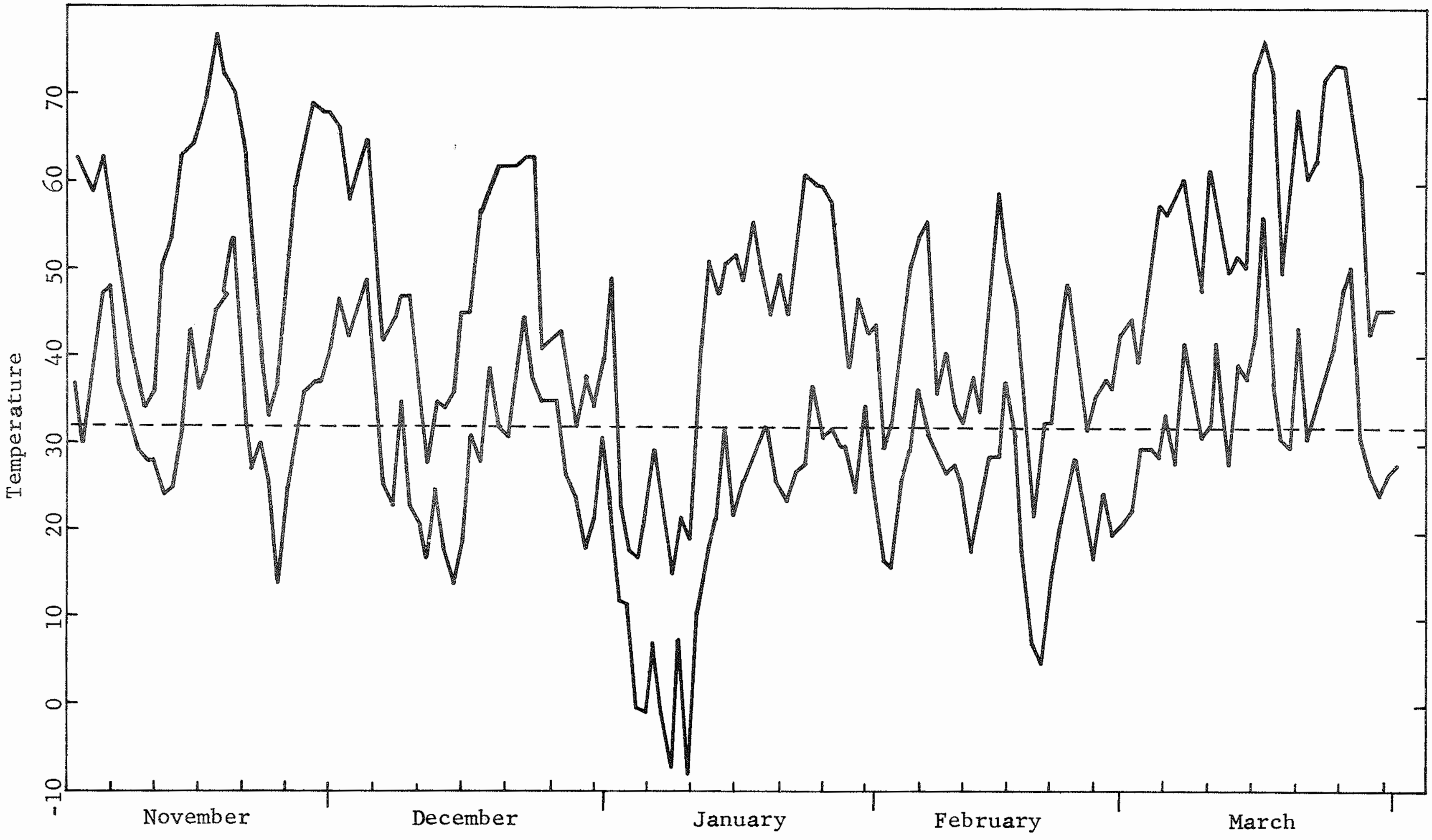


FIGURE 6.10 DAILY MAXIMUM MINIMUM TEMPERATURES AT GREENVILLE, ILLINOIS, 1941-1942

the rainfall data from their study, a similar application has been made with the proposed model.

Mukewater Creek is one of numerous small watersheds which have been studied in detail by the United States Geological Survey in co-operation with the Texas Water Development Board, and the United States Soil Conservation Service. Sauer (1965) has given the physiographic features as well as a summary of the hydrologic data for the period 1952-1960. Figure 6.11 shows the location of the watershed as well as the location of the rain gauges. The watershed contains 70.4 square miles above the stream gauging station at Trickham, Texas. About one half the watershed area is devoted to farming and the other half to ranching. Sauer reported the existence of 211 stock ponds by March, 1962. These controlled 20 percent of the drainage area. Six flood retarding structures were built between 1960-1965. These control almost 40 percent of the drainage area. Sauer concluded that areal distribution of the rain was insignificant when correlating rainfall and runoff. Coskun and Moore utilized the rainfall records from four recording rain gauges to produce a single hourly rainfall record for use in their application of the Stanford Model.

While some attempt was made to assign parameter values from available information, the emphasis in this application has been on determining the "best" set of parameters. Those parameters which are common to both the Stanford Model and to this model were assigned the values used by Coskun and Moore. Other values were assigned on the basis of the experience with the Edwardsville watershed. Only mean daily flow values are available for comparison to simulated values, except for hydrographs

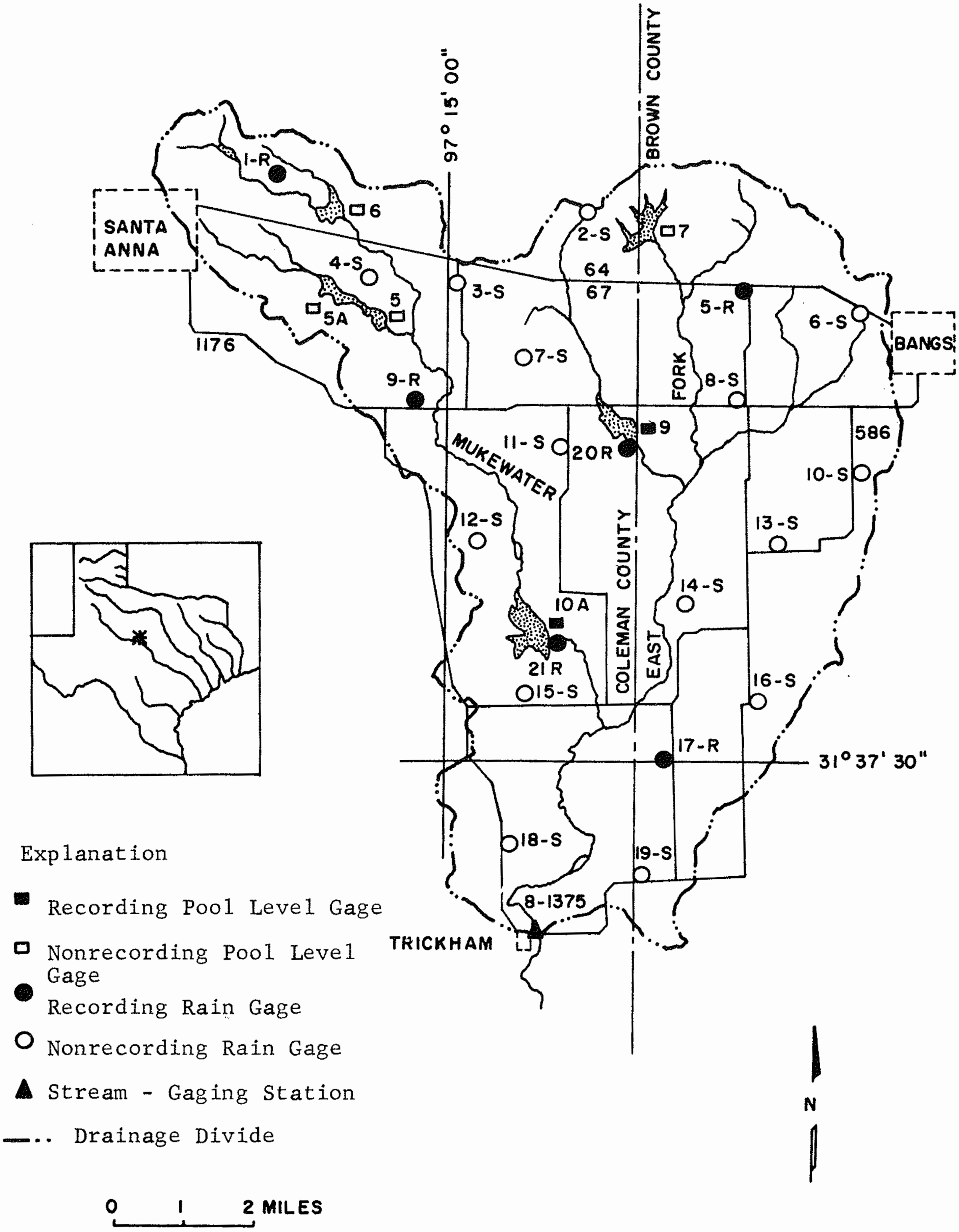


FIG. 6.11 MUKEWATER CREEK STUDY AREA

of the storms of May 11-13, 17-18, 1957 and February 22-23, 1958, which were reported by Coskun and Moore.

Results of the simulation are shown in Figures 6.12 through 6.19. Figures 6.12, 6.13, and 6.14 show the measured and simulated hydrographs for the three storms cited above. Figures 6.15 through 6.19 show a comparison of mean daily flow values for five of the more active months.

A direct comparison to the Stanford Model is difficult to make except on a statistical basis. Table 6.5 shows a comparison of the monthly runoff values as simulated by Coskun and Moore, those as simulated by this study, and the measured values. Also shown is the correlation coefficient for mean daily flows. As in the Edwardsville application, the mean daily flow series contains numerous zero values which enhance the correlation coefficient. Were it possible to choose some single measure of goodness of fit by which to judge a set of parameters, a computer program could be utilized to choose an optimum set of parameter values. However, the insensitivity of the correlation coefficient, even when the zero flow days have been eliminated, render it nearly useless for this purpose. Perhaps the most useful such measure is simply the sum of the absolute value of the errors. Such a sum has the serious drawback that all errors are weighted equally, i.e., a 10 second foot day error carries the same significance whether made on a day when the mean daily flow was 100 cfs or 1000 cfs. In the latter case, the error is of the same order of magnitude as the stream flow measurement inaccuracies, and obviously should not be considered significant. If a relative error is used instead, defined as the ratio of the error to the measured flow, an awkward situation prevails when the measured flow is zero and the simulated flow

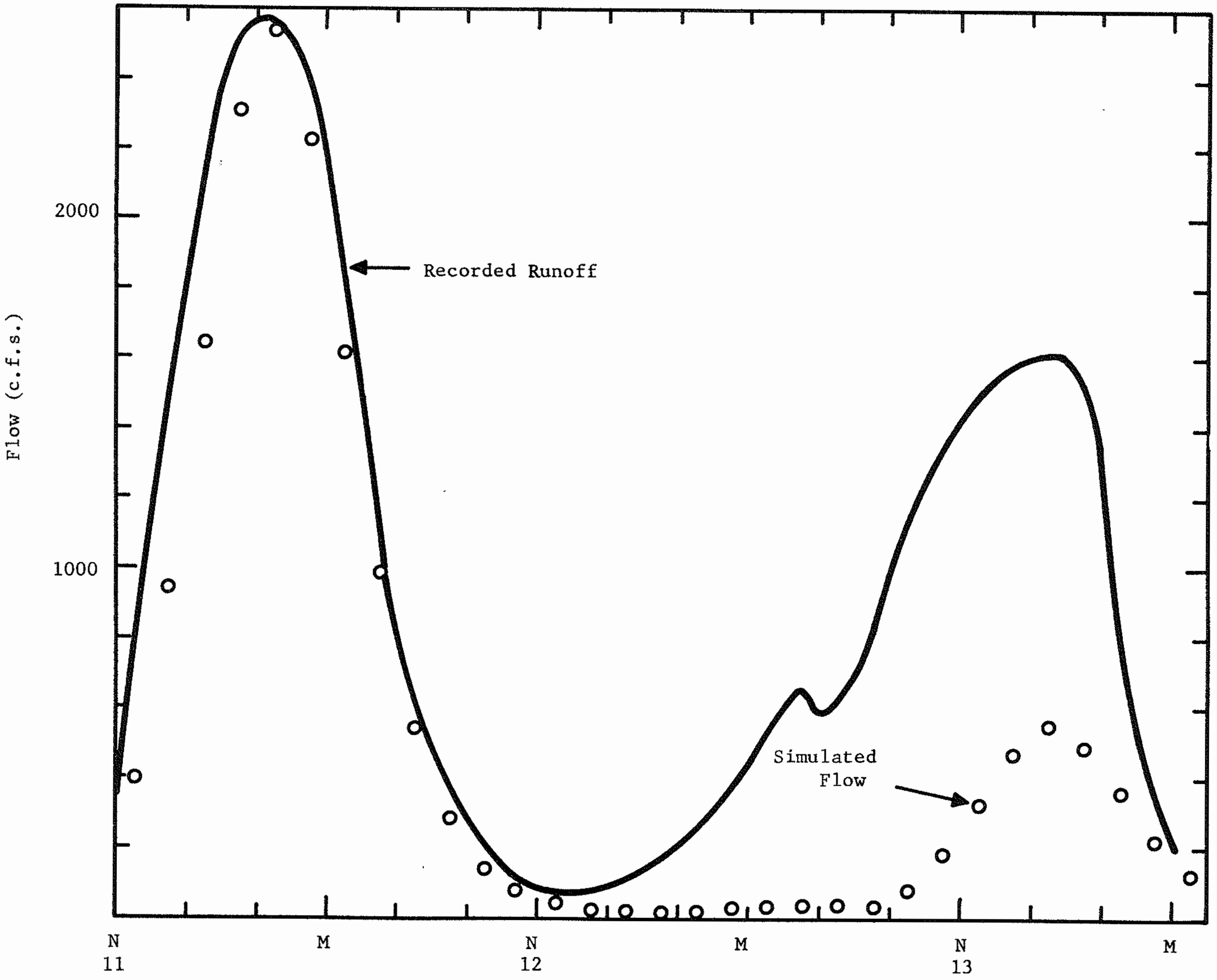


FIGURE 6.12 STORM OF MAY 11-13, 1957

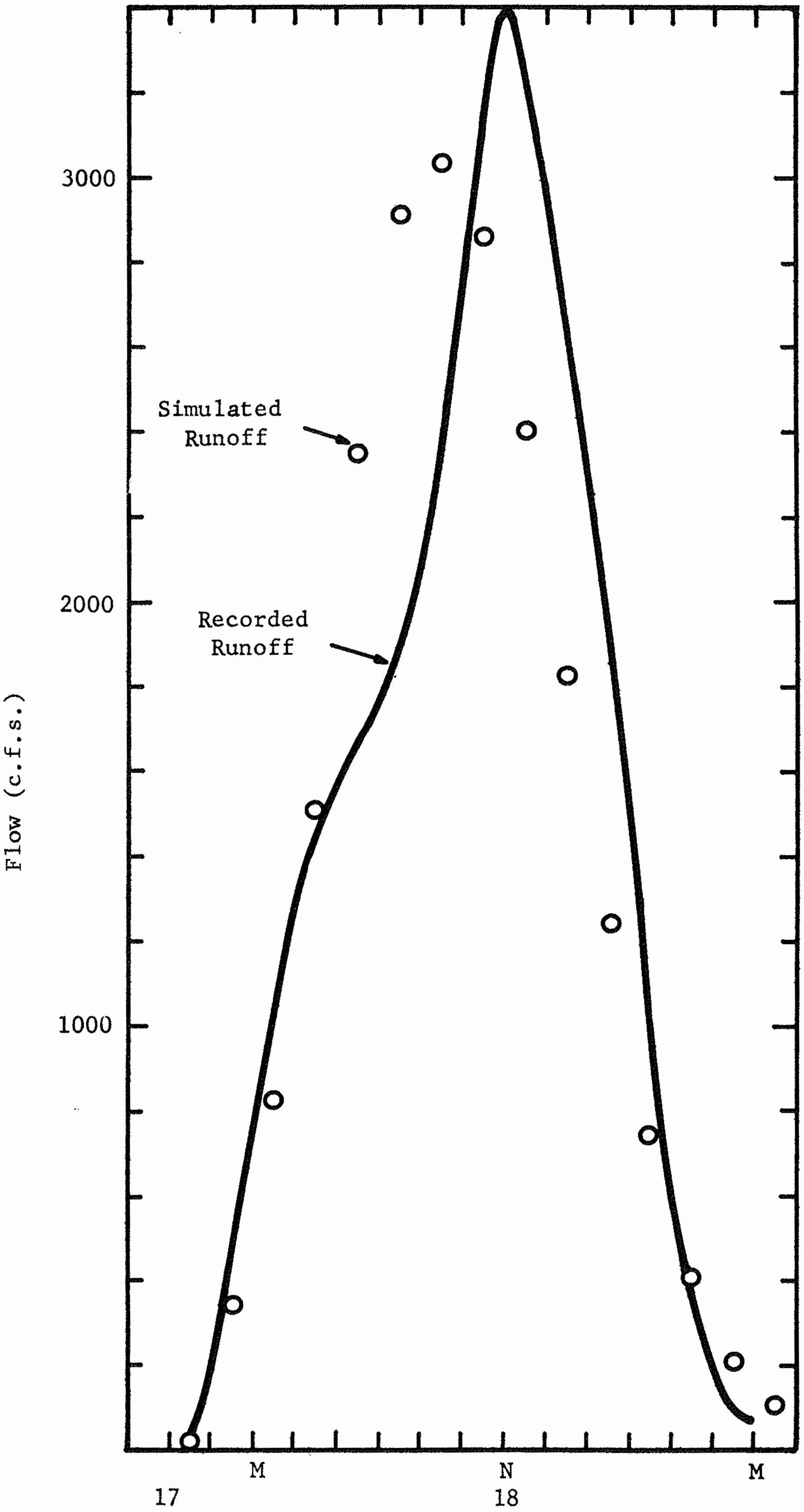


FIGURE 6.13 STORM OF MAY 17-18, 1957

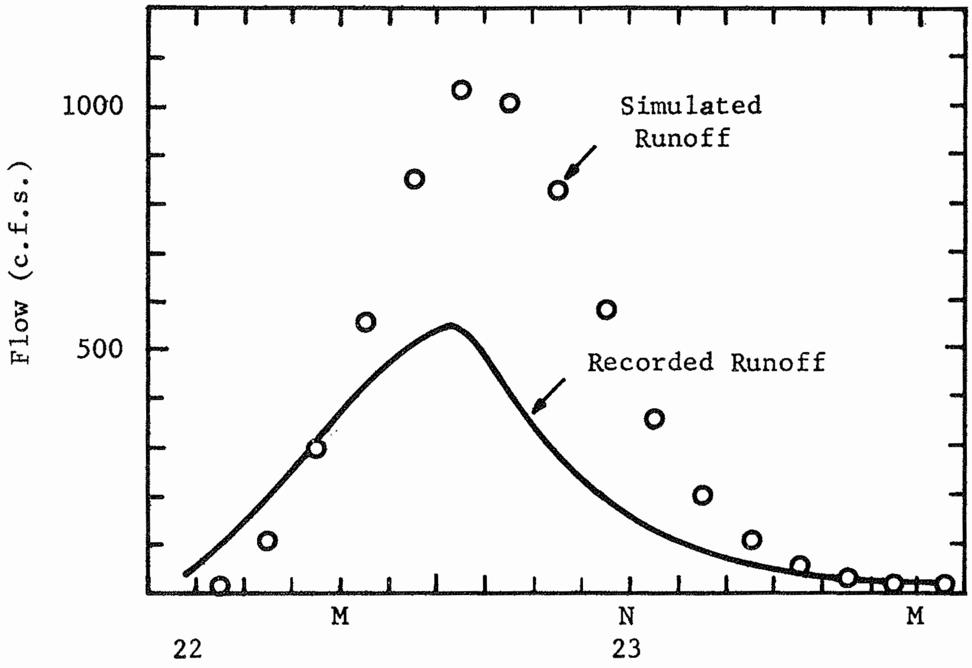


FIGURE 6.14 STORM OF FEBRUARY 22-23, 1958

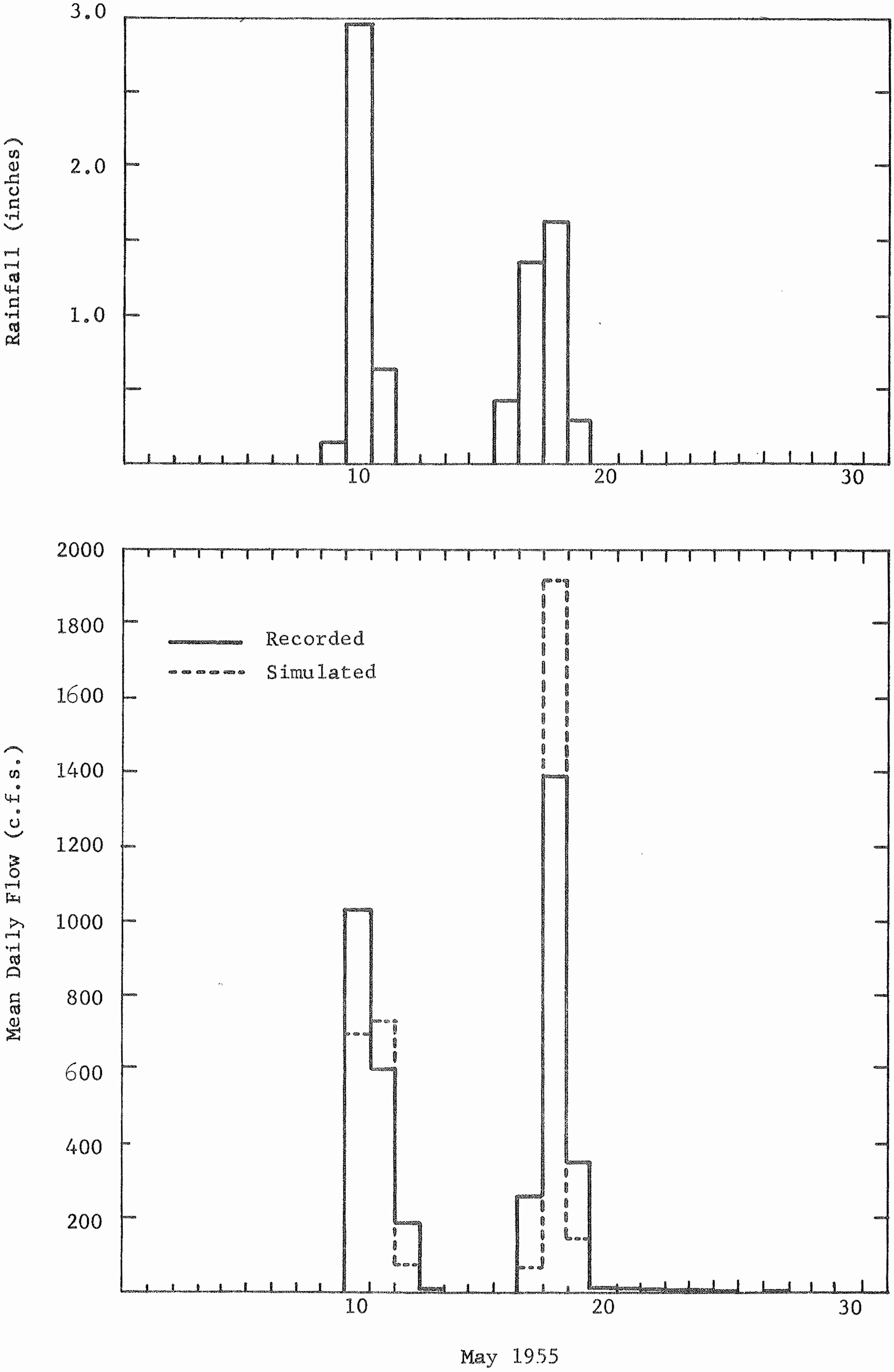


FIGURE 6.15 PRECIPITATION AND RUNOFF FOR MAY 1955

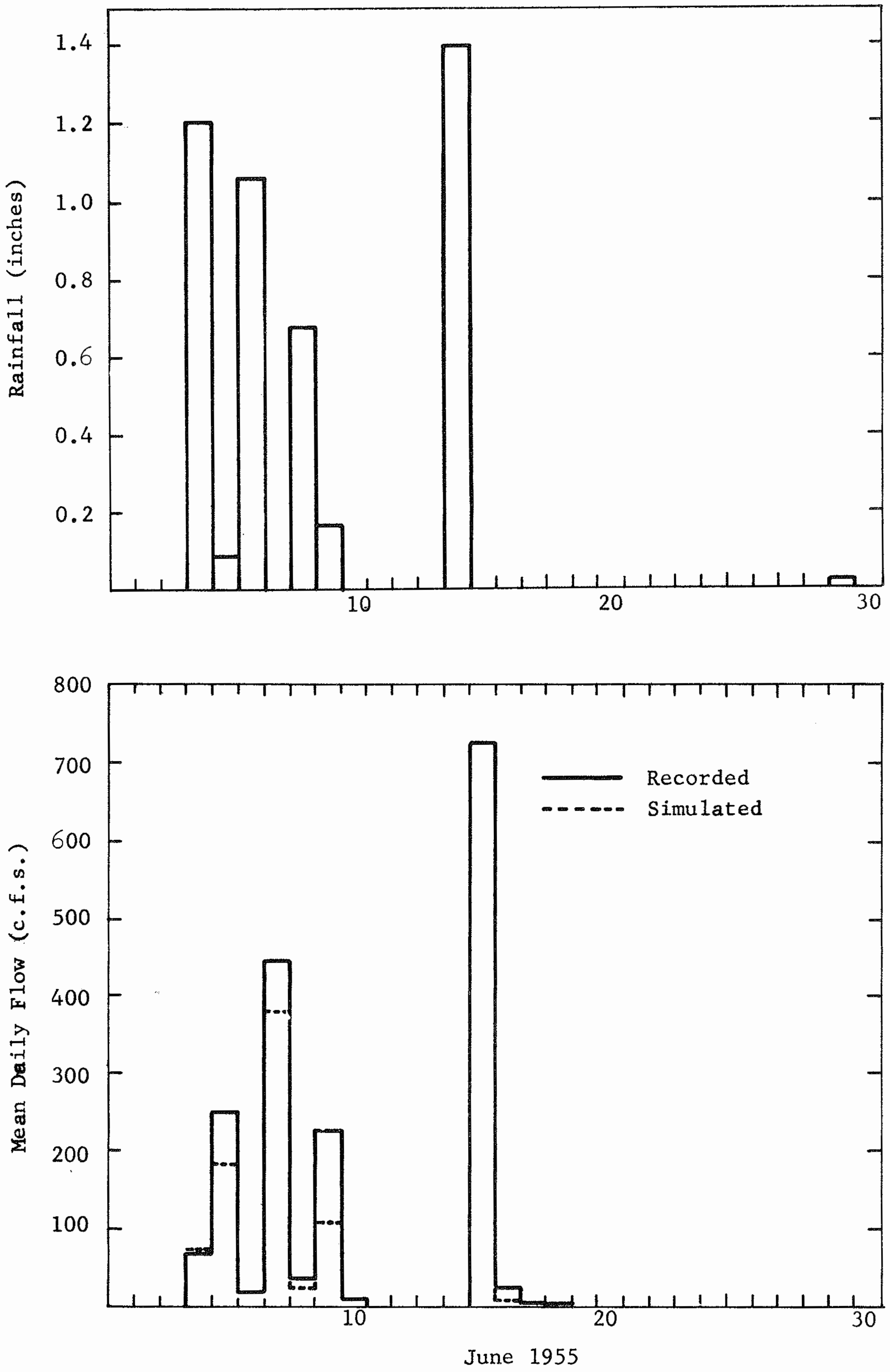


FIGURE 6.16 PRECIPITATION AND RUNOFF FOR JUNE 1955

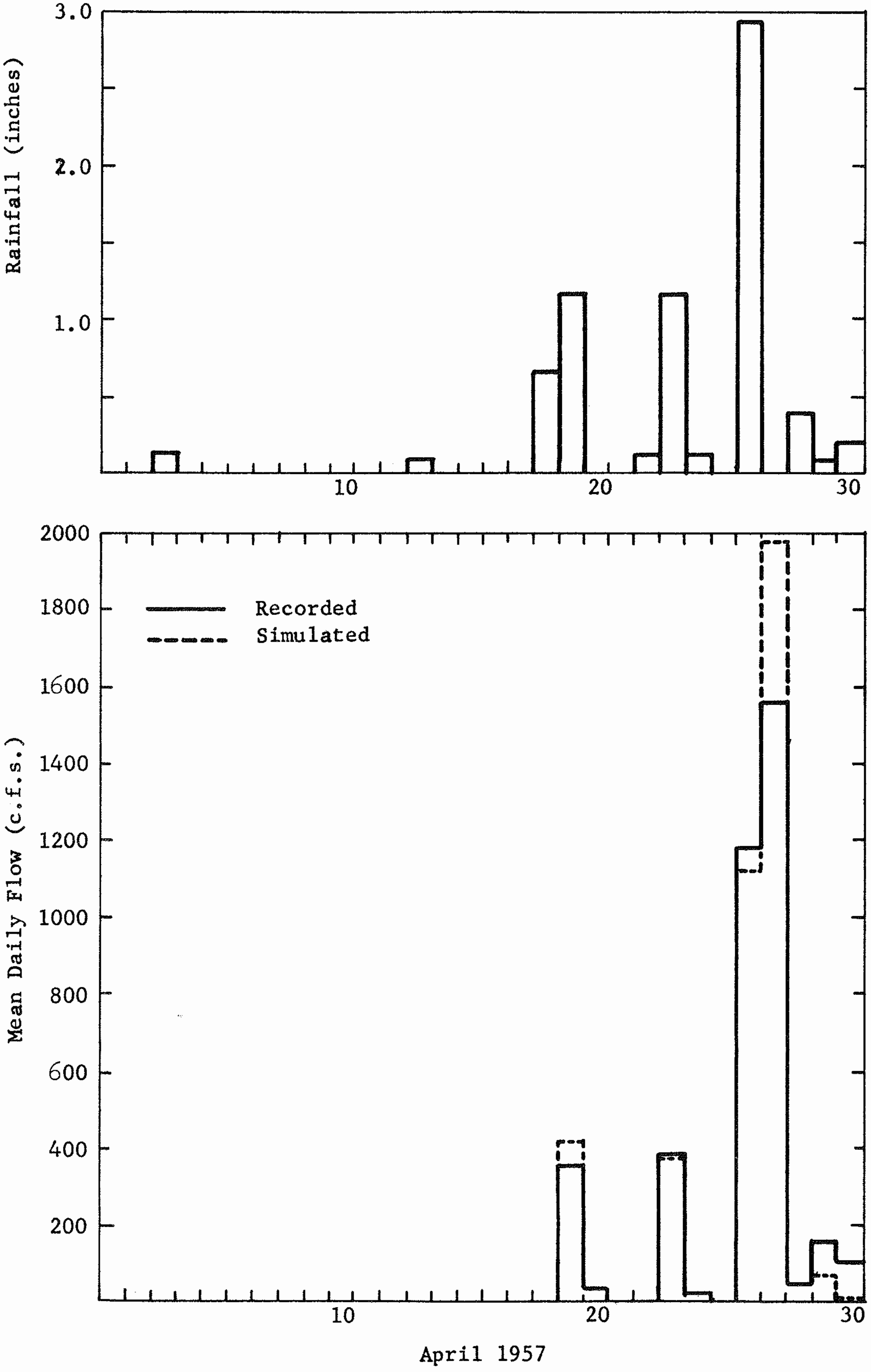


FIGURE 6.17 PRECIPATION AND RUNOFF FOR APRIL 1957

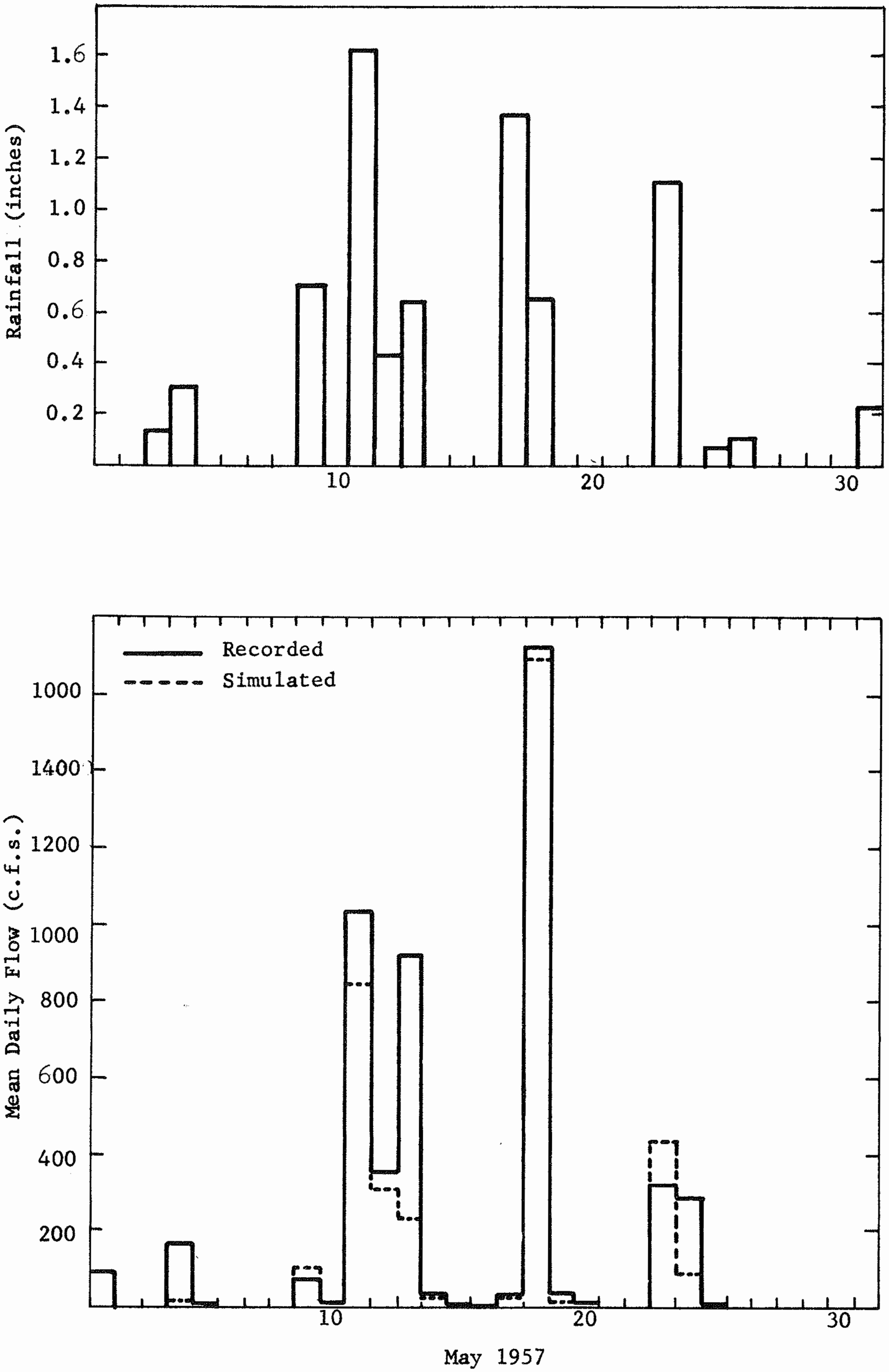


FIGURE 6.18 PRECIPATION AND RUNOFF FOR MAY 1957

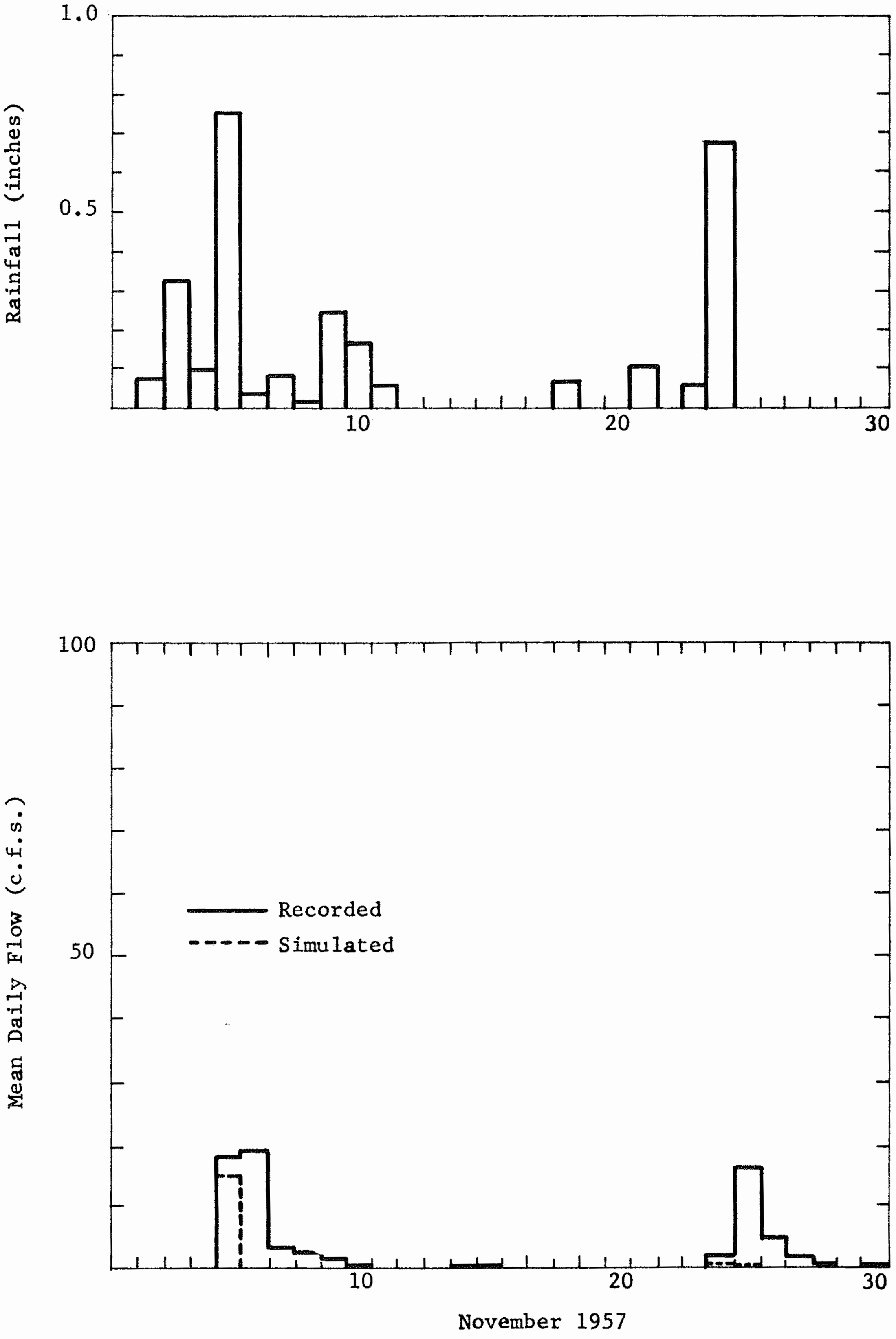


FIGURE 6.19 PRECIPITATION AND RUNOFF FOR NOVEMBER 1957

Water Year	Source	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Annual	Correlation Coefficient
1953 -1954	Recorded Stanford U. T.	0.50 0.60 .77					0.17 0.01 .03	0.25 0.18 .49	0.18 0.14 .17	0.02				1.10 0.97 1.46	0.9500 .9593
1954 -1955	Recorded Stanford U. T.		0.05 0.02	0.01		0.03 0.01	0.03		2.03 1.80 1.92	0.95 0.42 0.80	0.91 1.27 .58	0.06 0.01 .01	0.49 0.53 .30	4.55 4.10 3.62	0.9318 .9434
1955 -1956	Recorded Stanford U. T.		Data Not Available					0.10 0.25	2.15 2.31					2.25 2.57	0.9970
1956 -1957	Recorded Stanford U. T.	0.07 0.05 .06	0.05 0.02	0.02		0.01	0.08 0.07 .16	2.03 2.03 2.10	2.75 2.58 2.03	0.20 0.14 .30	0.01	0.01	0.01 0.02	5.19 4.96 4.65	0.9550 .9544
1957 -1958	Recorded Stanford U. T.	0.12 0.18 .05	0.04 0.07 .10	0.03	0.01 0.04	0.17 0.13 .29	0.17 0.14 .06	0.04 0.09 .03	0.11 0.08 .27	0.07 0.11 .26		0.10 0.16 .14	0.03	0.83 1.06 1.11	0.9284 .7402
1958 -1959	Recorded Stanford U. T.	0.01	0.01					0.01	0.01 0.04 .11	2.24 3.18 2.50	2.00 2.62 1.67	0.03	0.02	4.25 5.92 4.31	0.9766 .9792

TABLE 6.5 COMPARISON OF RECORDED AND SIMULATED RUNOFF VALUES IN INCHES

is nonzero. Both the annual correlation coefficient and the sum of the absolute value of the errors were used in arriving at the "optimal" set of parameters for Mukewater Creek.

Among those parameters which cannot be readily assigned numerical values from field data, the length of overland flow, the constants in the infiltration equation (C_1, C_2, and saturated permeability), and the thickness of the upper zone seem to be rather important. Some guidance can be obtained from the existing runoff data, and from current computer runs. Figure 6.20 shows the results of one such computer run. Consider a storm in which a considerable amount of rainfall fell in a short period. If no runoff was produced, essentially all the water infiltrated. The infiltration rate throughout the storm must be equal to or greater than the rainfall rate. In Figure 6.20, several of the isolated one hour storms which produced no runoff are shown by horizontal line segments. The left end of the line is plotted at the value of Upper Zone Storage which existed at the beginning of the storm. The line terminates at that value of Upper Zone Storage which would obtain if all of the rainfall were infiltrated. The infiltration curve (equation 5.12) must be an upper envelope for these line eegments. Obviously, to obtain values of the Upper Zone Storage at the beginning of the storm requires the simulation of the entire period. However, unless large changes are made in the parameters from run to run, the values of Upper Zone Storage do not seem to vary over a very large range. When applied to the Mukewater Creek data, the envelope lacked the proper shape for small values of Upper Zone thickness.

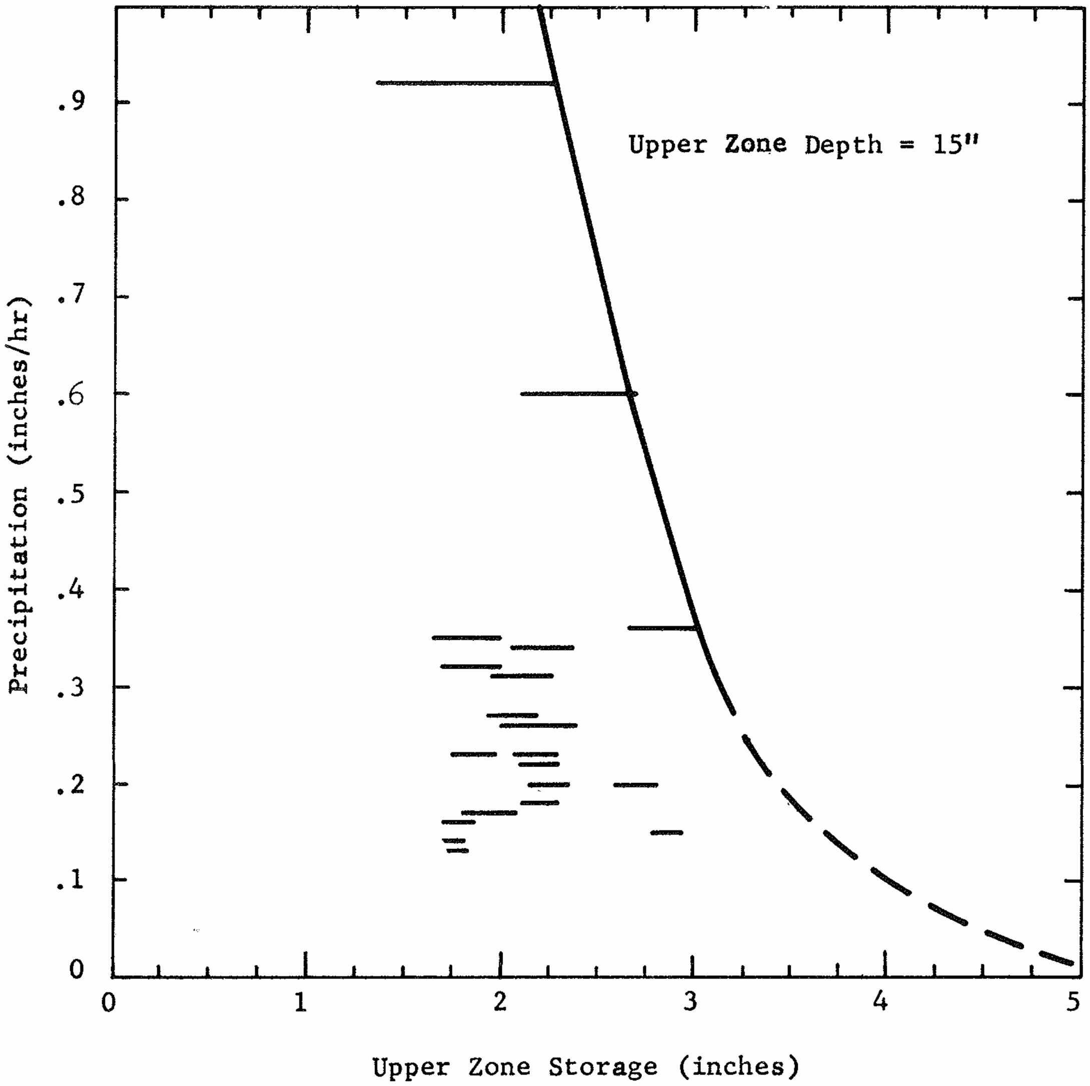


FIGURE 6.20 UPPER ZONE STORAGE FOR STORMS WITHOUT RUNOFF

After the parameters seem to be of the proper magnitude, further corrections can be determined from plots similar to Figure 6.21. The current values of C_1, C_2, Upper Zone thickness, and saturated permeability are used to plot the infiltration rate as a function of Upper Zone Storage. Each storm is then examined to determine whether a larger or smaller infiltration rate is required to obtain agreement between simulated and recorded values. In Figure 6.21, the results are indicated by an arrow showing the required direction of change for that storm. The results of such a plot may be that some segment of the infiltration curve must be shifted. Figure 6.22 shows the result of varying C_1; Figure 6.23 shows changes due to various values of C_2; while Figure 6.24 indicates the affects of depth of the Upper Zone when infiltration is not limited by rainfall. Such curves aid in choosing a new parameter value.

As stated earlier, Sauer reported no significant increase in correlation of runoff and rainfall when areal distribution of rainfall was considered. This conclusion was based on a comparison of recorded runoff and predicted runoff. To determine the predicted runoff, Sauer constructed a coaxial correlation graph using the weighted rainfall. To test the effects of areal distribution of rainfall, he utilized this coaxial correlation graph on each of the 19 segments and added the resulting runoff values. However, he did not compute API (antecedent precipitation index) values for each segment; instead he assumed a uniform value throughout the watershed. Possibly quite different results might be obtained if API were allowed to vary throughout the watershed. An examination of those storms for which this model gave poor results suggests some correlation with those storms which exhibited quite noticable areal distribution. Quite likely, Mukewater Creek is too large to be treated as a homogeneous unit by the model.

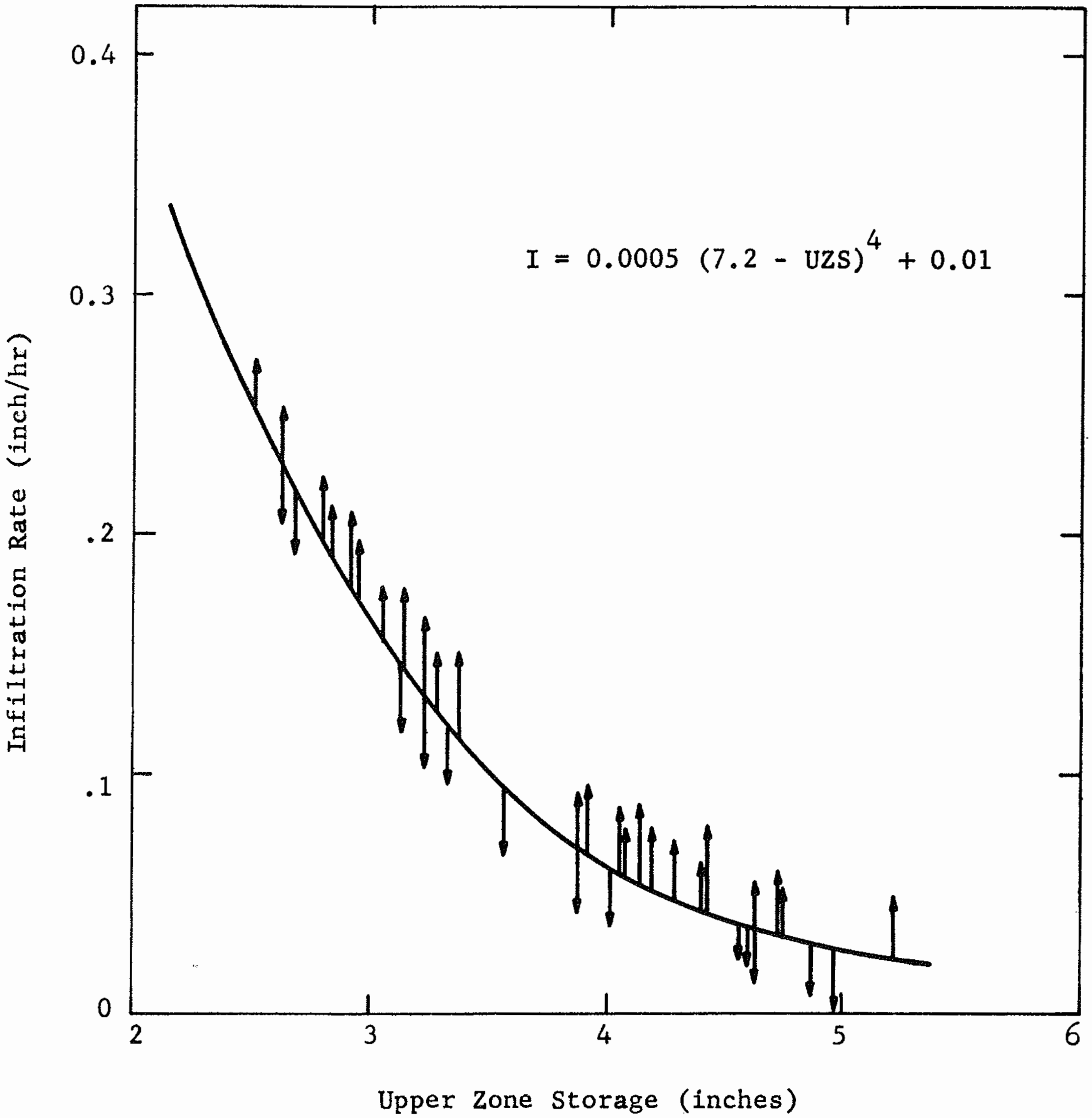


FIGURE 6.21 CHANGES NEEDED IN INFILTRATION RATE

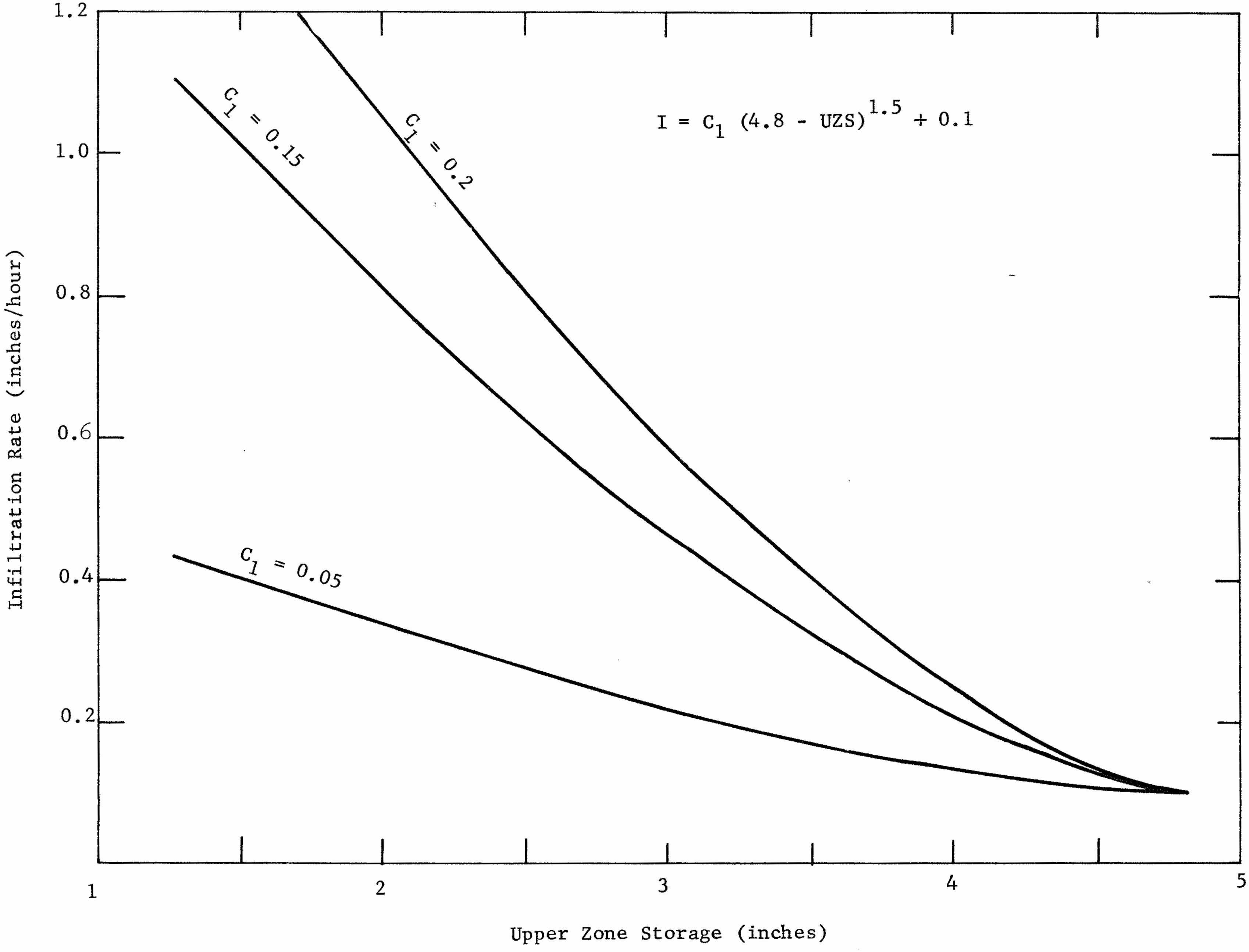


FIGURE 6.22 INFILTRATION RATE FOR VARIOUS VALUES OF C_1

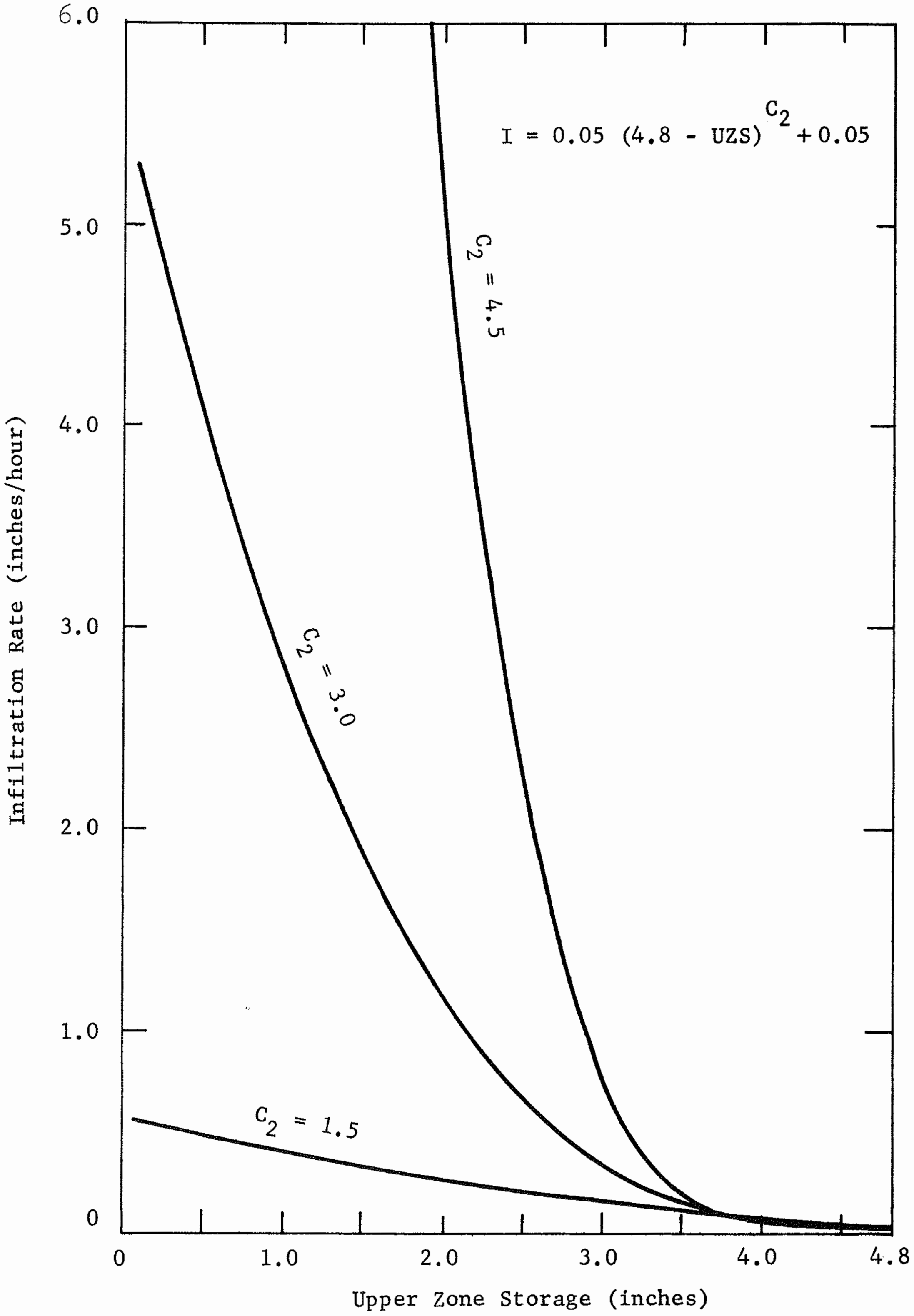


FIGURE 6.23 INFILTRATION RATE FOR VARIOUS VALUES OF C_2

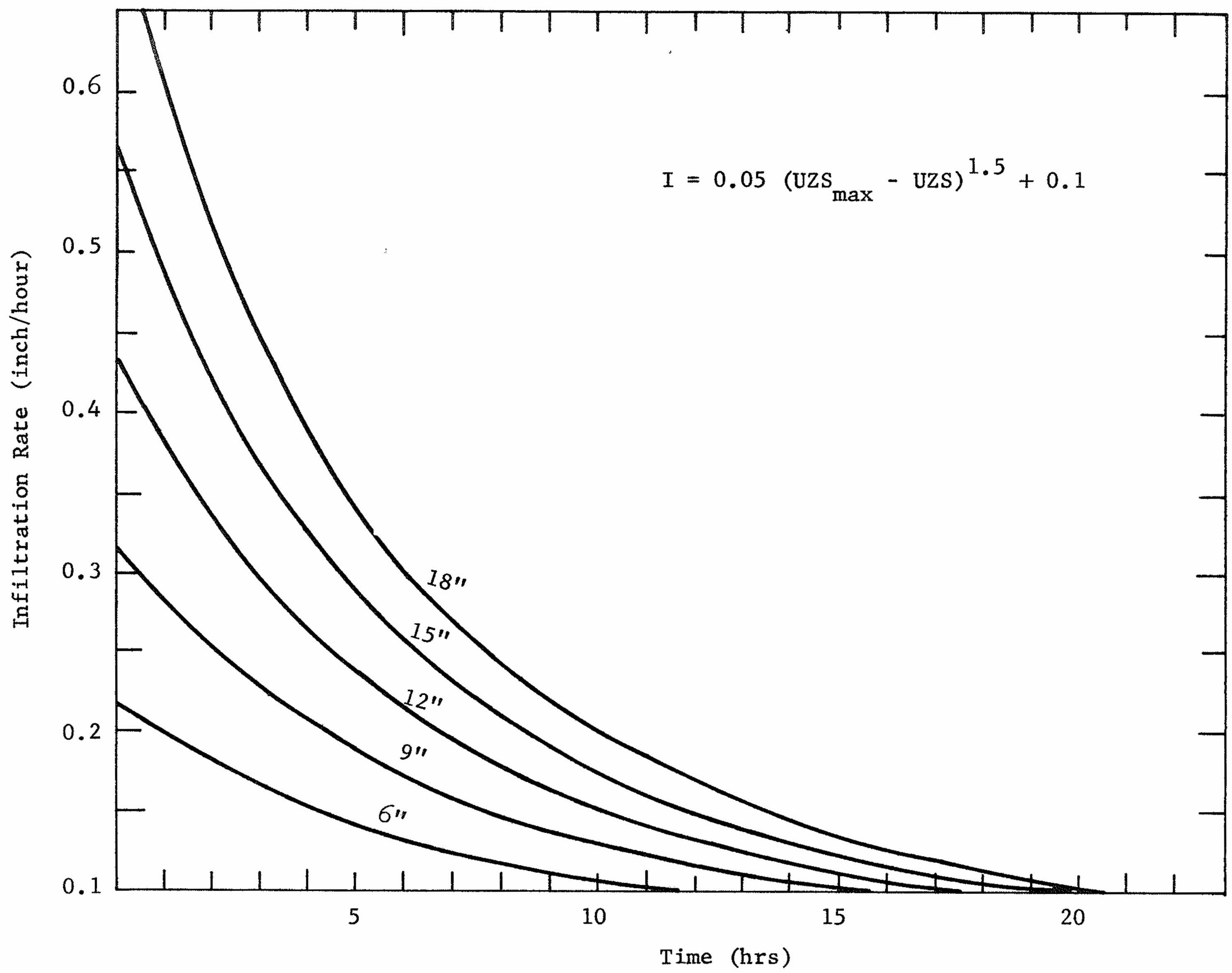


FIGURE 6.24 EFFECTS OF DEPTH OF UPPER ZONE ON INFILTRATION RATES

Chapter 7

CONCLUSIONS AND AREAS OF FUTURE RESEARCH

The validity of the various concepts incorporated into the model cannot be thoroughly tested by application to two watersheds. While the results of the application to the Edwardsville watershed were not as good as expected, those from the Mukewater Creek watershed are considerably more encouraging. Each of the 42 input parameters either has exact physical meaning or is an index of a physical quantity. The parameters in the latter category have been held to a minimum. There remain, however, many unsolved problems when modeling a watershed. Foremost of these problems is the spatial variation in most of the parameters. The Stanford Watershed Model attempted to solve this by assuming a linear distribution across the watershed. However, this is equivalent to assuming some average value of the parameter, such as has been done in the proposed model. The work reported by Holtan and Lopez (1969) uses three zones of differing characteristics to account for the spatial variation. Quite possible, as digital computers become larger, the watershed can be modeled in smaller segments, thereby achieving a greater degree of homogeniety in each subarea.

The simulation of the infiltration process needs further improvement. While Holtan's approximation is more closely related to the physical phenomenon than other empirical equations, research using finite difference methods to model the flow in both the saturated and the unsaturated zones should yield even better approximations.

The Mukewater Creek application indicates a serious deficiency in the manner in which the interflow is handled. The classical, but empirical recession constant has not been utilized because it lacks physical significance. The Stanford Model does use this method, and the results are quite apparent in the correlation coefficients for 1957-1958 (Table 6.5). This water year contained twice as many (109) days of recession type flow as did any other year. Were these portions of the hydrograph closely modeled, the correlation coefficeint would improve considerably. Future research needs to be directed toward defining a physically meaningful interflow model.

BIBLIOGRAPHY

Ayers, H. D., and J. Balek, "An Hourly Water Balance Model as a Basis for Continuous Water Resources Assessment on a Watershed," Hydrological Aspects of the Utilization of Water, International Association of Scientific Hydrology, 1968.

Biswas, T. D., D. R. Nielsen, and J. W. Biggar, "Redistribution of Soil Water After Infiltration," Water Resources Research, Vol. 2, No. 3, page 513-524, 1966.

Boughton, M. E., "A Mathematical Model for Relating Runoff to Rainfall With Daily Data," Civil Engineering Transactions, The Institution of Engineers, Australia, Vol. CE8:1, page 83-97, April, 1966.

van Bavel, C. H. M., "Potential Evaporation: The Combination Concept and Its Experimental Verification," Water Resources Research, Vol. 2, No. 3, page 455-567, 1966.

Chow, V. T., Hydrologic Determination of Waterway Areas for the Design of Drainage Structures in Small Drainage Basins, Illinois Experiment Station Bulletin 462, 1962.

Chow, V. T., ed., Handbook of Hydrology, McGraw-Hill, 1964.

Coskun, Erdal and W. L. Moore, "Numerical Simulation of a Watershed as a Means to Evaluate Some Effects of Floodwater - Retarding Structures on Runoff," Technical Report HYD 14-6901, The University of Texas at Austin 1969.

Dawdy, D. R., "Mathematical Modeling in Hydrology," presented at the International Seminar for Hydrology Professors, Urbana, Illinois, July, 1969.

Fox, L., An Introduction to Numerical Linear Algebra, Oxford University Press, 1965.

Fluker, B. J., "Soil Temperatures," Soil Science, Vol. 86 page 35-46, 1958.

Gardner, W. R., "Mathematics of Isothermal Water Conduction in Unsaturated Soils," Water and Its Conduction in Soils, Special Report 40, National Research Council, Highway Research Board, page 78-87, 1958.

Gardner, W. R. and Milton Fireman, "Laboratory Studies of Evaporation from Soil Columns in the Presence of a Water," Soil Science, Vol. 85, page 244-249, 1958.

Gardner, W. R., "Solutions of the Flow Equation for the Drying of Soils and Other Porous Media," Soil Science Society of America Proceedings, Vol. 23, No. 3, page 183-187, 1959.

Hanks, R. J. and S. A. Bowers, "Numerical Solution of the Moisture Flow Equation for Infiltration into Layered Soils," Soil Science Society of America Proceedings, Vol. 28, page 614-619, 1964.

Holtan, H. N., A Concept for Infiltration Estimates in Watershed Engineering, ARS 41-51, U. S. Department of Agriculture, 1961.

Holtan, H. N. and N. E. Minshall, Plot Samples of Watershed Hydrology, ARS 41-133, U. S. Department of Agriculture, January, 1968.

Holtan, H. N. and N. C. Lopez, "An Engineering-Oriented Model of Watershed Hydrology," presented at International Seminar for Hydrology Professors, Urbana, Illinois, July, 1969.

Ibrahim, H. A. and W. Brutsaert, "Intermittent Infiltration into Soils with Hysteresis," Journal of the Hydraulics Division, Proceedings, American Society of Civil Engineers, Vol. 94, No. HY1, January, 1968.

Kent, K. M., A Method for Estimating Volume and Rate of Runoff in Small Watersheds, SCS-TP-149, Soil Conservation Service, U. S. Department of Agriculture, January, 1968.

King, "Description of Soil Characteristics for Partially Saturated Flow," Soil Science Society of America Proceedings, Vol. 29, page 359-362, 1965.

Kohler, M. A. and R. K. Linsley, Predicting the Runoff from Storm Rainfall, U. S. Weather Bureau Research Paper 34, 1951.

Kuehl, D. W. and V. P. Schermerhorn, "Hydrologic Digital Model of Williamette Basin Tributaries for Operational River Forecasting," a paper presented at the American Society of Civil Engineers National Meeting on Water Resources Engineering, New York, October, 1967.

Liakopoulos, A. C., "Theoretical Prediction of Evaporation Losses from Groundwater," Water Resources Research, Vol. 2, No. 2, page 227-240, 1966.

Linsley, Ray K. and N. H. Crawford, Digital Simulation in Hydrology: Stanford Watershed Model IV, Technical Report 39, Department of Civil Engineering, Stanford University, July, 1966.

Nielsen, D. R., D. Kirkham, and W. R. van Wijk, "Measuring Water Stored Temporarily Above the Field Moisture Capacity," Soil Science Society of America Proceedings, Vol. 23, page 408-412, 1959.

Nielsen, D. R., D. Kirkham, and W. R. van Wijk, "Diffusion Equation Calculations of Field Soil Water Infiltration Profiles," Soil Science Society of America Proceedings, Vol. 25, No. 3, page 165-168, 1961.

Phillip, J. R., "The Theory of Infiltration: 1. The Infiltration Equation and Its Solution," Soil Science, Vol. 83, page 345-357, 1957.

Poulovassilis, A., "Hysteresis of Pore Water, an Application of the Concept of Independent Domains," Soil Science, Vol. 93, page 405-412, 1962.

Remson, I. and J. R. Randolph, Review of Some Elements of Soil-Moisture Theory, Geological Survey Professional Paper 411-D, U. S. Geological Survey, 1962.

Remson, I., R. L. Drake, S. S. McNeary, and E. M. Walls, "Vertical Drainage of an Unsaturated Soil," Journal of the Hydraulics Division, Proceedings, American Society of Civil Engineers, Vol. 91, No. HY1, 1965.

Richards, L. A., "Capillary Conduction of Liquids Through Porous Media," Physics, Vol. 1, No. 5, page 318-333, 1931.

Richtmyer, R. D., Difference Methods for Initial-Value Problems, Interscience, 1957.

Rockwood, D. M., "Columbia Basin Stream Flow Routing by Computer," Journal of Waterways and Harbors Division, Proceedings, American Society of Civil Engineers, Vol. 84, No. HY7, 1958.

Rockwood, D. M., Application of Stream Flow Synthesis and Reservoir Regulation--SSARR--Program to the Lower Mekong River," The Use of Analog and Digital Computers in Hydrology, International Association of Scientific Hydrology, Vol. 1, page 329-344, 1968.

Rubin, J. and R. Steinhardt, "Soil Water Relations During Rain Infiltration: I. Theory," Soil Science Society of America Proceedings, Vol. 27, page 246-251, 1963.

Rubin, J. and R. Steinhardt, "Soil Water Relations During Rain Infiltration: III. Water Uptake at Incipient Ponding," Soil Science Society of American Proceedings, Vol. 28, page 614-619, 1964.

Rubin, J., "Theory of Rainfall Uptake by Soils Initially Drier than their Field Capacity and Its Application," Water Resources Research, Vol. 2, No. 4, page 739-749, 1966.

Rubin, J., "Numerical Analysis of Ponded Rainfall Infiltration," Proceedings, Symposium on Water in Unsaturated Zone, Wageningen, 1966.

Sauer, S. P., "Hydrological Studies of Small Watersheds, Mukewater Creek, Colorado River Basin, Texas, 1952-60," Report 6, Texas Water Development Board, 1965.

Schermerhorn, V. P. and D. W. Kuehl, "Operational Stream Flow Forecasting With the SSARR Model," Use of Analog and Digital Computers in Hydrology, International Association of Scientific Hydrology, Vol. 1, page 280-288, 1968.

Smith, G. D., Numerical Solution of Partial Differential Equations, Oxford University Press, 1965.

Vachaud, M. B. G., Transactions, Jaroslav Cerni, Institute for Development of Water Resources, Vol. XIII, No. 39, page 75-90, 1966.

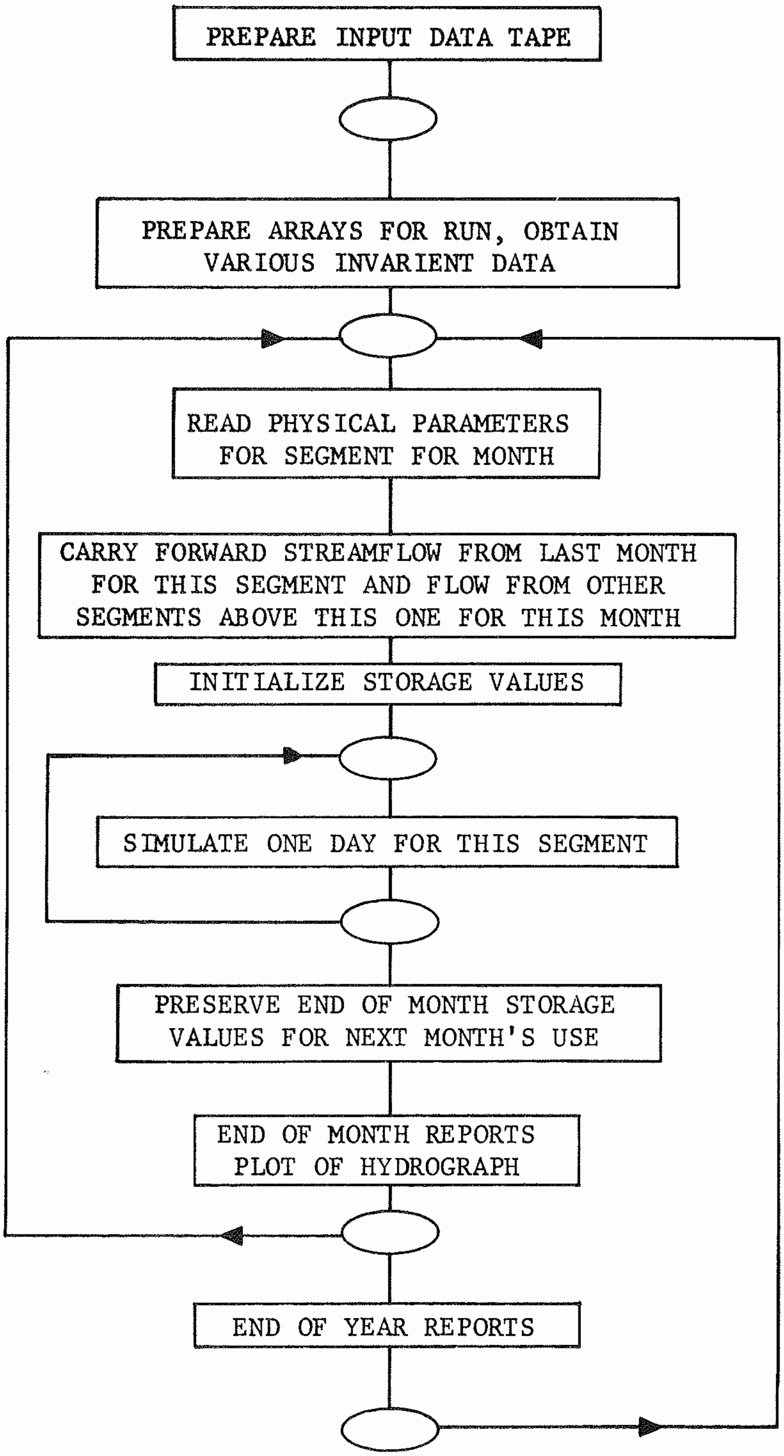
Watson, K. K., "An Instantaneous Profile Method for Determining the Hydraulic Conductivity of Unsaturated Porous Materials," Water Resources Research, Vol. 2, No. 4, page 709-715, 1966.

Watson, K. K., "Experimental and Numerical Study of Column Drainage," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 93, No. HY1, 1967.

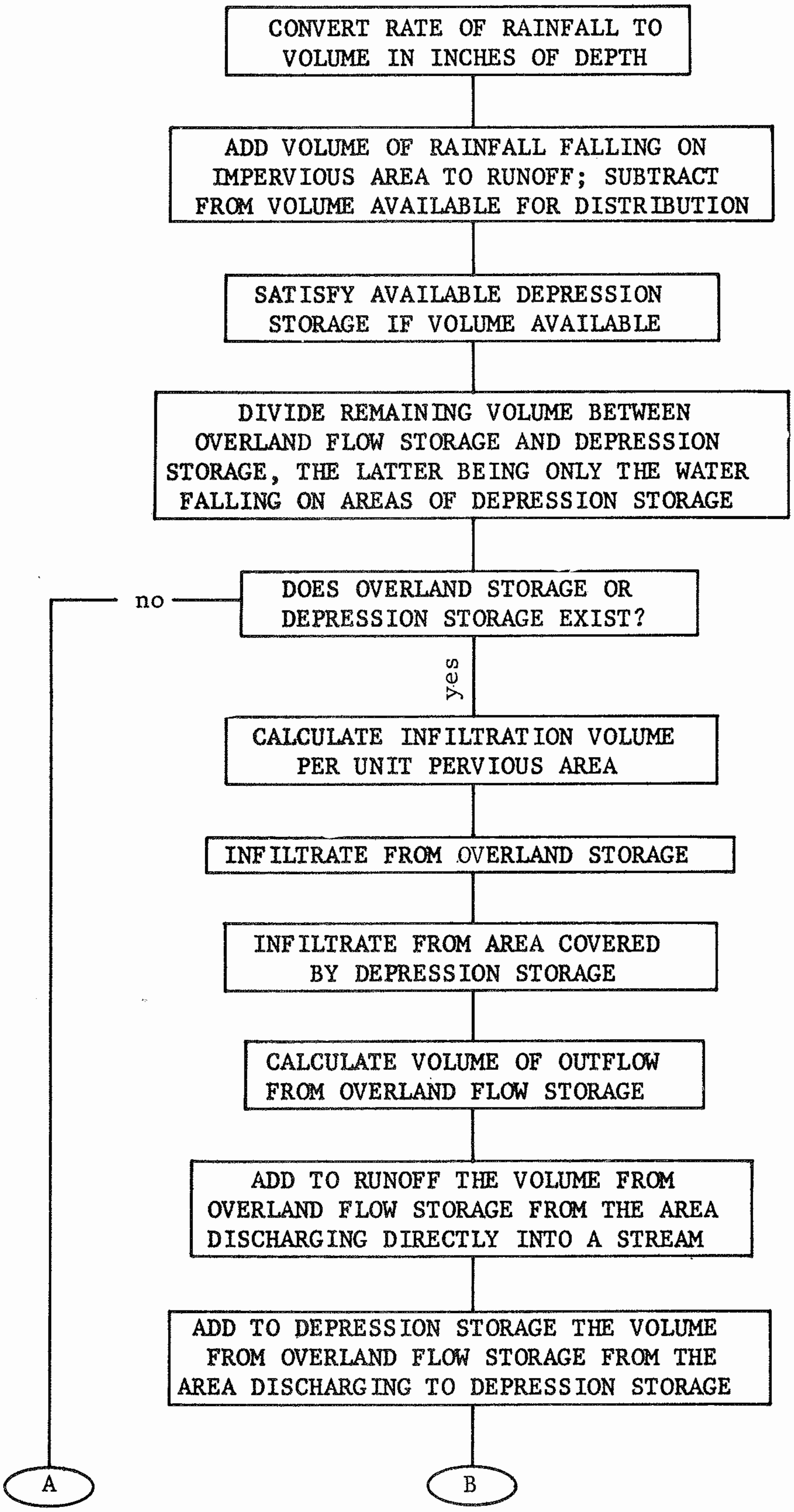
Youngs, E. G., "Moisture Profiles During Vertical Infiltration," Soil Science, Vol. 84, page 283-290, 1957.

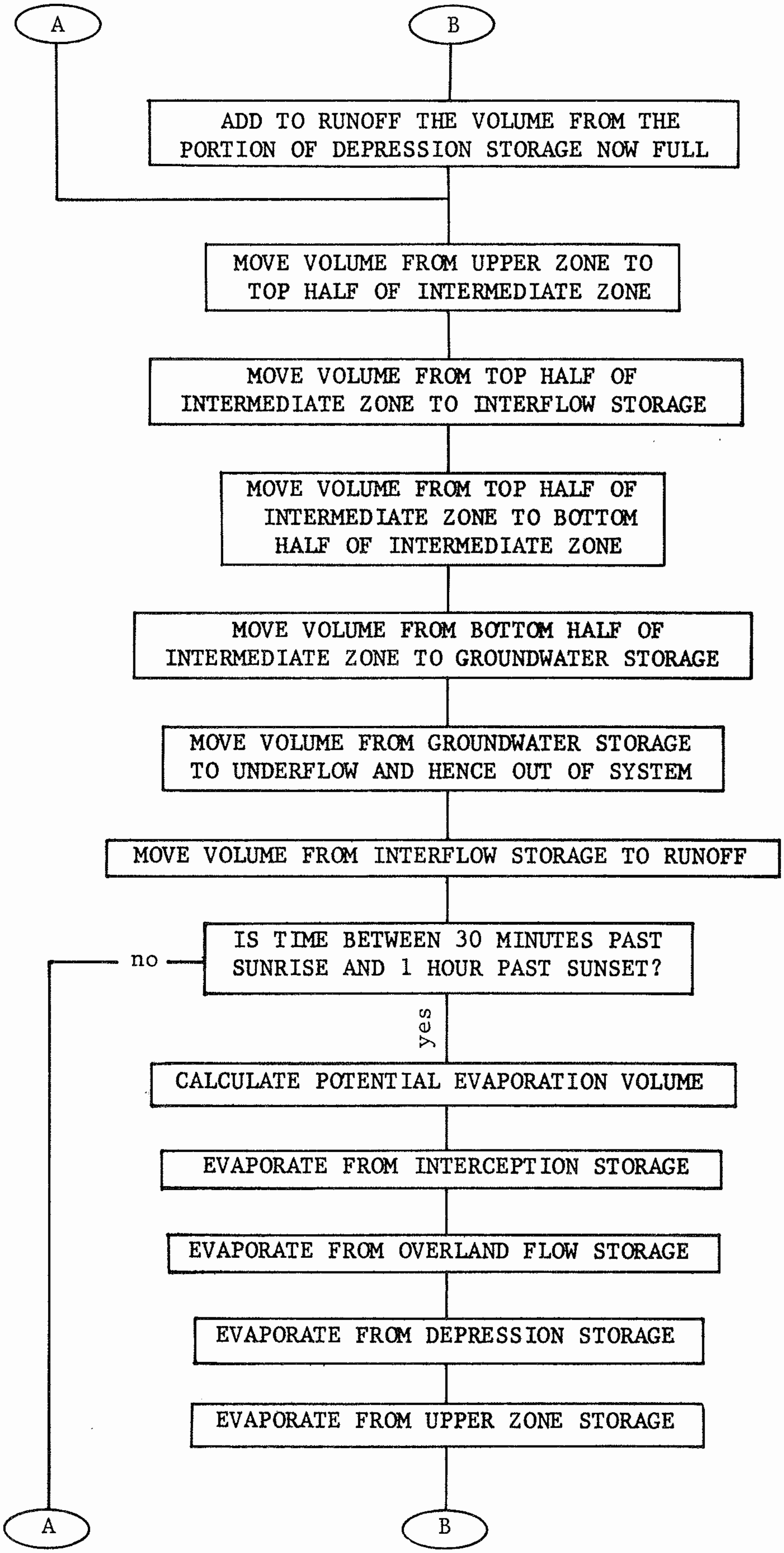
APPENDIX I

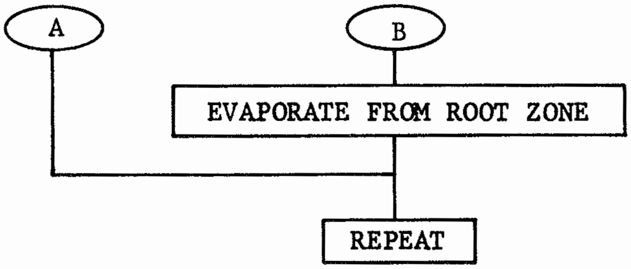
MAJOR STEPS IN COMPUTER PROGRAM



DETAILED FLOW CHART




A
B
ADD TO RUNOFF THE VOLUME FROM THE PORTION OF DEPRESSION STORAGE NOW FULL
MOVE VOLUME FROM UPPER ZONE TO TOP HALF OF INTERMEDIATE ZONE
MOVE VOLUME FROM TOP HALF OF INTERMEDIATE ZONE TO INTERFLOW STORAGE
MOVE VOLUME FROM TOP HALF OF INTERMEDIATE ZONE TO BOTTOM HALF OF INTERMEDIATE ZONE
MOVE VOLUME FROM BOTTOM HALF OF INTERMEDIATE ZONE TO GROUNDWATER STORAGE
MOVE VOLUME FROM GROUNDWATER STORAGE TO UNDERFLOW AND HENCE OUT OF SYSTEM
MOVE VOLUME FROM INTERFLOW STORAGE TO RUNOFF
IS TIME BETWEEN 30 MINUTES PAST SUNRISE AND 1 HOUR PAST SUNSET?
no
yes
CALCULATE POTENTIAL EVAPORATION VOLUME
EVAPORATE FROM INTERCEPTION STORAGE
EVAPORATE FROM OVERLAND FLOW STORAGE
EVAPORATE FROM DEPRESSION STORAGE
EVAPORATE FROM UPPER ZONE STORAGE
A
B


A
B
EVAPORATE FROM ROOT ZONE
REPEAT

```
      DIMENSION AD(38)                                                  TWM   2
      DIMENSION BIZS1(10)                                               TWM   3
      DIMENSION CARRYO(10,20),C(20),CHNLG(10)                           TWM   4
      DIMENSION DELIN1(10), DS1(10), DAILYF(31)                         TWM   5
      DIMENSION EVAP1(12), EVAP2(12), EVAP3(12)                         TWM   6
      DIMENSION EOMINC(10,12), EOMSUR(10,12), EOMUZ(10,12), EOMINT(10,12TWM   7
     1)                                                                 TWM   8
      DIMENSION EOMGW(10,12), EOMINF(10,12)                             TWM   9
      DIMENSION FLOINT(25)                                              TWM  10
      DIMENSION GWS1(10)                                                TWM  11
      DIMENSION ICASE(10,25), JPREC(10), IRFCOD(10)                     TWM  12
      DIMENSION JDPM(12)                                                TWM  13
      DIMENSION JPLOT(120)                                              TWM  14
      DIMENSION NAMSEG(19), NEWVAL(12)                                  TWM  15
      DIMENSION OLS1(10)                                                TWM  16
      DIMENSION PREC(1440)                                              TWM  17
      DIMENSION SIMFLO(1440)                                            TWM  18
      DIMENSION SWEIFL(10)                                              TWM  19
      DIMENSION SRAIN(10,12), SEVAP(10,12), SSF(10,12), SOLF(10,12)     TWM  20
      DIMENSION SGWF(10,12), SIF(10,12), SUF(10,12), SUMERR(10,25)      TWM  21
      DIMENSION SABSER(10,25), SERRSQ(10,25), SUMX(10), SUMY(10)        TWM  22
      DIMENSION RECFLO(1440)                                            TWM  23
      DIMENSION TIZS1(10),TRANPO(12)                                    TWM  24
      DIMENSION UZS1(10)                                                TWM  25
      DIMENSION VINST1(10)                                              TWM  26
      DIMENSION WEIGH(25)                                               TWM  27
      DIMENSION XX(10), XY(10)                                          TWM  28
      DIMENSION YY(10)                                                  TWM  29
      DATA R/1H+/,B/1H*/,BLANK/1H /,S/1H-/                              TWM  30
      DATA AD/-.4033,-.3842,-.3526,-.3100,-.2582,-.1992,-.1350,-.0675,.0TWM  31
     1014,.0698,.1361,.1986,.2557,.3057,.3472,.3789,.3996,.4087,.4058,.3TWM  32
     2911,.3652,.3290,.2838,.2309,.1720,.1086,.0421,-.0257,-.0933,-.1590TWM  33
     3,-.2208,-.2769,-.3253,-.3642,-.3917,-.4066,-.4080,-.3954/         TWM  34
      DATA FLOINT/0.,1.,1.6,2.7,4.5,7.4,12.2,20.1,33.1,54.6,90.,148.4,24TWM  35
     14.7,403.4,665.1,1096.6,1808.,2981.,4914.8,8103.1,13359.7,22026.5,3TWM  36
     26315.5,59874.1,98715.8/                                           TWM  37
```

```
      COMMON MAT(16),SCRAP(31),IHOUR(15),TRS(1440)                      TWM   38
      DATA JDPM/31,28,31,30,31,30,31,31,30,31,30,31/                    TWM   39
      READ 2280, ISEGMT,ITAPE,IYR,LYR,MASS                              TWM   40
      PRINT 2470, ISEGMT,ITAPE,IYR,LYR,MASS                             TWM   41
      READ 2280, (JPREC(I),I=1,ISEGMT)                                  TWM   42
      PRINT 2470, (JPREC(I),I=1,ISEGMT)                                 TWM   43
      IF (ITAPE) 140,140,10                                             TWM   44
C***********************************************************************TWM
C          PREPARE INPUT DATA TAPE                                      TWM
C***********************************************************************TWM
 10   MONTH=9                                                           TWM   45
      READ 2280, (IRECOD(I),I=1,ISEGMT)                                 TWM   46
      PRINT 2470, (IRECOD(I),I=1,ISEGMT)                                TWM   47
      JYR=IYR                                                           TWM   48
      REWIND 3                                                          TWM   49
      REWIND 4                                                          TWM   50
      WRITE (3)(IRECOD(I),I=1,ISEGMT)                                   TWM   51
 20   MONTH=MONTH+1                                                     TWM   52
      IF (JYR-LYR) 40,30,40                                             TWM   53
 30   IF (MONTH-10) 40,140,40                                           TWM   54
 40   IF (MONTH-13) 60,50,60                                            TWM   55
 50   MONTH=1                                                           TWM   56
      JYR=JYR+1                                                         TWM   57
 60   READ 2290, ISTGAG,KSEGMT,WFSG                                     TWM   58
      PRINT 2480, ISTGAG,KSEGMT,WFSG                                    TWM   59
      IPREC=JPREC(KSEGMT)                                               TWM   60
      IDAYS=JDPM(MONTH)                                                 TWM   61
      IF (MONTH-2) 90,70,90                                             TWM   62
 70   IF (MOD(JYR,4)) 90,80,90                                          TWM   63
 80   IDAYS=29                                                          TWM   64
 90   ISIZE=1440/IPREC                                                  TWM   65
      CALL DATAIN (PREC,MONTH,JYR,IPREC,MASS,KSEGMT,IABS(IRECOD(KSEGMT))TWM   66
     1,IDAYS,0,ISEGMT)                                                  TWM   67
C***********************************************************************TWM
C         DATAIN READS ONE MONTHS PRECIPITATION DATA AND CONVERTS IT TO TWM
C           A RECORD OF THE RATE (INCH/HR) EVERY IPREC MINUTES.  THIS   TWM
```

```
C             RECORD IS WRITTEN ON TAPE 3.  IF DATA NEECED FOR ANOTHER  TWM
C             SEGMENT, THIS IS WRITTEN ON TAPE 4.                       TWM
C***********************************************************************TWM
      IF (ISTGAG) 110,110,100                                           TWM
100   CALL DATAMG (PREC,IPREC,WFSG,IDAYS,MONTH,JYR,KSEGMT)              TWM
C***********************************************************************TWM
C              DATAMG READS THE STORAGE GAUGE RECORD FROM CARDS AND THE TWM
C             RECORDER RECORD FROM TAPE 3 AND MERGES THEM INTO THE RECORTWM
C             FOR THIS SEGMENT.  THIS RECORD IS THEN WRITTEN ON TAPE 3. TWM
C***********************************************************************TWM
110   IF (IRECOD(KSEGMT)) 120,130,130                                   TWM
120   READ 2280, JRINT                                                  TWM
      CALL DATAIN (RECFLO,MONTH,JYR,JRINT,0,KSEGMT,KSEGMT,IDAYS,0,ISEGMTTWM
     1)                                                                 TWM
130   PRINT 2340, KSEGMT,MONTH,JYR                                      TWM
      GO TO 20                                                          TWM
C***********************************************************************TWM
C        PRECIPITATION TAPE COMPLETE                                    TWM
C***********************************************************************TWM
140   REWIND 3                                                          TWM
      REWIND 4                                                          TWM
      IFIRST=1                                                          TWM
      ISCRTH=1                                                          TWM
      IOLD=4                                                            TWM
      INEW=2                                                            TWM
      READ 2290, IRUN                                                   TWM
      IF (IRUN-1) 150,160,150                                           TWM
150   CALL EXIT                                                         TWM
C***********************************************************************TWM
C        BEGIN SIMULATION RUN                                           TWM
C***********************************************************************TWM
160   UNDFLO=0.                                                         TWM
      READ(3) (IRECOD(I),I=1,ISEGMT)                                    TWM
C***********************************************************************TWM
C        STATISTICAL CLASS DEFINITION                                   TWM
C***********************************************************************TWM
```

```
      DO 170 I=1,24                                                     TWM   87
      WEIGH(I)=ALOG(.5*(FLOINT(I)+FLOINT(I+1)))+1.                      TWM   88
170   CONTINUE                                                          TWM   89
      WEIGH(25)=2.*WEIGH(24)-WEIGH(23)                                  TWM   90
C***********************************************************************TWM
C        WATERSHED LOCATION                                             TWM
C***********************************************************************TWM
      READ 2320, XLAT,XLONG,CORTZ                                       TWM   91
      XLAT=XLAT*.01745                                                  TWM   92
C***********************************************************************TWM
C        MONTHLY PAN EVAPORATION                                        TWM
C***********************************************************************TWM
      READ 2300, (SCRAP(I),I=2,13)                                      TWM   93
      READ 2300, (TRANPO(I), I = 1, 12)                                 TWM   94
      DO 180 I=2,13                                                     TWM   95
      TRANPO(I-1) = TRANPO(I-1)/SCRAP(I)                                TWM   96
      SCRAP(I)=SCRAP(I)/FLOAT(JDPM(I-1))                                TWM   97
180   CONTINUE                                                          TWM   98
      SCRAP(1)=SCRAP(13)                                                TWM   99
      SCRAP(14)=SCRAP(2)                                                TWM  100
C***********************************************************************TWM
C        CONVERT TO DAILY PAN EVAPORATION FORMULA                       TWM
C***********************************************************************TWM
      DO 190 I=2,13                                                     TWM  101
      EVAP1(I-1)=(SCRAP(I-1)-2.*SCRAP(I)+SCRAP(I+1))/1800.              TWM  102
      EVAP2(I-1)=-(SCRAP(I-1)-SCRAP(I))/30.                             TWM  103
      EVAP3(I-1)=(3.*SCRAP(I-1)+6.*SCRAP(I)-SCRAP(I+1))/8.              TWM  104
190   CONTINUE                                                          TWM  105
C***********************************************************************TWM
C        THE PAN EVAPORATION FOR ANY DAY OF THE MONTH CAN BE ESTIMATED  TWM
C          FROM PAN EVP = EVAP1(I)*X*X + EVAP2(I) * X + EVAP3(I) WHERE  TWM
C          I IS  THE MONTH IN WHICH THE DAY OCCURS.                     TWM
C***********************************************************************TWM
      READ 2280, (NEWVAL(I),I=1,12)                                     TWM  106
      MONTH=9                                                           TWM  107
      JYR=IYR                                                           TWM  108
```

```
      JDTD=213                                                          TWM  109
C***********************************************************************TWM
C        SET CARRYOVER ARRAY TO 0                                       TWM
C***********************************************************************TWM
      DO 200 I=1,ISEGMT                                                 TWM  110
      CHNLG(I) = 0.                                                     TWM  111
200   CONTINUE                                                          TWM  112
C***********************************************************************TWM
C        INITIALIZE STATISTICAL ANALYSIS VARIABLES                      TWM
C***********************************************************************TWM
      DO 210 I=1,ISEGMT                                                 TWM  113
      SUMX(I)=0.                                                        TWM  114
      SUMY(I)=0.                                                        TWM  115
      XX(I)=0.                                                          TWM  116
      YY(I)=0.                                                          TWM  117
      XY(I)=0.                                                          TWM  118
      SWEIFL(I)=0.                                                      TWM  119
      DO 210 J=1,25                                                     TWM  120
      ICASE(I,J)=0                                                      TWM  121
      SUMERR(I,J)=0.                                                    TWM  122
      SABSER(I,J)=0.                                                    TWM  123
      SERRSQ(I,J)=0.                                                    TWM  124
210   CONTINUE                                                          TWM  125
C***********************************************************************TWM
C        RE-ENTRYY POINT FOR NEW MONTH                                  TWM
C***********************************************************************TWM
220   MONTH=MONTH+1                                                     TWM  126
      REWIND INEW                                                       TWM  127
      REWIND IOLD                                                       TWM  128
      JDTD=JDTD+JDPM(MONTH-1)                                           TWM  129
      IF (JYR-LYR) 240,230,240                                          TWM  130
230   IF (MONTH-10) 240,150,240                                         TWM  131
C***********************************************************************TWM
C        EXIT POINT WHEN COMPLETE                                       TWM
C***********************************************************************TWM
240   JSEGMT=0                                                          TWM  132
```

```
      DO 250 I=1,1440                                                   TWM  133
      SIMFLO(I)=0.                                                      TWM  134
      PREC(I)=0.                                                        TWM  135
250   CONTINUE                                                          TWM  136
C***********************************************************************TWM
C        NEW CALENDER YEAR                                              TWM
C***********************************************************************TWM
      IF (MONTH-13) 280,260,280                                         TWM  137
260   JDTD=0                                                            TWM  138
      MONTH=1                                                           TWM  139
      JYR=JYR+1                                                         TWM  140
      JDPY=365                                                          TWM  141
C***********************************************************************TWM
C        LEAP YEARS                                                     TWM
C***********************************************************************TWM
      IF (MOD(JYR,4)) 280,270,280                                       TWM  142
270   JDPY=366                                                          TWM  143
280   IDAYS=JDPM(MONTH)                                                 TWM  144
      IF (MONTH-2) 310,290,310                                          TWM  145
290   IF (MOD(JYR,4)) 310,300,310                                       TWM  146
300   IDAYS=29                                                          TWM  147
C***********************************************************************TWM
C        RUN EACH SEGMENT THROUGH ONE MONTH                             TWM
C***********************************************************************TWM
310   IF (NEWVAL(MONTH)+IFIRST) 330,330,320                             TWM  148
320   READ 2310, KSEGMT,JRINT,ISEG1,ISEG2,NRELEM,LAG,(C(I),I=1,NRELEM)  TWM  149
330   ISIZE=1440/JRINT                                                  TWM  150
      IPREC=JPREC(KSEGMT)                                               TWM  151
      YESDAY = CHNLG(KSEGMT)                                            TWM  152
      DO 340 I=1,1440                                                   TWM  153
      SIMFLO(I)=0.                                                      TWM  154
340   CONTINUE                                                          TWM  155
C***********************************************************************TWM
C        CONSTRUCT RUNOFF ARRAY FOR EACH DAY ON TAPE                    TWM
C***********************************************************************TWM
      DO 350 I=1,IDAYS                                                  TWM  156
```

```
      WRITE (INEW) MONTH,I,JYR,KSEGMT,JRINT,ISIZE,(SIMFLO(IA),IA=1,1440)TWM  157
350   CONTINUE                                                          TWM  158
      IF (NEWVAL(MONTH)*IFIRST) 430,430,360                             TWM  159
360   READ 2320, PANFAC,ALPHA,RTZONE                                    TWM  160
      READ 2280, IOPT1,IOPT2,IOPT3,IOPT4                                TWM  161
      IF (IRECOD(KSEGMT)) 362, 363, 363                                 TWM  162
362   IOPT5 = 1                                                         TWM  163
      GO TO 364                                                         TWM  164
363   IOPT5 = 0                                                         TWM  165
364   CONTINUE                                                          TWM  166
      IF (IOPT1-1) 380,370,380                                          TWM  167
370   READ 2320, BASE                                                   TWM  168
380   IF (IOPT3-1) 400,390,400                                          TWM  169
390   READ 2280, IFILM                                                  TWM  170
400   CONTINUE                                                          TWM  171
      IF (IOPT3-1) 410,420,410                                          TWM  172
410   IF (IOPT4-1) 430,420,430                                          TWM  173
420   READ 2330, LTR,(NAMSEG(I),I=1,19)                                 TWM  174
430   CONTINUE                                                          TWM  175
      IF (JYR-IYR) 450,440,450                                          TWM  176
440   IF (MONTH-10) 450,750,450                                         TWM  177
450   IF (ISEG1) 680,680,460                                            TWM  178
460   CONTINUE                                                          TWM  179
C***********************************************************************TWM
C        ASSIMULATE RUNOFF FROM UPSTREAM SEGMENT(S) INTO RUNOFF ARRAY   TWM
C             ON TAPE                                                   TWM
C***********************************************************************TWM
C                  FIRST SEGMENT                                        TWM
C***********************************************************************TWM
      CALL TPSWCH (IOLD,INEW,ISEGMT,KSEGMT,IDAYS,SIMFLO)                TWM  180
      REWIND IOLD                                                       TWM  181
470   READ (IOLD) MONTH1,IA.JYR1,JSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,144TWM  182
     10)                                                                TWM  183
      CALL TAPCHK(1,IA,MONTH,MONTH1,JYR,JYR1,1)                         TWM  184
      IF (JSEGMT-ISEG1) 470,480,470                                     TWM  185
480   DO 510 I=1,IDAYS                                                  TWM  186
```

```
177         IF (IRINT-JRINT) 490,500,490                                      TWM  187
178   490   CALL SHIFTT (JRINT,IRINT,SIMFLO)                                  TWM  188
179   500   WRITE (INEW) MONTH1,I,JYR,KSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,1440TWM  189
          1)                                                                  TWM  190
180         READ (IOLD)MONTH1,IA,JYR1,JSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,1440TWM  191
          1)                                                                  TWM  192
181         CALL TAPCHK(I+1,IA,MONTH,MONTH1,JYR,JYR1,2)                       TWM  193
182   510   CONTINUE                                                          TWM  194
     C***********************************************************************TWM
     C                  SECOND SEGMENT                                        TWM
     C***********************************************************************TWM
183         IF (ISEG2) 680,680,520                                            TWM  195
184   520   CALL TPSWCH (IOLD,INEW,1,KSEGMT,IDAYS,SIMFLO)                     TWM  196
185         REWIND ISCRTH                                                     TWM  197
186   530   READ (IOLD) MONTH1,IA,JYR1,JSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,144TWM  198
          10)                                                                 TWM  199
187         WRITE (INEW) MONTH1,IA,JYR1,JSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,14TWM  200
          140)                                                                TWM  201
188         IF (JSEGMT-ISEG2) 550,540,550                                     TWM  202
189   540   WRITE (ISCRTH) MONTH1,IA,JYR1,JSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,TWM  203
          11440)                                                              TWM  204
190   550   IF (JSEGMT+1-KSEGMT) 530,560,530                                  TWM  205
191   560   IF (IA-JDPM(MONTH1)) 530,570,530                                  TWM  206
192   570   REWIND ISCRTH                                                     TWM  207
193         DO 610 I=1,IDAYS                                                  TWM  208
194         READ (IOLD) MONTH1,IA,JYR1,JSEGMT,IRINT,ISIZE,(SIMFLO(IB),IB=1,144TWM  209
          10)                                                                 TWM  210
195         CALL TAPCHK(I,IA,MONTH,MONTH1,JYR,JYR1,3)                         TWM  211
196         READ (ISCRTH) MONTH1,IA,JYR1,JSEGMT,IRINT1,JSIZE,(PREC(IB),IB=1,14TWM  212
          140)                                                                TWM  213
197         CALL TAPCHK(I,IA,MONTH,MONTH1,JYR,JYR1,4)                         TWM  214
198         IF (IRINT1-JRINT) 580,590,580                                     TWM  215
199   580   CALL SHIFTT (JRINT,IRINT1,PREC)                                   TWM  216
200   590   CONTINUE                                                          TWM  217
201         DO 600 II=1,ISIZE                                                 TWM  218
202         SIMFLO(II)=SIMFLO(II)+PREC(II)                                    TWM  219
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```
600   CONTINUE                                                          TWM  220
      WRITE (INEW) MONTH,I,JYR,KSEGMT,JRINT,ISIZE,(SIMFLO(IB),IB=1,1440)TWM  221
610   CONTINUE                                                          TWM  222
C***********************************************************************TWM
C        LAG FLOW THROUGH THIS SEGMENT                                  TWM
C***********************************************************************TWM
      IF (LAG) 680,680,620                                              TWM  223
620   DO 630 I=1,1440                                                   TWM  224
630   PREC(I)=0.                                                        TWM  225
      IT=LAG+1                                                          TWM  226
      CALL TPSWCH (IOLD,INEW,ISEGMT,KSEGMT,IDAYS,SIMFLO)                TWM  227
640   READ (IOLD) MONTH1,IA,JYR1,JSEGMT,JRINT,ISIZE,(SIMFLO(IB),IB=1,144TWM  228
     10)                                                                TWM  229
      DO 650 II=IT,ISIZE                                                TWM  230
      IA=ISIZE+IT-II                                                    TWM  231
      TRS(IA)=SIMFLO(IA)                                                TWM  232
      SIMFLO(IA)=SIMFLO(IA-LAG)                                         TWM  233
650   CONTINUE                                                          TWM  234
      DO 660 II=1,LAG                                                   TWM  235
      SIMFLO(II)=PREC(II)                                               TWM  236
      PREC(II)=TRS(ISIZE-LAG+II)                                        TWM  237
660   CONTINUE                                                          TWM  238
      WRITE (INEW) MONTH,IA,JYR,KSEGMT,JRINT,ISIZE,(SIMFLO(IB),IB=1,1440TWM  239
     1)                                                                 TWM  240
      IF (IA-IDAYS) 640,670,670                                         TWM  241
670   CONTINUE                                                          TWM  242
C***********************************************************************TWM
C        ADD FLOW GENERATED LAST MONTH, BUT NOT YET PAST STREAM GAUGING TWM
C          STATION.                                                     TWM
C***********************************************************************TWM
680   II=0                                                              TWM  243
      IA=0                                                              TWM  244
      JSIZE = NRELEM                                                    TWM  245
690   II=II+1                                                           TWM  246
      CALL TPSWCH (IOLD,INEW,ISEGMT,KSEGMT,IDAYS,SIMFLO)                TWM  247
      READ (IOLD) MONTH1,I,JYR1,JSEGMT,JRINT,ISIZE,(SIMFLO(IB),IB=1,1440TWM  248
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```
           1)                                                                      TWM  249
230          IB=II+JSIZE                                                           TWM  250
231          IF (IB- NRELEM) 710, 710, 700                                         TWM  251
232   700    JSIZE = NRELEM - IA                                                   TWM  252
233   710    DO 720 I=1,JSIZE                                                      TWM  253
234          SIMFLO(I)=SIMFLO(I)+CARRYO(KSEGMT,I+IA)                               TWM  254
235   720    CONTINUE                                                              TWM  255
236          WRITE (INEW) MONTH,II,JYR,KSEGMT,JRINT,ISIZE,(SIMFLO(IB),IB=1,1440TWM  256
           1)                                                                      TWM  257
237          IA=IB                                                                 TWM  258
238          IF (IB - NRELEM) 690, 730, 730                                        TWM  259
239   730    CONTINUE                                                              TWM  260
240          IF (II-IDAYS) 740,750,750                                             TWM  261
241   740    READ (IOLD) MONTH1,IA,JYR1,JSEGMT,JRINT1,ISIZE,(SIMFLO(IB),IB=1,14TWM  262
           140)                                                                    TWM  263
242          WRITE (INEW) MONTH1,IA,JYR1,JSEGMT,JRINT1,ISIZE,(SIMFLO(IB),IB=1,1TWM  264
           1440)                                                                   TWM  265
243          II=II+1                                                               TWM  266
244          GO TO 730                                                             TWM  267
245   750    CONTINUE                                                              TWM  268
      C***********************************************************************TWM
      C         CALCULATE BASIC TIME CYCLE, MAY NOT BE LONGER THAN 15 MINUTES. TWM
      C***********************************************************************TWM
246          LOOP=1440/JRINT                                                       TWM  269
247          IT=JRINT                                                              TWM  270
248          IF (LOOP-96) 760,780,780                                              TWM  271
249   760    LOOP=96                                                               TWM  272
250          IT=15                                                                 TWM  273
251          IF (JRINT-20) 780,770,780                                             TWM  274
252   770    LOOP=144                                                              TWM  275
253          IT=10                                                                 TWM  276
254   780    CONTINUE                                                              TWM  277
255          IF (NEWVAL(MONTH)+IFIRST) 840,840,790                                 TWM  278
      C***********************************************************************TWM
      C         READ PARAMETERS                                                TWM
      C***********************************************************************TWM
```

```
790    READ 2320, ATOTAL,APERVS,AOLFSF,AOLFDS,DSMAX,VINSTM,DEPTHI,DEPTHU,TWM
      1CHANLG,C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14,C15,ROUGH,SLTWM
      2OPE,VLENGH,SATPRM,UZST,VIZST,C16,SMMIN                             TWM
       IFIRST=0                                                          TWM
       DEPTHU=DEPTHU*12.                                                 TWM
       DEPTHI=DEPTHI*12.                                                 TWM
       X=-C4                                                             TWM
       UZMIN=DEPTHU*AMAX1(SMMIN,X)                                       TWM
       VIZMIN=.5*DEPTHI*AMAX1(SMMIN,X)                                   TWM
       IF (ATOTAL) 800,810,810                                           TWM
800    ATOTAL=-640.*ATOTAL                                               TWM
C*********************************************************************TWM
C         PRINT PARAMETERS                                               TWM
C*********************************************************************TWM
810    PRINT 2970, MONTH,JYR                                             TWM
       PRINT 2980, KSEGMT,JRINT,IT                                       TWM
       PRINT 2840, ATOTAL,APERVS,AOLFSF,AOLFDS,DSMAX,VINSTM,DEPTHI,DEPTHUTWM
      1,CHANLG,RTZONE                                                    TWM
       PRINT 2960, ROUGH,SLOPE,VLENGH,SATPRM,UZST,VIZST                  TWM
       PRINT 3020, UZMIN,VIZMIN                                          TWM
       PRINT 2850, C1,UZST,C2,SATPRM                                     TWM
       PRINT 2860, C3,C4,C5,C6                                           TWM
       PRINT 2870, C7,C8,C9                                              TWM
       PRINT 2880, C10                                                   TWM
       PRINT 2890, C11                                                   TWM
       PRINT 2900                                                        TWM
       PRINT 2910, C12                                                   TWM
       PRINT 2920, C13                                                   TWM
       PRINT 2930, C14                                                   TWM
       PRINT 2950, C16                                                   TWM
       PRINT 2940, C15                                                   TWM
       IF (JYR-IYR) 840,820,840                                          TWM
820    IF (MONTH-10) 840,830,840                                         TWM
C*********************************************************************TWM
C         READ INITIAL VALUES                                            TWM
C*********************************************************************TWM
```

```
830   READ 2320, TI7S1(KSEGMT),BIZS1(KSEGMT),OLS1(KSEGMT),DS1(KSEGMT),UZTWM   309
     1S1(KSEGMT),GWS1(KSEGMT),DELIN1(KSEGMT),VINST1(KSEGMT)             TWM   310
C***********************************************************************TWM
C        INITIALIZE STORAGE                                             TWM
C***********************************************************************TWM
840   VINSTG=VINST1(KSEGMT)                                             TWM   311
      OLS=OLS1(KSEGMT)                                                  TWM   312
      DS=DS1(KSEGMT)                                                    TWM   313
      U7S=U7S1(KSEGMT)                                                  TWM   314
      TIZS=TIZS1(KSEGMT)                                                TWM   315
      BIZS=BIZS1(KSEGMT)                                                TWM   316
      GWS=GWS1(KSEGMT)                                                  TWM   317
      DELINF=DELIN1(KSEGMT)                                             TWM   318
C***********************************************************************TWM
C        CHECK INITIAL STORAGE VALUES AGAINST MINIMUM/MAXIMUM VALUES    TWM
C***********************************************************************TWM
      IF (DS-DSMAX) 860,860,850                                         TWM   319
850   PRINT 3030, DS,DSMAX                                              TWM   320
      DS=DSMAX                                                          TWM   321
860   IF (U7S-U7ST) 880,880,870                                         TWM   322
870   PRINT 2990, U7S,U7ST                                              TWM   323
      U7S=UZST                                                          TWM   324
880   IF (U7S-U7MIN) 890,900,900                                        TWM   325
890   PRINT 2990, U7S,U7MIN                                             TWM   326
      UZS=U7MIN                                                         TWM   327
900   IF (TIZS-VIZMIN) 910,920,920                                      TWM   328
910   PRINT 3000, TIZS,VIZMIN                                           TWM   329
      TIZS=VIZMIN                                                       TWM   330
920   IF (TIZS-VI7ST) 940,940,930                                       TWM   331
930   PRINT 3000, TIZS,VIZST                                            TWM   332
      TIZS=VIZST                                                        TWM   333
940   IF (BIZS-VI7MIN) 950,960,960                                      TWM   334
950   PRINT 3010, BIZS,VIZMIN                                           TWM   335
      BI7S=VIZMIN                                                       TWM   336
960   IF (BIZS-VI7ST) 980,980,970                                       TWM   337
970   PRINT 3010, BIZS,VIZST                                            TWM   338
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      BIZS=VIZST                                                        TWM  339
980   CONTINUE                                                          TWM  340
C***********************************************************************TWM
C        INITIALIZE STATISTICAL VARIABLES                               TWM
C***********************************************************************TWM
      SSRAIN=0.                                                         TWM  341
      SSEVAP=0.                                                         TWM  342
      SSSF=0.                                                           TWM  343
      SSOLF=0.                                                          TWM  344
      SSGWF=0.                                                          TWM  345
      SSIF=0.                                                           TWM  346
      SSUF=0.                                                           TWM  347
      DO 990 I=1,1440                                                   TWM  348
      TRS(I)=0.                                                         TWM  349
990   CONTINUE                                                          TWM  350
C***********************************************************************TWM
C        DAY LOOP                                                       TWM
C***********************************************************************TWM
      REWIND 1                                                          TWM  354
      CALL TPSWCH (IOLD,INEW,ISEGMT,KSEGMT,IDAYS,SIMFLO)                TWM  355
      DO 1530 IDAY=1,IDAYS                                              TWM  356
      READ(3)MONTH1,IAI.  JYR1,KSEGMT,IT,ISIZE,(PREC(IB),IB=1,1440)     TWM  357
      CALL TAPCHK(IDAY,IAI,  MONTH,MONTH1,JYR,JYR1,5)                   TWM  358
      READ (IOLD) MONTH1,IA,JYR1,JSEGMT,JRINT,JSIZE,(SIMFLO(IB),IB=1,144TWM  359
     10)                                                                TWM  360
      CALL TAPCHK(IDAY,IA,   MONTH,MONTH1,JYR,JYR1,6)                   TWM  361
C***********************************************************************TWM
C        ADD FLOW GENERATED YESTERDAY                                   TWM
C***********************************************************************TWM
      DO 1000 I=1,JSIZE                                                 TWM  362
      SIMFLO(I)=TRS(I)+SIMFLO(I)                                        TWM  363
      TRS(I)=0.                                                         TWM  364
1000  CONTINUE                                                          TWM  365
      IA=JSIZE+1                                                        TWM  366
      DO 1010 I=IA,1440                                                 TWM  367
      TRS(I-IA+1)=TRS(I)                                                TWM  368
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      TRS(I)=0.                                                         TWM  369
1010  CONTINUE                                                          TWM  370
C***********************************************************************TWM
C        INITIALIZE DAILY FLOW SUMS                                     TWM
C***********************************************************************TWM
      SDAYFL=0.                                                         TWM  371
      RO=0.                                                             TWM  372
      DELT=FLOAT(IT)/60.                                                TWM  373
      X=IDAY                                                            TWM  374
C***********************************************************************TWM
C        POTENTIAL EVAPORATION FOR THIS DAY                             TWM
C***********************************************************************TWM
      POTEVP=        (EVAP1(MONTH)*X*X+EVAP2(MONTH)*X+EVAP3(MONTH))     TWM  375
C        DETERIME SUNRISE AND SUNSET, EVAPORATION IS ASSUMED TO OCCUR   TWM
C          FROM 30 MINUTES AFTER SUNRISE (TB), UNTIL 1 HOUR AFTER       TWM
C          SUNSET (TE), WITH THE MAXIMUM RATE OCCURRING AT A TIME (TH)  TWM
C          3/4 FROM THE BEGINNING TO THE END.                           TWM
      X=FLOAT(JDTD)+X                                                   TWM  376
      JAD=IFIX(X)/10+1                                                  TWM  377
      DELTA=AD(JAD)+(X-FLOAT(10*JAD-10))/10.*(AD(JAD+1)-AD(JAD))        TWM  378
      COSH=(-SIN(XLAT)*SIN(DELTA)-.0145)/(COS(XLAT)*COS(DELTA))         TWM  379
      H=ARCOS(COSH)*3.82044                                             TWM  380
      IF (IFIX(X)-260) 1020,1030,1030                                   TWM  381
1020  ET=12.+(9.36-.0467*X+6.9*SIN(.04*(X-14.)))/60.                    TWM  382
      GO TO 1040                                                        TWM  383
1030  ET=12.+(-15.3+.04*X+13.6*SIN(.0308*(X-360.)))/60.                 TWM  384
1040  X=AMOD(XLONG,15.)                                                 TWM  385
      IF (X-7.5) 1050,1050,1060                                         TWM  386
1050  CORREC=X/15.                                                      TWM  387
      GO TO 1070                                                        TWM  388
1060  CORREC=X/15.-1.                                                   TWM  389
1070  TB=ET-H+CORREC+.5+CORTZ                                           TWM  390
      TE=ET+H+CORREC+1.+CORTZ                                           TWM  391
      TH=.75*(TE-TB)+TB                                                 TWM  392
      E4=SIN(.2618*(TE-TH+6.))                                          TWM  393
      E5=SIN(.2618*(TB-TH+6.))                                          TWM  394
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      E2=(E4-E5)/(TE-TB)                                                TWM  395
      E3=(TE*E5-TB*E4)/(TE-TB)                                          TWM  396
      E1=POTEVP/((3.82*(COS(.2618*(TB-TH+6.))-COS(.2618*(TE-TH+6.))))+.5TWM  397
     1*E2*(TB*TB-TE*TE)+E3*(TB-TE))                                     TWM  398
C***********************************************************************TWM
C        BASIC TIME LOOP                                                TWM
C***********************************************************************TWM
      DO 1520 I=1,ISIZE                                                 TWM  399
      RAIN=PREC(I)*DELT                                                 TWM  400
      SSRAIN=SSRAIN+RAIN                                                TWM  401
      IF (RAIN-.0001) 1090,1090,1080                                    TWM  402
C***********************************************************************TWM
C        PERVIOUS - IMPERVIOUS SEPARATION                               TWM
C***********************************************************************TWM
1080  X=(1.-APERVS)*RAIN                                                TWM  403
      CALL ADJUST (RAIN,RO,X)                                           TWM  404
C***********************************************************************TWM
C        INTERCEPTION                                                   TWM
C***********************************************************************TWM
      CALL ADJUST (RAIN,VINSTG,AMIN1(RAIN,VINSTM-VINSTG))               TWM  405
C***********************************************************************TWM
C        OVERLAND FLOW AND DEPRESSION STORAGE                           TWM
C***********************************************************************TWM
1090  X1=(AOLFSF+AOLFDS)*RAIN                                           TWM  406
      OLSI=OLS                                                          TWM  407
C***********************************************************************TWM
C        RAIN - OVERLAND STORAGE                                        TWM
C***********************************************************************TWM
      CALL ADJUST (RAIN,OLS,X1)                                         TWM  408
      DS=DS+RAIN                                                        TWM  409
      IF (DS-.0001) 1100,1100,1110                                      TWM  410
1100  IF (OLS-.0001) 1210,1210,1110                                     TWM  411
C***********************************************************************TWM
C        INFILTRATION                                                   TWM
C***********************************************************************TWM
1110  IF (U7ST -U7S) 1112, 1112, 1114                                   TWM  412
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1112  SEEP = DELT * SATPRM                                              TWM  413
      GO TO 1116                                                        TWM  414
1113  SEEP = DELT * SATPRM                                              TWM  415
1114  SEEP=DELT*(C1*(UZST-UZS)**C2*SATPRM)                              TWM  416
1116  X=(1.-AOLFSF-AOLFDS)*DS/DSMAX                                     TWM  417
      IF (DS/DSMAX-1.) 1130,1130,1120                                   TWM  418
1120  X=1.-AOLFSF-AOLFDS                                                TWM  419
1130  Y=UZST-UZS                                                        TWM  420
C***********************************************************************TWM
C        INFILTRATE FROM OVERLAND FLOW STORAGE                          TWM
C***********************************************************************TWM
      X4 = AMIN1(SEEP*(1.-X),OLS,Y*(1.-X))                              TWM  421
      CALL ADJUST (OLS, UZS, X4)                                        TWM  422
      IF (SEEP*(1.-X) - X4) 1132, 1132, 1131                            TWM  423
1131  X4 = AMIN1((SEEP*(1.-X)-X4),OLS,(VIZST-TIZS))                     TWM  424
      CALL ADJUST (OLS, TIZS, X4)                                       TWM  425
C***********************************************************************TWM
C        INFILTRATE FROM DEPRESSION STORAGE                             TWM
C***********************************************************************TWM
1132  X4 = AMIN1(X*SEEP,DS,Y*X)                                         TWM  426
      CALL ADJUST (DS, UZS, X4)                                         TWM  427
      IF (X*SEEP - X4) 1134, 1134, 1133                                 TWM  428
1133  X4 = AMIN1((X*SEEP-X4),DS,(VIZST-TIZS))                           TWM  429
      CALL ADJUST ( DS, TIZS, X4)                                       TWM  430
C***********************************************************************TWM
C***********************************************************************TWM
C        CALCULATE OVERLAND FLOW                                        TWM
C***********************************************************************TWM
1134  IF (OLSI) 1140, 1140, 1150                                        TWM  431
1140  IF (OLS) 1210,1210,1150                                           TWM  432
1150  OFSAVG=.5*(OLSI+OLS)                                              TWM  433
      OFSEQU=.000818*(X1*ROUGH*VLENGH)**0.6*VLENGH/SLOPE**0.3           TWM  434
      IF (OFSAVG-OFSEQU) 1170,1170,1160                                 TWM  435
1160  OFSEQU=OFSAVG                                                     TWM  436
1170  OLF=64200.*SLOPE**.5*(OFSAVG*(1.+.6*(OFSAVG/OFSEQU)**3)/VLENGH)**1TWM  437
     1.67/(ROUGH*VLENGH)*DELT                                           TWM  438
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```
C***********************************************************************TWM
C        OVERLAND FLOW INTO STREAM                                      TWM
C***********************************************************************TWM
      CALL ADJUST (OLS,RO,AMIN1(OLS*AOLFSF/(AOLFSF+AOLFDS),AOLFSF*OLF)) TWM  439
C***********************************************************************TWM
C        OVERLAND FLOW INTO DEPRESSION STORAGE                          TWM
C***********************************************************************TWM
      CALL ADJUST (OLS,DS,AMIN1(AOLFDS*OLF,AOLFDS/(AOLFDS+AOLFSF)*OLS)) TWM  440
C***********************************************************************TWM
C        RUNOFF FROM DEPRESSION STORAGE                                 TWM
C***********************************************************************TWM
      IF (DS/DSMAX-1.) 1190,1180,1180                                   TWM  441
1180  X=1.-AOLFSF                                                       TWM  442
      GO TO 1200                                                        TWM  443
1190  X=(1.-AOLFSF)*(DS/DSMAX)**.5                                      TWM  444
1200  CONTINUE                                                          TWM  445
      CALL ADJUST (DS,RO,AMIN1(X*OLF,DS))                               TWM  446
      SSOLF=SSOLF+(X+AOLFSF)*OLF                                        TWM  447
C***********************************************************************TWM
C        UPPER ZONE TO TOP INTERMEDIATE ZONE                            TWM
C***********************************************************************TWM
1210  CONTINUE                                                          TWM  448
      XK=C3*((UZS/DEPTHU+TIZS/(.5*DEPTHI))*.5+C4)**C5+C6                TWM  449
      IF (XK) 1211, 1212, 1212                                          TWM  450
1211  XK = 0.                                                           TWM  451
1212  PSI1=-C7*(UZS/DEPTHU+C8)**C9                                      TWM  452
      PSI2=-C7*(TIZS/(.5*DEPTHI)+C8)**C9                                TWM  453
      X=XK*((PSI1-PSI2)/(.5*(.5*DEPTHI+DEPTHU))+1.)*DELT                TWM  454
      IF (X) 1220,1280,1250                                             TWM  455
1220  X=-X                                                              TWM  456
      IF (X-(TIZS-VIZMIN)) 1240,1240,1230                               TWM  457
1230  X=TIZS-VIZMIN                                                     TWM  458
1240  CALL ADJUST(TIZS,UZS,AMIN1(X,UZST-UZS))                           TWM  459
      GO TO 1280                                                        TWM  460
1250  CONTINUE                                                          TWM  461
      IF (X-(UZS-UZMIN)) 1270,1270,1260                                 TWM  462
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 1260 X=UZS-UZMIN                                                       TWM  463
 1270 CALL ADJUST (UZS,TIZS,AMIN1(X,VIZST-TIZS))                        TWM  464
C***********************************************************************TWM
C         INTERFLOW                                                     TWM
C***********************************************************************TWM
 1280 IF (TIZS/VIZST-C10) 1300,1300,1290                                TWM  465
 1290 VINFLO=C16*(TIZS-C10*VIZST)*DELT                                  TWM  466
      CALL ADJUST (TIZS,DELINF,AMIN1(VINFLO,TIZS-VIZMIN))               TWM  467
C***********************************************************************TWM
C         MOVE FROM TOP TO BOTTOM IN INTERMEDIATE ZONE.                 TWM
C***********************************************************************TWM
 1300 CONTINUE                                                          TWM  468
      XK=C3*((TIZS+BIZS)/DEPTHI+C4)**C5+C6                              TWM  469
      IF (XK) 1301, 1302, 1302                                          TWM  470
 1301 XK = 0.                                                           TWM  471
 1302 PSI1=-C7*(BIZS/(.5*DEPTHI)+C8)**C9                                TWM  472
      X=XK*((PSI2-PSI1)/(.5*DEPTHI)+1.)*DELT                            TWM  473
      IF (X) 1310,1360,1340                                             TWM  474
 1310 X=-X                                                              TWM  475
      IF (X-(BIZS-VIZMIN)) 1320,1330,1330                               TWM  476
 1320 X=BIZS-VIZMIN                                                     TWM  477
 1330 CALL ADJUST (BIZS,TIZS,X)                                         TWM  478
      GO TO 1370                                                        TWM  479
 1340 CONTINUE                                                          TWM  480
      IF (X-(TIZS-VIZMIN)) 1360,1360,1350                               TWM  481
 1350 X=TIZS-VIZMIN                                                     TWM  482
 1360 CALL ADJUST (TIZS,BIZS,X)                                         TWM  483
 1370 CONTINUE                                                          TWM  484
C***********************************************************************TWM
C         MOVE FROM BOTTOM OF INTERMEDIATE ZONE TO GROUNDWATER ZONE.    TWM
C***********************************************************************TWM
      X=SATPRM*(1.-PSI1/(.25*DEPTHI))*DELT                              TWM  485
      IF (X-(BIZS-VIZMIN)) 1390,1390,1380                               TWM  486
 1380 X=BIZS-VIZMIN                                                     TWM  487
 1390 CALL ADJUST (BIZS,GWS,X)                                          TWM  488
C***********************************************************************TWM
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C        OUTFLOW FROM GROUNDWATER TO STREAM                             TWM
C***********************************************************************TWM
      Y=C13*GWS*DELT                                                    TWM  489
      IF (GWS-C11) 1410,1410,1400                                       TWM  490
 1400 X=(GWS-C11)*C12*DELT                                              TWM  491
      SSGWF=SSGWF+X                                                     TWM  492
      CALL ADJUST (GWS,RO,X)                                            TWM  493
C***********************************************************************TWM
C        UNDERFLOW                                                      TWM
C***********************************************************************TWM
 1410 CALL ADJUST (GWS,UNDFLO,Y)                                        TWM  494
      SSUF=SSUF+Y                                                       TWM  495
C***********************************************************************TWM
C        RUNOFF FROM INTERFLOW                                          TWM
C***********************************************************************TWM
      IF (DELINF-.000001) 1430,1430,1420                                TWM  496
 1420 X=(C14*DELINF+C15)*DELT                                           TWM  497
      CALL ADJUST (DELINF,RO,X)                                         TWM  498
      SSIF=SSIF+X                                                       TWM  499
C***********************************************************************TWM
C        EVAPORATION FROM STORAGE                                       TWM
C***********************************************************************TWM
 1430 HOUR=FLOAT(I*IT)/60.                                              TWM  500
      IF (HOUR-TB) 1465,1465,1440                                       TWM  501
 1440 IF (HOUR-TE) 1450,1465,1465                                       TWM  502
 1450 EVAPOT=-E1*(SIN(.2618*(HOUR-TW+6.))-E2*HOUR-E3)*DELT*PANFAC       TWM  503
      SSEVAP = SSEVAP + ABS(EVAPOT)                                     TWM  504
      CONSUM = TRANPO(MONTH) * ABS(EVAPOT) + EVAPOT                     TWM  505
C***********************************************************************TWM
C             EVAPORATION FROM INTERCEPTION STORAGE                     TWM
C***********************************************************************TWM
      CALL ADJUST (VINSTG,EVAPOT,AMIN1(VINSTG,ABS(EVAPOT)))             TWM  506
C***********************************************************************TWM
C             EVAPORATION FROM OVERLAND STORAGE                         TWM
C***********************************************************************TWM
C***********************************************************************TWM
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C              EVAPORATION FROM DEPRESSION STORAGE                      TWM
C***********************************************************************TWM
      CALL ADJUST (DS,EVAPOT,AMIN1(DS,ABS(EVAPOT)*DS/DSMAX*(1.-AOLFSF-AOTWM  507
     1LFDS)))                                                           TWM  508
C***********************************************************************TWM
C              EVAPORATION FROM UPPER ZONE STORAGE                      TWM
C***********************************************************************TWM
      CALL ADJUST(UZS,EVAPOT,AMIN1(ABS(EVAPOT)*((UZS-UZMIN)/(UZST-UZMIN)TWM  509
     1)                                                                 TWM  510
     1**ALPHA*(AOLFSF+AOLFDS),UZS-UZMIN) )                              TWM  511
      CONSUM = CONSUM - EVAPOT                                          TWM  512
 1455 IF (RTZONE - DEPTHU) 1456,1456,1457                               TWM  513
 1456 CALL ADJUST(UZS,EVAPOT,AMIN1(UZS-UZMIN ,CONSUM))                  TWM  514
      GO TO 1460                                                        TWM  515
 1457 CALL ADJUST(UZS,EVAPOT,AMIN1(UZS-UZMIN,DEPTHU*CONSUM/RTZONE))     TWM  516
      CALL ADJUST(TIZS,EVAPOT,AMIN1(TIZS=VIZMIN,CONSUM*(1.-DEPTHU/RTZONETWM  517
     1)))                                                               TWM  518
C***********************************************************************TWM
C        END OF MOVEMENT OF WATER FOR THIS CYCLE. IS THIS END OF JRINT  TWM
C          PERIOD                                                       TWM
C***********************************************************************TWM
 1460 SSEVAP = SSEVAP + EVAPOT                                          TWM  519
 1465 IF (MOD(I+IT,JRINT)) 1520,1470,1520                               TWM  520
C***********************************************************************TWM
C        CALCULATIONS FOR THIS INTERVAL COMPLETE.  LAG RUNOFF THROUGH   TWM
C          HISTOGRAM                                                    TWM
C***********************************************************************TWM
 1470 SDAYFL=SDAYFL+RO                                                  TWM  521
      SSSF=SSSF+RO                                                      TWM  522
      IF (RO-.0001) 1520,1520,1480                                      TWM  523
 1480 DO 1510 J=1,NRELEM                                                TWM  524
      II=I+J-1                                                          TWM  525
      IF (II-ISIZE) 1490,1490,1500                                      TWM  526
 1490 SIMFLO(II)=C(J)*RO*ATOTAL+SIMFLO(II)                              TWM  527
      GO TO 1510                                                        TWM  528
 1500 TRS(II-ISIZE)=C(J)*RO*ATOTAL+TRS(II-ISIZE)                        TWM  529
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1510  CONTINUE                                                          TWM  530
      RO=0.                                                             TWM  531
C***********************************************************************TWM
C        END OF BASIC TIME LOOP                                         TWM
C***********************************************************************TWM
1520  CONTINUE                                                          TWM  532
C***********************************************************************TWM
C        CHANNEL LAG                                                    TWM
C***********************************************************************TWM
      SIMFLO(1)=(1.-CHANLG)*SIMFLO(1)+YESDAY                            TWM  533
      YESDAY=CHANLG*SIMFLO(JSIZE)                                       TWM  534
      DO 1560 IA=2,JSIZE                                                TWM  535
      SIMFLO(IA)=SIMFLO(IA)+(1.-CHANLG)*CHANLG*SIMFLO(IA-1)             TWM  536
1560  CONTINUE                                                          TWM  537
C***********************************************************************TWM
C        CONVERT SDAYFL FROM INCHES PER DAY TO CFS.  ATOTAL IS IN ACRES TWM
C***********************************************************************TWM
      DAILYF(IDAY)=SDAYFL*ATOTAL*.042014                                TWM  538
      WRITE (INEW) MONTH,IDAY,JYR,KSEGMT,JRINT,ISIZE,(SIMFLO(IB),IB=1,14TWM  539
     140)                                                               TWM  540
C***********************************************************************TWM
C        END OF DAY LOOP                                                TWM
C***********************************************************************TWM
1530  CONTINUE                                                          TWM  541
      PRINT 2970, MONTH, JYR                                            TWM  542
C***********************************************************************TWM
C        PRESERVE ALL FLOWS WHICH ORIGINATE THIS MONTH, BUT DO NOT      TWM
C          APPEAR AS STREAM FLOW UNTIL NEXT MONTH                       TWM
C***********************************************************************TWM
      DO 1550 I = 1, NRELEM                                             TWM  543
      CARRYO(KSEGMT,I)=TRS(I)                                           TWM  544
1550  CONTINUE                                                          TWM  545
C***********************************************************************TWM
C        STORE END OF MONTH STORAGE VALUES FOR NEXT MONTHS STARING      TWM
C          VALUES.                                                      TWM
C***********************************************************************TWM
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      BIZS1(KSEGMT)=BIZS                                                TWM  546
      DELIN1(KSEGMT)=DELINF                                             TWM  547
      DS1(KSEGMT)=DS                                                    TWM  548
      GWS1(KSEGMT)=GWS                                                  TWM  549
      OLS1(KSEGMT)=OLS                                                  TWM  550
      TIZS1(KSEGMT)=TIZS                                                TWM  551
      UZS1(KSEGMT)=UZS                                                  TWM  552
      VINST1(KSEGMT)=VINSTG                                             TWM  553
      SRAIN(KSEGMT,MONTH)=SSRAIN                                        TWM  554
      SEVAP(KSEGMT,MONTH)=SSEVAP                                        TWM  555
      SSF(KSEGMT,MONTH)=SSSF                                            TWM  556
      SOLF(KSEGMT,MONTH)=SSOLF                                          TWM  557
      SGWF(KSEGMT,MONTH)=SSGWF                                          TWM  558
      SIF(KSEGMT,MONTH)=SSIF                                            TWM  559
      SUF(KSEGMT,MONTH)=SSUF                                            TWM  560
      EOMINC(KSEGMT,MONTH)=VINSTG                                       TWM  561
      EOMSUR(KSEGMT,MONTH)=DS+OLS                                       TWM  562
      EOMUZ(KSEGMT,MONTH)=UZS                                           TWM  563
      EOMINT(KSEGMT,MONTH)=TIZS+BIZS                                    TWM  564
      EOMGW(KSEGMT,MONTH)=GWS                                           TWM  565
      EOMINF(KSEGMT,MONTH)=DELINF                                       TWM  566
      CHNLG(KSEGMT) = YESDAY                                            TWM  567
C***********************************************************************TWM
C        END OF MONTH REPORTS                                           TWM
C***********************************************************************TWM
      PRINT 2810, KSEGMT,MONTH,JYR                                      TWM  568
      PRINT 2820, (DAILYF(I),I=1,IDAYS)                                 TWM  569
      Y1=60.5/FLOAT(JRINT)                                              TWM  570
      X11=0.                                                            TWM  571
      X12=0.                                                            TWM  572
      DO 1580 I=1,1440                                                  TWM  573
 1580 RECFLO(I)=0.                                                      TWM  574
      CALL TPSWCH (IOLD,INEW,ISEGMT,KSEGMT,IDAYS,SIMFLO)                TWM  575
      DO 2090 II=1,IDAYS                                                TWM  576
      IFLAG=0                                                           TWM  577
      READ (IOLD) MONTH1,IAI,JYR1,JSEGMT,JRINT,JSIZE,(SIMFLO(IB),IB=1,14TWM  578
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           140)                                                           TWM  579
           CALL TAPCHK(II,IAI,MONTH,MONTH1,JYR,JYR1,7)                    TWM  580
           IF (IOPT5) 1610,1620,1610                                      TWM  581
     1610  CONTINUE                                                       TWM  582
           READ(3)MONTH1,IAI,JYR1,KSEGMT,JRINT,JSIZE,(RECFLO(IB),IB=1,1440) TWM  583
           CALL TAPCHK(II,IAI,MONTH,MONTH1,JYR,JYR1,8)                    TWM  584
     1620  CONTINUE                                                       TWM  585
           IF (IOPT1-1) 1590,1600,1590                                    TWM  586
     1590  IF (IOPT3-1) 1960,1600,1960                                    TWM  587
     1600  CONTINUE                                                       TWM  588
           DO 1640 I=1,JSIZE                                              TWM  589
C**********************************************************************TWM
C             CONVERT SIMULATED FLOW TO C.F.S.                            TWM
C**********************************************************************TWM
           X=SIMFLO(I)*Y1                                                 TWM  590
           X11=X11+X                                                      TWM  591
           X12=X12+RECFLO(I)                                              TWM  592
           TRS(I)=0.                                                      TWM  593
           IF (X-BASE) 1640,1630,1630                                     TWM  594
     1630  IFLAG=1                                                        TWM  595
           TRS(I)=X                                                       TWM  596
     1640  CONTINUE                                                       TWM  597
           IF (IFLAG-1) 2000,1650,1650                                    TWM  598
     1650  KFIRST=1                                                       TWM  599
           KSECND=0                                                       TWM  600
           X1=0.                                                          TWM  601
           X2=0.                                                          TWM  602
           DO 1950 I=1,JSIZE                                              TWM  603
           IF (TRS(I)) 1670,1660,1670                                     TWM  604
     1660  IF (RECFLO(I)) 1670,1740,1670                                  TWM  605
     1670  IF (I-1) 1680,1730,1680                                        TWM  606
     1680  IF (I-JSIZE) 1700,1690,1700                                    TWM  607
     1690  KSECND=JSIZE                                                   TWM  608
           GO TO 1780                                                     TWM  609
     1700  CONTINUE                                                       TWM  610
           IF (TRS(I-1)) 1730,1710,1730                                   TWM  611
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1710  IF (RECFLO(I-1)) 1730,1720,1730                                  TWM  612
1720  KFIRST=I                                                         TWM  613
1730  KSECND=I                                                         TWM  614
      GO TO 1950                                                       TWM  615
1740  IF (I-1) 1750,1770,1750                                          TWM  616
1750  IF (TRS(I-1)) 1780,1760,1780                                     TWM  617
1760  IF (RECFLO(I-1)) 1780,1770,1780                                  TWM  618
1770  KFIRST=I                                                         TWM  619
      KSECND=I                                                         TWM  620
      GO TO 1950                                                       TWM  621
1780  IDAY=IAI                                                         TWM  622
      IF (IOPT1-1) 1840,1790,1840                                      TWM  623
1790  IHOURS=(JRINT*KFIRST)/60                                         TWM  624
      IMIN=MOD(JRINT*KFIRST,60)                                        TWM  625
      PRINT 2780, KSEGMT,MONTH,IDAY,JRINT,IHOURS,IMIN                  TWM  626
      JFIRST=KFIRST                                                    TWM  627
      X1=0.                                                            TWM  628
      X2=0.                                                            TWM  629
      X1Y1 = 0.                                                        TWM  630
      SX1X1 = 0.                                                       TWM  631
      SX2X2 = 0.                                                       TWM  632
      DO 1800 IK=KFIRST,KSECND                                         TWM  633
      X2=X2+RECFLO(IK)                                                 TWM  634
      X1=X1+SIMFLO(IK)                                                 TWM  635
      X1Y1 = X1Y1 + RECFLO(IK) * TRS(IK)                               TWM  636
      SX2X2 = SX2X2 + TRS(IK) * TRS(IK)                                TWM A636
      SX1X1 = SX1X1 + RECFLO(IK) *RECFLO(IK)                           TWM  637
      XN = KSECND - KFIRST                                             TWM  638
1800  CONTINUE                                                         TWM  639
      XN = KSECND - KFIRST                                             TWM  640
1810  JJ=MIN0(KSECND,KFIRST+11)                                        TWM  641
      PRINT 2790, (TRS(IK),IK=KFIRST,JJ)                               TWM  642
      PRINT 2800, (RECFLO(IK),IK=KFIRST,JJ)                            TWM  643
      IF (JJ-KSECND) 1820,1830,1830                                    TWM  644
1820  KFIRST=JJ+1                                                      TWM  645
      GO TO 1810                                                       TWM  646
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1830  KFIRST=KSECND+1                                                      TWM  647
      X1=X1*Y1*FLOAT(JRINT)/(60.5*ATOTAL)                                  TWM  648
      X2 = X2*FLOAT(JRINT)/(60.5*ATOTAL)                                   TWM  649
      PRINT 2450, X2,X1                                                    TWM  650
      IF (XU * X2) 1835, 1835, 1834                                        TWMA650
1834  CORRCO = (X1Y1 - X1 * X2/XN)/((SX1X1 - X1*X1/XN)*(SX2X2 - X2*X2/XNTWM  651
     1     ))                                                              TWM  652
      PRINT 2455, CORRCO                                                   TWM  653
1835  X1=0.                                                                TWM  654
      X2=0.                                                                TWM  655
      PRINT 2830                                                           TWM  656
1840  IF (IOPT3-1) 1950,1850,1950                                          TWM  657
C*********************************************************************TWM
C         PLOT INDIVIDUAL STORMS                                          TWM
C*********************************************************************TWM
1850  FLOMAX=0.                                                            TWM  658
      KFIRST=JFIRST                                                        TWM  659
      DO 1860 IA=KFIRST,JJ                                                 TWM  660
      FLOMAX=AMAX1(FLOMAX,TRS(IA),RECFLO(IA))                              TWM  661
1860  CONTINUE                                                             TWM  662
      J=JJ-KFIRST+1                                                        TWM  663
      LINE=0                                                               TWM  664
      YP=FLOMAX*.25                                                        TWM  665
      XP=FLOMAX*.5                                                         TWM  666
      ZP=FLOMAX*.75                                                        TWM  667
      PRINT 2390, YP,XP,ZP,FLOMAX                                          TWM  668
      PRINT 2400                                                           TWM  669
      DO 1940 IA=KFIRST,JJ                                                 TWM  670
      IHOURS=(JRINT*IA)/60                                                 TWM  671
      IMIN=MOD(JRINT*IA,60)                                                TWM  672
      DO 1870 IR=1,120                                                     TWM  673
1870  JPLOT(IR)=BLANK                                                      TWM  674
      IR=(RECFLO(IA)/FLOMAX)*120.+.5                                       TWM  675
      IS=(TRS(IA)/FLOMAX)*120.+.5                                          TWM  676
1890  IF (IR) 1892, 1892, 1891                                             TWM  677
1891  JPLOT(IR) = R                                                        TWM  678
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 1892 IF (IS) 1900, 1900, 1893                                          TWM  679
 1893 JPLOT(IS)=S                                                       TWM  680
      IF (IR - IS) 1900, 1880, 1900                                     TWM  681
 1880 IF (IR) 1900, 1900, 1885                                          TWM  682
 1885 JPLOT(IR) = B                                                     TWM  683
 1900 IF (MOD(LINE,5)) 1910,1920,1910                                   TWM  684
 1910 PRINT 2410, (JPLOT(IX),IX=1,120)                                  TWM  685
      GO TO 1930                                                        TWM  686
 1920 PRINT 2420, IHOURS,IMIN,(JPLOT(IX),IX=1,120)                      TWM  687
 1930 LINE=LINE+1                                                       TWM  688
 1940 CONTINUE                                                          TWM  689
      PRINT 2430                                                        TWM  690
      PRINT 2440, YP,XP,ZP,FLOMAX                                       TWM  691
 1950 CONTINUE                                                          TWM  692
C***********************************************************************TWM
C         PLOT HYDROGRAPH FOR MONTH                                     TWM
C***********************************************************************TWM
 1960 IF (IOPT4-1) 1990,1970,1990                                       TWM  693
 1970 FLOMAX=0.                                                         TWM  694
      DO 1980 I=1,J                                                     TWM  695
      PREC(I)=FLOAT(I*JRINT)                                            TWM  696
      TRS(I)=SIMFLO(I)*Y                                                TWM  697
      FLOMAX=AMAX1(FLOMAX,TRS(I))                                       TWM  698
 1980 CONTINUE                                                          TWM  699
      FLOMAX=FLOAT(IFIX(FLOMAX)/25+1)*25.                               TWM  700
C***********************************************************************TWM
C     CALL FLOWPLT(PREC,SIMFLO,RECFLO,FLOMAX,JRINT,J,JYR,1,J,MONTH,     TWM
C             NAMSEG, LTR, 120.)                                        TWM
 1990 IF (IOPT2-1) 2090,2000,2090                                       TWM  701
 2000 IF (IOPT5) 2020,2010,2020                                         TWM  702
C***********************************************************************TWM
 2010 PRINT 2270                                                        TWM  703
      GO TO 2090                                                        TWM  704
 2020 CONTINUE                                                          TWM  705
      DO 2080 I=1,JSIZE                                                 TWM  706
      X=SIMFLO(I) * 60.5/FLOAT(JRINT)                                   TWM  707
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      Y=RECFLO(I)                                                       TWM  708
      SUMX(KSEGMT)=SUMX(KSEGMT)+X                                       TWM  709
      SUMY(KSEGMT)=SUMY(KSEGMT)+Y                                       TWM  710
      XX(KSEGMT)=XX(KSEGMT)+X*X                                         TWM  711
      YY(KSEGMT)=YY(KSEGMT)+Y*Y                                         TWM  712
      XY(KSEGMT)=XY(KSEGMT)+X*Y                                         TWM  713
      ERR=X-Y                                                           TWM  714
      IF (ABS(ERR)-.00001) 2030,2030,2040                               TWM  715
2030  ERR=0.                                                            TWM  716
2040  IF (Y-1.) 2050,2050,2060                                          TWM  717
2050  IND=1                                                             TWM  718
      GO TO 2070                                                        TWM  719
2060  IND=2.*ALOG(Y)+2.                                                 TWM  720
2070  CONTINUE                                                          TWM  721
      ICASE(KSEGMT,IND)=ICASE(KSEGMT,IND)+1                             TWM  722
      SUMERR(KSEGMT,IND)=SUMERR(KSEGMT,IND)+ERR                         TWM  723
      SABSER(KSEGMT,IND)=SABSER(KSEGMT,IND)+ABS(ERR)                    TWM  724
      SERRSQ(KSEGMT,IND)=SERRSQ(KSEGMT,IND)+ERR*ERR                     TWM  725
      SWEIFL(KSEGMT)=SWEIFL(KSEGMT)+ABS(ERR)*WEIGH(IND)                 TWM  726
2080  CONTINUE                                                          TWM  727
2090  CONTINUE                                                          TWM  728
       X11=X11*FLOAT(JRINT)/(60.5*ATOTAL)                               TWM  729
      X12=X12*FLOAT( JRINT)/(60.5*ATOTAL)                               TWM  730
      PRINT 2460, SSRAIN,X12,X11                                        TWM  731
      IF (MONTH-9) 220,2100,220                                         TWM  732
C***********************************************************************TWM
C         YEAR-END REPORTS                                              TWM
C***********************************************************************TWM
2100  DO 2240 I=1,ISEGMT                                                TWM  733
      SSRAIN=0.                                                         TWM  734
      SSEVAP=0.                                                         TWM  735
      SSSF=0.                                                           TWM  736
      SSOLF=0.                                                          TWM  737
      SSGWF=0.                                                          TWM  738
      SSIF=0.                                                           TWM  739
      SSUF=0.                                                           TWM  740
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      DO 2110 J=1,12                                                    TWM  741
      SSRAIN=SSRAIN+SRAIN(I,J)                                          TWM  742
      SSEVAP=SSEVAP+SEVAP(I,J)                                          TWM  743
      SSSF=SSSF+SSF(I,J)                                                TWM  744
      SSOLF=SSOLF+SOLF(I,J)                                             TWM  745
      SSGWF=SSGWF+SGWF(I,J)                                             TWM  746
      SSIF=SSIF+SIF(I,J)                                                TWM  747
      SSUF=SSUF+SUF(I,J)                                                TWM  748
 2110 CONTINUE                                                          TWM  749
      AVINFL=SSSF/FLOAT(1440*JDPY/JRINT)                                TWM  750
      PRINT 2490, I,JYR                                                 TWM  751
      PRINT 2500                                                        TWM  752
      PRINT 2510,(SRAIN(I,J),J=10,12),(SRAIN(I,J),J=1,9),SSRAIN         TWM  753
      PRINT 2520                                                        TWM  754
      PRINT 2530,(SEVAP(I,J),J=10,12),(SEVAP(I,J),J=1,9),SSEVAP         TWM  755
      PRINT 2520                                                        TWM  756
      PRINT 2540,(SSF(I.J),J=10,12).( SSF(I,J),J=1,9), SSSF             TWM  757
      PRINT 2520                                                        TWM  758
      X=ATOTAL/12.                                                      TWM  759
      DO 2120 K=1,12                                                    TWM  760
      SSF(I,K)=SSF(I,K)*X                                               TWM  761
 2120 CONTINUE                                                          TWM  762
      SSSF=SSSF*X                                                       TWM  763
      PRINT 2550,(SSF(I.J),J=10,12),(SSF(I,J),J=1,9),SSSF               TWM  764
      X=.504166667/FLOAT(IDAYS)                                         TWM  765
      DO 2130 K=1,12                                                    TWM  766
      SSF(I,K)=SSF(I,K)*X                                               TWM  767
 2130 CONTINUE                                                          TWM  768
      SSSF=SSSF*X                                                       TWM  769
      PRINT 2550,(SSF(I,J),J=10,12).(SSF(I,J),J=1,9),SSSF               TWM  770
      PRINT 2570                                                        TWM  771
      PRINT 2580,(SOLF(I,J),J=10,12),(SOLF(I,J),J=1,9),SSOLF            TWM  772
      PRINT 2590                                                        TWM  773
      PRINT 2600,(SGWF(I,J).J=10,12),(SGWF(I,J),J=1,9),SSGWF            TWM  774
      PRINT 2610,(SIF(I.J),J=10,12).(SIF(I,J),J=1,9),SSIF               TWM  775
      PRINT 2520                                                        TWM  776
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      PRINT 2620, (SUF(I,J),J=10,12),(SUF(I,J),J=1,9),SSUF              TWM  777
      PRINT 2520                                                          TWM  778
      PRINT 2630                                                          TWM  779
      PRINT 2640,(EOMINC(I,J),J=10,12),(EOMINC(I,J),J=1,9)               TWM  780
      PRINT 2650,(EOMSUR(I,J),J=10,12),(EOMSUR(I,J),J=1,9)               TWM  781
      PRINT 2660,(EOMUZ(I,J),J=10,12),(EOMU7(I,J),J=1,9)                 TWM  782
      PRINT 2670                                                          TWM  783
      PRINT 2680,(EOMINT(I,J),J=10,12),(EOMINT(I,J),J=1,9)               TWM  784
      PRINT 2690,(EOMGW(I,J),J=10,12),(EOMGW(I,J),J=1,9)                 TWM  785
      PRINT 2700,(EOMINF(I,J),J=10,12),(EOMINF(I,J),J=1,9)               TWM  786
      IF (IOPT2-1) 2230,2140,2230                                         TWM  787
C***********************************************************************TWM
C         CONVERT FLOWS FROM INCHES PER TIME INTERVAL TO C.F.S.          TWM
C***********************************************************************TWM
 2140 CONTINUE                                                            TWM  788
      PRINT 2490, I, JYR                                                  TWM  789
      PRINT 2710                                                          TWM  790
      PRINT 2720, JRINT                                                   TWM  791
      PRINT 2730                                                          TWM  792
      DO 2180 J=1,24                                                      TWM  793
      IF (ICASE(I,J)-1) 2160,2170,2170                                    TWM  794
 2160 PRINT 2740, FLOINT(J),FLOINT(J+1),ICASE(I,J),SUMERR(I,J),SABSER(I,TWM  795
     1J)                                                                  TWM  796
      GO TO 2180                                                          TWM  797
 2170 X=ICASE(I,J)                                                        TWM  798
      AVGERR=SUMERR(I,J)/X                                                TWM  799
      AVABER=SABSER(I,J)/X                                                TWM  800
      STDERR=SQRT((SERRSQ(I,J)-SUMERR(I,J)*SUMERR(I,J)/X)/(X-1.))         TWM  801
      PRINT 2740, FLOINT(J),FLOINT(J+1),ICASE(I,J),AVGERR,AVABER,STDERR TWM  802
 2180 CONTINUE                                                            TWM  803
      IF (ICASE(I,25)) 2200,2190,2200                                     TWM  804
 2190 PRINT 2750, FLOINT(25),ICASE(I,25)                                  TWM  805
      GO TO 2210                                                          TWM  806
 2200 X=ICASE(I,25)                                                       TWM  807
      AVGERR=SUMERR(I,25)/X                                               TWM  808
      AVABER=SABSER(I,25)/X                                               TWM  809
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      STDERR=SQRT((SERRSQ(I,25)-SUMERR(I,25)*SUMERR(I,25)/X)/(X-1.))     TWM 810
      PRINT 2750, FLOINT(25),ICASE(I,25),AVGERR,AVABER,STDERR            TWM 811
 2210 X=0.                                                               TWM 812
      DO 2220 J=1,25                                                     TWM 813
      X=X+WEIGH(J)*FLOAT(ICASE(I,J))                                     TWM 814
 2220 CONTINUE                                                           TWM 815
      COEFF=SWEIFL(I)/(X*AVINFL*ATOTAL*60.5/FLOAT(JRINT))                TWM 816
      PRINT 2760, COEFF                                                  TWM 817
      X=JDPY*1440/JRINT                                                  TWM 818
      CORRCO=(XY(I)-SUMX(I)*SUMY(I)/X)/SQRT((XX(I)-SUMX(I)*SUMX(I)/X)*(YTWM 819
     1Y(I)-SUMY(I)*SUMY(I)/X))                                           TWM 820
      PRINT 2770, CORRCO                                                 TWM 821
 2230 CONTINUE                                                           TWM 822
 2240 CONTINUE                                                           TWM 823
      DO 2250 I=1,ISEGMT                                                 TWM 824
      SUMX(I)=0.                                                         TWM 825
      SUMY(I)=0.                                                         TWM 826
      XX(I)=0.                                                           TWM 827
      YY(I)=0.                                                           TWM 828
      XY(I)=0.                                                           TWM 829
      SWEIFL(I)=0.                                                       TWM 830
      DO 2250 J=1,25                                                     TWM 831
      ICASE(I,J)=0                                                       TWM 832
      SUMERR(I,J)=0.                                                     TWM 833
      SABSER(I,J)=0.                                                     TWM 834
      SERRSQ(I,J)=0.                                                     TWM 835
 2250 CONTINUE                                                           TWM 836
      GO TO 220                                                          TWM 837
C                                                                        TWM
 2260 FORMAT (/1H 12F10.5)                                               TWM 838
 2270 FORMAT (89H0STATISTICAL ANALYSIS CANNOT BE PERFORMED WITHOUT RECORTWM 839
     1DED STREAMFLOW.  OPTION 2 IGNORED.)                                TWM 840
 2280 FORMAT (20I4)                                                      TWM 841
 2290 FORMAT (2I4,F4.3)                                                  TWM 842
 2300 FORMAT (12F6.0)                                                    TWM 843
 2310 FORMAT (I2,I4,2(I2,4X),I2,I4,14F4.0)                               TWM 844
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2320  FORMAT (8F10.0)                                                   TWM  845
2330  FORMAT (I2,2X,19A4)                                               TWM  846
2340  FORMAT (1H 38HPRECIPITATION TAPE FOR SEGMENT NUMBER I3,17H COMPLETTWM  847
     1E FOR THE I2,12HTH MONTH, 19 I2, 1H.)                             TWM  848
2350  FORMAT (1H I2,F9.2, 13F9.4)                                       TWM  849
2360  FORMAT (4H0DAY2X,7HRAIN-  2X,6HINTER-1X,16HOVERLAND STORAGE1X,18HDTWM  850
     1EPRESSION STORAGE3X,13HU. Z. STORAGE3X,16HT. I. Z. STORAGE1X,17HINTWM  851
     2TERFLOW STORAGE1X,9HPOTENTIAL1X,12HUNSAT EVAPO-)                  TWM  852
2370  FORMAT (1H 6X,6HFALL  7HCEPTION4X,2HIN4(6X,3HOUT7X,2HIN),6X,3HOUT,TWM  853
     13X,9HEVAPORAT.1X,11HRATION POT./)                                 TWM  854
2380  FORMAT (1H I2,9X,F9.6,3(4X,F9.6,5X),3F9.6)                        TWM  855
2390  FORMAT (1H17HTIME  024X,1X,F8.3,3(22X,F8.3))                      TWM  856
2400  FORMAT (7H ENDING123(1H.))                                        TWM  857
2410  FORMAT (1H 6X,1H.120A1,2X,1H.)                                    TWM  858
2420  FORMAT (1H 1X,I2,1X,I2,1H.120A1,2X,1H.)                           TWM  859
2430  FORMAT (1H 6X,123(1H.))                                           TWM  860
2440  FORMAT (1H 6X,1H0.25X,F8.3,3(22X,F8.3)////)                       TWM  861
2450  FORMAT (1H 17HRECORDED FLOW IS F8.4,20H, SIMULATED FLOW IS F8.4)  TWM  862
2455  FORMAT (1H  46HTHE CORRELATION COEFFICIENT FOR THIS STORM IS F7.4)TWM  863
2460  FORMAT (1H 17HPRECIPITATION IS F8.4,18HRECORDED FLOW IS  F8.4,18HSTWM  864
     1IMULATED FLOW IS  F8.4)                                           TWM  865
2470  FORMAT (1H 10I10)                                                 TWM  866
2480  FORMAT (1H 2I10,F10.4)                                            TWM  867
2490  FORMAT (1H144X,15HSEGMENT NUMBER I3,5X,23HYEAR ENDING SEP. 30, 19ITWM  868
     12)                                                                TWM  869
2500  FORMAT (1H015X,3HOCT6X,3HNOV6X,3HDEC6X,3HJAN6X,3HFEB6X,3HMAR6X,3HATWM  870
     1PR6X,3HMAY6X,3HJUN6X,3HJUL6X,3HAUG6X,3HSEP 9X,6HANNUAL)           TWM  871
2510  FORMAT (1H 8HRAINFALL7X,12(F4.2,5X), 3X,F6.2)                     TWM  872
2520  FORMAT (1H 2X,8H(INCHES))                                         TWM  873
2530  FORMAT (1H 11HEVAPORATION4X,12(F4.2,5X), 3X,F6.2)                 TWM  874
2540  FORMAT (1H 10HSTREAMFLOW5X,12(F4.2,5X), 3X,F6.2)                  TWM  875
2550  FORMAT (1H 3X,7HACRE-FT4X,12(F6.1,3X),1X,F8.1)                    TWM  876
2560  FORMAT (1H 2X,10HC.F.S.-DAY3X,12(F6.1,3X),F8.1)                   TWM  877
2570  FORMAT (1H 8HOVERLAND)                                            TWM  878
2580  FORMAT (1H 3X,10HFLOW(INCH)2X,12(F4.2,5X), 3X,F6.2)               TWM  879
2590  FORMAT (1H 11HGROUNDWATER)                                        TWM  880
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2600  FORMAT (1H 3X,10HFLOW(INCH)2X,12(F4.2,5X), 3X,F6.2)                   TWM  881
2610  FORMAT (1H 9HINTERFLOW6X,12(F4.2,5X), 3XF6.2)                          TWM  882
2620  FORMAT (1H 9HUNDERFLOW6X,12(F4.2,5X), 3X,F6.2)                         TWM  883
2630  FORMAT (1H050HEND OF MONTH VALUES OF STORAGE VOLUMES, IN INCHES.) TWM  884
2640  FORMAT (1H 12HINTERCEPTION3X,12(F4.2,5X))                              TWM  885
2650  FORMAT (1H 7HSURFACE8X,12(F4.2,5X))                                    TWM  886
2660  FORMAT (1H 10HUPPER ZONE 5X,12(F4.2,5X))                               TWM  887
2670  FORMAT (1H 12HINTERMEDIATE)                                            TWM  888
2680  FORMAT (1H 7X,4HZONE3X,12(F5.2,4X))                                    TWM  889
2690  FORMAT (1H 11HGROUNDWATER4X,12(F6.2,3X))                               TWM  890
2700  FORMAT (1H 9HINTERFLOW6X,12(F4.2,5X))                                  TWM  891
2710  FORMAT (1H055X,20HSTATISTICAL ANALYSIS)                                TWM  892
2720  FORMAT (1H024HBASIC TIME INCREMENT IS I4,9H MINUTES.)                  TWM  893
2730  FORMAT (1H03X,13HFLOW INTERVAL8X,5HCASES3X,10HAVG. ERROR3X,15HAVG.TWM  894
     1 ABS. ERROR2X,14HSTANDARD ERROR)                                       TWM  895
2740  FORMAT (1H F8.1,3H - F8.1,5X,I8,5X,F8.1,7X,F8.1,9X,F9.2)               TWM  896
2750  FORMAT (1H F8.1,3H - 13X,I8,5X,F8.1,7X,F8.1,9X,F9.2)                   TWM  897
2760  FORMAT (1H047HTHE COEFFICIENT OF WEIGHTED ABSOLUTE ERRORS IS F15.7TWM  898
     1)                                                                      TWM  899
2770  FORMAT (1H058HTHE CORRELATION COEFFICIENT OF THE INTERVAL FLOWS ISTWM  900
     1 R =  F6.4)                                                            TWM  901
2780  FORMAT (1H015HSEGMENT NUMBER I3,5X,I2,10HTH MONTH, I2,43HTH DAY.  TWM  902
     1TIME INTERVAL BETWEEN READINGS IS I4,39H MINUTES.  FLOWS ARE IN C.TWM  903
     2F.S. STARTING/3H ATI2,9H HOURS,  I2,9H MINUTES.)                       TWM  904
2790  FORMAT (1H 23X,12F9.3)                                                 TWM  905
2800  FORMAT (1H 23X,12F9.3,/)                                               TWM  906
2810  FORMAT (1H045HSIMULATED MEAN DAILY FLOW FOR SEGMENT NUMBER I3,5H FTWM  907
     1OR I2,12HTH MONTH, 19I2,10H IN C.F.S.)                                 TWM  908
2820  FORMAT (1H 13F10.1)                                                    TWM  909
2830  FORMAT (1H0)                                                           TWM  910
2840  FORMAT (14H TOTAL AREA = F6.1,6H ACRES5X,25HFRACTION PERVIOUS AREATWM  911
     1 = F5.3,5X,/68H FRACTION OF PERVIOUS AREA CONTRIBUTING RUNOFF DIRETWM  912
     2CTLY TO STREAM = F5.3,/71H FRACTION OF PERVIOUS AREA CONTRIBUTING TWM  913
     3RUNOFF TO DEPRESSION STORAGE = F5.3,5X,29HMAXIMUM DEPRESSION STORATWM  914
     4GE = F6.2,14H INCH PER UNIT/23H AREA OF PERVIOUS AREA,5X,31HMAXIMUTWM  915
     5M INTERCEPTION STORAGE = F6.2,6H INCH,5X,29HDEPTH OF INTERMEDIATE TWM  916
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            6ZONE = F6.1,4H IN./24H UPPER ZONE THICKNESS = F8.3,4H IN.5X,14HCHATWM   917
            7NNEL LAG = F4.2,5X,22HROOT ZONE THICKNESS = F5.2,7H INCHES)       TWM   918
858   2850  FORMAT (21H INFILTRATION RATE = F8.2,4H * (F8.4,19H - SOIL MOISTURTWM   919
            1E)**F8.4,3H + F8.3)                                               TWM   920
859   2860  FORMAT (28H UNSATURATED PERMEABILITY = F8.2,19H *(SOIL MOISTURE + TWM   921
            1F8.4,3H)**F8.3,3H + E11.4)                                        TWM   922
860   2870  FORMAT (26H SOIL MOISTURE TENSION = -E11.4,19H *(SOIL MOISTURE + FTWM   923
            18.2,4H)** F8.3)                                                   TWM   924
861   2880  FORMAT (89H MINIMUM VALUE OF STORAGE IN TOP INTERMEDIATE ZONE FOR TWM   925
            1TRANSFER TO INTERFLOW TO OCCUR IS F8.2)                           TWM   926
862   2890  FORMAT (73H MINIMUM VALUE OF STORAGE IN GROUNDWATER STORAGE FOR OUTWM   927
            1TFLOW TO OCCUR IS F8.2)                                           TWM   928
863   2900  FORMAT (38H DAILY RECESSION CONSTANTS ARE    FROM15X,2HTO)         TWM   929
864   2910  FORMAT (33X,11HGROUNDWATER7X,6HSTREAM8X,F8.2)                      TWM   930
865   2920  FORMAT (33X,11HGROUNDWATER6X,9HUNDERFLOW6X,F8.2)                   TWM   931
866   2930  FORMAT (34X,9HINTERFLOW8X,6HSTREAM8X,F8.2)                         TWM   932
867   2940  FORMAT (24H INTERFLOW BASE FLOW IS F8.2)                           TWM   933
868   2950  FORMAT (31X,15HTOP INTER.ZONE 4X,9HINTERFLOW6X,F8.2)               TWM   934
869   2960  FORMAT (29H MANNINGS ROUGHNESS FACTOR = F6.4,5X,22HOVERLAND FLOW STWM   935
            1LOPE = F7.5,14H AND LENGTH = F8.0,4H FT.2X,25HSATURATED PERMEABILITWM   936
            2TY = F8.3,/7H IN/MIN5X,29HMAXIMUM UPPER ZONE STORAGE = F6.4,5X,36HTWM   937
            3MAXIMUM INTERMEDIATE ZONE STORAGE = F8.4)                         TWM   938
870   2970  FORMAT (1H130X,I2,3H/19I2)                                         TWM   939
871   2980  FORMAT (1H015HSEGMENT NUMBER I2,5X,20HROUTING INTERVAL IS I3,5X,5HTWM   940
            1 MIN.5X,20HBASIC TIME CYCLE IS I2,5H MIN.)                        TWM   941
872   2990  FORMAT (34H INITIAL VALUE OF U.Z. STORAGE OF F6.2,22H LESS THAN MITWM   942
            1NIMUM OF F6.2,23H RESET TO MINIMUM VALUE)                         TWM   943
873   3000  FORMAT (34H INITIAL VALUE OF T.I. STORAGE OF F6.2,22H LESS THAN MITWM   944
            1NIMUM OF F6.2,23H RESET TO MINIMUM VALUE)                         TWM   945
874   3010  FORMAT (34H INITIAL VALUE OF B.I. STORAGE OF F6.2,22H LESS THAN MITWM   946
            1NIMUM OF F6.2,23H RESET TO MINIMUM VALUE)                         TWM   947
875   3020  FORMAT (30H MINIMUM UPPER ZONE STORAGE = F8.4,10X,37H MINIMUM INTETWM   948
            1RMEDIATE ZONE STORAGE = F8.4)                                     TWM   949
876   3030  FORMAT (38H INITAL VALUE OF DEPRESSION STORAGE = F6.3,32H, GREATERTWM   950
            1 THAN MAXIMUM VALUE OF F6.3,24H, RESET TO MAXIMUM VALUE)          TWM   951
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DEPTHU      256,    258,    258,    261,    267,    416,    419,    421,
            477,    480,    481,

DO           78,     86,     92,    101,    104,    111,    124,    144,
            147,    176,    193,    201,    207,    212,    217,    233,
            321,    326,    331,    336,    367,    487,    498,    505,
            535,    538,    550,    564,    594,    622,    632,    635,
            657,    668,    695,    703,    722,    728,    755,    774,
            784,    791,
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DS          286,    292,    293,    294,    377,    377,    378,    385,
            386,    394,    395,    397,    398,    407,    408,    411,
            413,    413,    474,    474,    474,    510,    524,

DSMAX       256,    267,    292,    293,    294,    385,    386,    408,
            411,    474,

DS1           4,    283,    286,    510,

EOMGW         7,    527,    747,    747,

EOMINC        6,    523,    742,    742,

EOMINF        7,    528,    748,    748,

EOMINT        6,    526,    746,    746,

EOMSUR        6,    524,    743,    743,

EOMUZ         6,    525,    744,    744,

ERR         676,    677,    678,    685,    686,    687,    687,    688,

ET          351,    353,    359,    360,

EVAPOT      470,    471,    472,    472,    473,    473,    474,    474,
            475,    475,    476,    478,    480,    481,    482,

EVAP1         5,     93,    344,

EVAP2         5,     94,    344,

EVAP3         5,     95,    344,

EXIT         75,
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E1          366,   470,
E2          364,   366,   470,
E3          365,   366,   470,
E4          362,   364,   365,
E5          363,   364,   365,
FLOAT        88,   342,   345,   347,   467,   532,   610,   611,
            658,   662,   669,   691,   692,   712,   727,   775,
            777,
FLOINT        8,    30,    79,    79,   757,   757,   763,   763,
            766,   772,
FLOMAX      620,   623,   623,   627,   628,   629,   630,   637,
            638,   653,   656,   660,   660,   662,   662,
GO           66,   155,   244,   352,   357,   382,   410,   427,
            446,   479,   491,   570,   576,   582,   608,   648,
            666,   681,   758,   767,   877,
GWS         290,   455,   456,   457,   458,   460,   461,   511,
            527,
GWS1          9,   283,   290,   511,
H            28,    28,    28,    28,   349,   359,   360,
HOUR        467,   468,   469,   470,   470,
I            35,    35,    36,    36,    39,    39,    40,    40,
             44,    44,    77,    77,    78,    79,    79,    79,
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          84,    84,    85,    85,    86,    87,    87,    87,
          88,    88,    88,    92,    93,    93,    93,    93,
          94,    94,    94,    95,    95,    95,    95,    97,
          97,   101,   102,   104,   105,   106,   107,   108,
         109,   110,   112,   113,   114,   115,   124,   125,
         126,   140,   140,   144,   145,   147,   148,   165,
         165,   176,   179,   181,   193,   195,   197,   204,
         207,   208,   229,   233,   234,   234,   234,   321,
         322,   331,   332,   332,   332,   333,   336,   337,
         337,   338,   367,   368,   467,   483,   488,   505,
         506,   506,   531,   531,   535,   536,   550,   551,
         553,   554,   557,   564,   565,   566,   567,   568,
         572,   573,   574,   575,   577,   578,   579,   580,
         581,   657,   658,   658,   659,   659,   660,   668,
         669,   670,   695,   704,   705,   706,   707,   708,
         709,   710,   713,   715,   715,   717,   717,   719,
         719,   723,   723,   726,   726,   729,   729,   732,
         732,   734,   734,   736,   736,   737,   737,   739,
         739,   742,   742,   743,   743,   744,   744,   746,
         746,   747,   747,   748,   748,   751,   756,   757,
         757,   757,   759,   760,   761,   762,   762,   762,
         763,   765,   766,   768,   769,   770,   771,   771,
         771,   772,   775,   777,   780,   780,   780,   780,
         780,   780,   780,   780,   780,   784,   785,   786,
         787,   788,   789,   790,   792,   793,   794,   795,

IA       148,   148,   173,   174,   180,   181,   186,   187,
         189,   191,   194,   195,   196,   197,   211,   213,
         214,   214,   215,   215,   221,   222,   225,   232,
         234,   237,   241,   242,   329,   330,   335,   336,
         337,   498,   499,   499,   499,   622,   623,   623,
         632,   633,   634,   637,   638,

IABS      59,

IAI      327,   328,   540,   541,   544,   545,   583,
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IB          173,    173,    179,    179,    180,    180,    186,    186,
            187,    187,    189,    189,    194,    194,    196,    196,
            204,    204,    211,    211,    221,    221,    229,    229,
            230,    231,    236,    236,    237,    238,    241,    241,
            242,    242,    327,    327,    329,    329,    502,    502,
            540,    540,    544,    544,    635,    636,

ICASE        10,    112,    684,    684,    756,    757,    759,    763,
            765,    766,    768,    772,    775,    792,

IDAY        326,    328,    330,    343,    501,    502,    583,    587,

IDAYS        54,     57,     59,     61,     64,    135,    138,    147,
            171,    176,    184,    193,    210,    222,    228,    240,
            325,    326,    531,    537,    538,    727,

IF           37,     46,     47,     48,     55,     56,     60,     62,
             74,    121,    122,    128,    133,    136,    137,    139,
            150,    153,    158,    160,    163,    164,    167,    168,
            169,    175,    177,    183,    188,    190,    191,    198,
            206,    222,    231,    238,    240,    248,    251,    255,
            263,    281,    282,    292,    295,    298,    301,    304,
            307,    310,    350,    355,    370,    378,    379,    380,
            386,    391,    396,    399,    400,    403,    408,    417,
            422,    424,    429,    432,    437,    441,    443,    448,
            453,    457,    463,    468,    469,    477,    483,    486,
            489,    542,    547,    548,    555,    559,    565,    566,
            567,    568,    572,    573,    577,    578,    579,    584,
            606,    613,    619,    639,    641,    643,    644,    646,
            655,    663,    664,    677,    679,    694,    749,    756,
            765,

IFILM       161,

IFIRST       69,    139,    150,    255,    257,
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IFIX       346,    350,    662,

IFLAG      539,    556,    559,

IHOUR       31,

IHOURS     585,    587,    633,    649,

II         201,    202,    202,    202,    212,    213,    217,    218,
           218,    219,    219,    224,    227,    227,    230,    236,
           240,    243,    243,    488,    489,    490,    490,    492,
           492,    538,    541,    545,

IK         594,    595,    596,    597,    597,    598,    598,    599,
           599,    604,    604,    605,    605,

IMIN       586,    587,    634,    649,

IND        680,    682,    684,    684,    685,    685,    686,    686,
           687,    687,    688,

INEW        72,    118,    148,    171,    179,    184,    187,    204,
           210,    221,    228,    236,    242,    325,    502,    537,

IOLD        71,    119,    171,    172,    173,    180,    184,    186,
           194,    210,    211,    228,    229,    241,    325,    329,
           537,    540,

IOPT1      152,    158,    547,    584,

IOPT2      152,    663,    749,

IOPT3      152,    160,    163,    548,    619,

IOPT4      152,    164,    655,
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IOPT5      154,   156,   542,   664,
IPREC       53,    58,    59,    61,   142,
IR         637,   639,   640,   643,   644,   645,
IRECOD      10,    39,    40,    44,    59,    62,    77,   153,
IRINT      173,   177,   178,   179,   180,   186,   187,   189,
           194,
IRINT1     196,   198,   199,
IRUN        73,    74,
IS         638,   641,   642,   643,
ISCRTH      70,   185,   189,   192,   196,
ISEGMT      33,    34,    35,    36,    39,    40,    44,    59,
            64,    77,   101,   104,   171,   210,   228,   325,
           537,   695,   784,
ISEG1      140,   169,   175,
ISEG2      140,   183,   188,
ISIZE       58,   141,   148,   173,   179,   180,   186,   187,
           189,   194,   201,   204,   211,   212,   213,   219,
           221,   229,   236,   241,   242,   327,   367,   489,
           492,   492,   502,
ISTGAG      51,    52,    60,
IT         209,   212,   213,   247,   250,   253,   266,   327,
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          342,    467,    483,

ITAPE      33,     34,     37,

IX        647,    647,    649,    649,

IYR        33,     34,     41,     99,    167,    281,

J         111,    112,    113,    114,    115,    487,    488,    490,
          492,    625,    657,    703,    704,    705,    706,    707,
          708,    709,    710,    715,    715,    715,    715,    717,
          717,    717,    717,    719,    719,    719,    719,    726,
          726,    726,    726,    732,    732,    732,    732,    734,
          734,    734,    734,    736,    736,    736,    736,    737,
          737,    737,    737,    739,    739,    739,    739,    742,
          742,    742,    742,    743,    743,    743,    743,    744,
          744,    744,    744,    746,    746,    746,    746,    747,
          747,    747,    747,    748,    748,    748,    748,    755,
          756,    757,    757,    757,    757,    757,    759,    760,
          761,    762,    762,    762,    763,    763,    763,    774,
          775,    775,    791,    792,    793,    794,    795,

JAD       346,    347,    347,    347,    347,

JDPM       11,     32,     54,     88,    120,    135,    191,

JDPY      132,    134,    712,    779,

JDTD      100,    120,    120,    129,    345,

JFIRST    588,    621,

JJ        603,    604,    605,    606,    607,    622,    625,    632,

JPLOT      12,    636,    640,    642,    645,    647,    649,

JPREC      10,     35,     36,     53,    142,
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JRINT       63,    64,   140,   141,   148,   177,   178,   198,
           199,   204,   211,   221,   229,   236,   246,   247,
           251,   266,   329,   483,   502,   532,   540,   544,
           585,   586,   587,   610,   611,   633,   634,   658,
           669,   691,   692,   712,   753,   777,   779,

JRINT1     241,   242,

JSEGMT     123,   173,   175,   180,   186,   187,   188,   189,
           190,   194,   196,   211,   229,   241,   242,   329,
           540,

JSIZE      196,   226,   230,   232,   233,   329,   331,   335,
           497,   498,   540,   544,   550,   564,   568,   569,
           668,

JYR         41,    46,    50,    50,    56,    59,    61,    64,
            65,    99,   121,   131,   131,   133,   137,   148,
           167,   174,   179,   181,   195,   197,   204,   221,
           236,   265,   281,   328,   330,   502,   504,   530,
           541,   545,   713,   751,

JYR1       173,   174,   180,   181,   186,   187,   189,   194,
           195,   196,   197,   211,   229,   241,   242,   327,
           328,   329,   330,   540,   541,   544,   545,

K          722,   723,   723,   728,   729,   729,

KFIRST     560,   574,   580,   585,   586,   588,   594,   600,
           602,   603,   604,   605,   607,   609,   621,   622,
           625,   632,

KSECND     561,   569,   575,   581,   594,   600,   602,   603,
           606,   609,

KSEGMT      51,    52,    53,    59,    59,    61,    62,    64,
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              64,    65,   140,   142,   143,   148,   153,   171,
             179,   184,   190,   204,   210,   221,   228,   234,
             236,   266,   283,   283,   283,   283,   283,   283,
             283,   283,   284,   285,   286,   287,   288,   289,
             290,   291,   325,   327,   502,   506,   508,   509,
             510,   511,   512,   513,   514,   515,   516,   517,
             518,   519,   520,   521,   522,   523,   524,   525,
             526,   527,   528,   529,   530,   537,   544,   587,
             671,   671,   672,   672,   673,   673,   674,   674,
             675,   675,   684,   684,   685,   685,   686,   686,
             687,   687,   688,   688,

LAG          140,   206,   209,   215,   217,   219,

LINE         626,   646,   650,   650,

LOOP         246,   248,   249,   252,

LTR          165,

LYR           33,    34,    46,   121,

MASS          33,    34,    59,

MAT           31,

MINO         603,

MOD           56,   133,   137,   483,   586,   634,   646,

MONTH         38,    45,    45,    47,    48,    49,    54,    55,
              59,    61,    64,    65,    98,   117,   117,   120,
             122,   128,   130,   135,   136,   139,   148,   150,
             168,   174,   181,   195,   197,   204,   221,   236,
             255,   265,   282,   328,   330,   344,   344,   344,
             472,   502,   504,   516,   517,   518,   519,   520,
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          521,    522,    523,    524,    525,    526,    527,    528,
          530,    541,    545,    587,    694,

MONTH1    173,    174,    179,    180,    181,    186,    187,    189,
          191,    194,    195,    196,    197,    211,    229,    241,
          242,    327,    328,    329,    330,    540,    541,    544,
          545,

NAMSEG     13,    165,

NEWVAL     13,     97,    139,    150,    255,

NRRELEM    140,    140,    226,    231,    232,    238,    487,    505,

OFSAVG    401,    403,    404,    405,    405,

OFSEQU    402,    403,    404,    405,

OLF       405,    406,    407,    413,    414,

OLS       285,    375,    376,    379,    389,    390,    392,    393,
          400,    401,    406,    406,    407,    407,    512,    524,

OLSI      375,    399,    401,

OLS1       14,    283,    285,    512,

PANFAC    151,    470,

POTEVP    344,    366,

PREC       15,     59,     61,    126,    196,    199,    202,    208,
          218,    219,    327,    368,    658,

PRINT      34,     36,     40,     52,     65,    265,    266,    267,
          268,    269,    270,    271,    272,    273,    274,    275,
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            276,    277,    278,    279,    280,    293,    296,    299,
            302,    305,    308,    311,    504,    530,    531,    587,
            604,    605,    612,    615,    618,    630,    631,    647,
            649,    652,    653,    665,    693,    713,    714,    715,
            716,    717,    718,    719,    720,    726,    732,    733,
            734,    735,    736,    737,    738,    739,    740,    741,
            742,    743,    744,    745,    746,    747,    748,    751,
            752,    753,    754,    757,    763,    766,    772,    778,
            781,

PSI1        419,    421,    439,    440,    452,

PSI2        420,    421,    440,

R            28,    640,

RAIN        368,    369,    370,    371,    372,    373,    373,    374,
            376,    377,

READ         33,     35,     39,     51,     63,     73,     77,     82,
             84,     85,     97,    140,    151,    152,    159,    161,
            165,    173,    180,    186,    194,    196,    211,    229,
            241,    256,    283,    327,    329,    540,    544,

RECFLO       21,     64,    536,    544,    553,    566,    573,    579,
            595,    597,    599,    599,    605,    623,    637,    670,

REWIND       42,     43,     67,     68,    118,    119,    172,    185,
            192,    324,

RO          341,    372,    406,    413,    460,    465,    484,    485,
            486,    490,    492,    494,

ROUGH       256,    268,    402,    405,

RTZONE      151,    267,    477,    480,    481,
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S             28,   642,
SABSER        20,   114,   686,   686,   757,   761,   770,   794,
SATPRM       256,   268,   270,   381,   383,   384,   452,
SCRAP         31,    84,    87,    88,    88,    90,    90,    91,
              91,    93,    93,    93,    94,    94,    95,    95,
              95,
SDAYFL       340,   484,   484,   501,
SEEP         381,   383,   384,   389,   391,   392,   394,   396,
             397,
SERRSQ        20,   115,   687,   687,   762,   771,   795,
SEVAP         18,   517,   705,   717,   717,
SGWF          19,   520,   708,   736,   736,
SHIFTT       178,   199,
SIF           19,   521,   709,   737,   737,
SIMFLO        16,   125,   145,   148,   171,   173,   178,   179,
             180,   184,   186,   187,   189,   194,   202,   202,
             204,   210,   211,   214,   215,   215,   218,   221,
             228,   229,   234,   234,   236,   241,   242,   325,
             329,   332,   332,   490,   490,   496,   496,   497,
             499,   499,   499,   502,   537,   540,   551,   596,
             659,   669,
SIN          348,   348,   351,   353,   362,   363,   470,
SLOPE        256,   268,   402,   405,
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SMMIN     256,   261,   262,
SOLF       18,   519,   707,   734,   734,
SQRT      762,   771,   780,
SRAIN      18,   516,   704,   715,   715,
SSEVAP    315,   471,   471,   482,   482,   517,   697,   705,
          705,   717,
SSF        18,   518,   706,   719,   719,   723,   723,   726,
          726,   729,   729,   732,   732,
SSGWF     318,   459,   459,   520,   700,   708,   708,   736,
SSIF      319,   466,   466,   521,   701,   709,   709,   737,
SSOLF     317,   414,   414,   519,   699,   707,   707,   734,
SSRAIN    314,   369,   369,   516,   693,   696,   704,   704,
          715,
SSSF      316,   485,   485,   518,   698,   706,   706,   712,
          719,   725,   725,   726,   731,   731,   732,
SSUF      320,   462,   462,   522,   702,   710,   710,   739,
STDERR    762,   763,   771,   772,
SUF        19,   522,   710,   739,   739,
SUMERR     19,   113,   685,   685,   757,   760,   762,   762,
          769,   771,   771,   793,
SUMX       20,   105,   671,   671,   780,   780,   780,   785,
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SUMY        20,    106,    672,    672,    780,    780,    780,    786,

SWEIFL      17,    110,    688,    688,    777,    790,

SX1X1      592,    599,    599,    614,

SX2X2      593,    598,    598,    614,

TAPCHK     174,    181,    195,    197,    328,    330,    541,    545,

TB         359,    361,    361,    363,    364,    365,    365,    366,
           366,    366,    366,    468,

TE         360,    361,    362,    364,    365,    365,    366,    366,
           366,    366,    469,

TH         361,    362,    363,    366,    366,    470,

TIZS       288,    301,    302,    303,    304,    305,    306,    392,
           393,    397,    398,    416,    420,    424,    425,    426,
           431,    431,    432,    433,    434,    434,    436,    445,
           448,    449,    450,    481,    481,    513,    526,

TIZS1       22,    283,    288,    513,

TO          66,    155,    244,    352,    357,    382,    410,    427,
           446,    479,    491,    570,    576,    582,    608,    648,
           666,    681,    758,    767,    877,

TPSWCH     171,    184,    210,    228,    325,    537,

TRANPO      22,     85,     87,     87,    472,

TRS         31,    214,    219,    322,    332,    333,    337,    337,
           338,    492,    492,    506,    554,    557,    565,    572,
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          578,   597,   598,   598,   604,   623,   638,   659,
          660,

UNDFLO     76,   461,

UZMIN     261,   269,   298,   299,   300,   429,   430,   475,
          475,   475,   478,   480,

UZS       287,   295,   296,   297,   298,   299,   300,   380,
          384,   388,   390,   395,   416,   419,   426,   426,
          429,   430,   431,   475,   475,   475,   478,   478,
          480,   480,   514,   525,

UZST      256,   268,   270,   295,   296,   297,   380,   384,
          388,   426,   475,

UZS1       23,   283,   287,   514,

VINFLO    433,   434,

VINSTG    284,   373,   373,   473,   473,   515,   523,

VINSTM    256,   267,   373,

VINST1     24,   283,   284,   515,

VIZMIN    262,   269,   301,   302,   303,   307,   308,   309,
          424,   425,   434,   443,   444,   448,   449,   453,
          454,   481,

VIZST     256,   268,   304,   305,   306,   310,   311,   312,
          392,   397,   431,   432,   433,

VLENGH    256,   268,   402,   402,   405,   405,

WEIGH      25,    79,    81,    81,    81,   688,   775,
```

```
WFSG       51,    52,    61,
WRITE      44,   148,   179,   187,   189,   204,   221,   236,
          242,   502,
X         260,   261,   262,   343,   344,   344,   344,   345,
          345,   346,   347,   350,   351,   351,   353,   353,
          354,   355,   356,   358,   371,   372,   385,   387,
          389,   389,   391,   392,   394,   394,   396,   397,
          409,   411,   413,   414,   421,   422,   423,   423,
          424,   425,   426,   429,   430,   431,   440,   441,
          442,   442,   443,   444,   445,   448,   449,   450,
          452,   453,   454,   455,   458,   459,   460,   464,
          465,   466,   551,   552,   555,   557,   669,   671,
          673,   673,   675,   676,   721,   723,   725,   727,
          729,   731,   759,   760,   761,   762,   762,   768,
          769,   770,   771,   771,   773,   775,   775,   777,
          779,   780,   780,   780,
XK        416,   417,   418,   421,   436,   437,   438,   440,
XLAT       82,    83,    83,   348,   348,
XLONG      82,   354,
XN        600,   602,   614,   614,   614,
XP        628,   630,   653,
XU        613,
XX         26,   107,   673,   673,   780,   787,
XY         26,   109,   675,   675,   780,   789,
X1        374,   376,   402,   562,   589,   596,   596,   610,
```

```
               610,     612,     614,     614,     614,     616,
X1Y1           591,     597,     597,     614,
X11            533,     552,     552,     691,     691,     693,
X12            534,     553,     553,     692,     692,     693,
X2             563,     590,     595,     595,     611,     611,     612,     613,
               614,     614,     614,     617,
X4             389,     390,     391,     392,     392,     393,     394,     395,
               396,     397,     397,     398,
Y              388,     389,     394,     456,     461,     462,     659,     670,
               672,     674,     674,     675,     676,     679,     682,
YESDAY         143,     496,     497,     529,
YP             627,     630,     653,
YY              27,     108,     674,     674,     780,     788,
Y1             532,     551,     610,
ZP             629,     630,     653,
```

```
        SUBROUTINE TPSWCH (IOLD,INEW,ISEGMT,KSEGMT,IDAYS,X)                  TWM  954
        DIMENSION X(1440)                                                    TWM  955
        ITEMP=IOLD                                                           TWM  956
        IOLD=INEW                                                            TWM  957
        INEW=ITEMP                                                           TWM  958
        REWIND IOLD                                                          TWM  959
        REWIND INEW                                                          TWM  960
        IF (ISEGMT-1) 20,10,20                                               TWM  961
 10     RETURN                                                               TWM  962
 20     READ (IOLD) MONTH1,IA,JYR1,JSEGMT,JRINT,JSIZE,(X(I),I=1,1440)        TWM  963
        WRITE (INEW) MONTH1,IA,JYR1,JSEGMT,JRINT,JSIZE,(X(I),I=1,1440)       TWM  964
        IF (JSEGMT+1-KSEGMT) 20,30,50                                        TWM  965
 30     IF (IA-IDAYS) 20,40,50                                               TWM  966
 40     RETURN                                                               TWM  967
 50     PRINT 60, JSEGMT,KSEGMT,IA,IDAYS                                     TWM  968
        CALL EXIT                                                            TWM  969
 60     FORMAT (1H039HTROUBLE IN TAPE MANIPLATION.  JSEGMT IS13,11H, KSEGMTTWM  970
       1T IS13,8H, IA IS I3,14H, AND IDAYS IS13)                             TWM  971
        END                                                                  TWM  972
```

```
     VARIABLE                 INDEX STATEMENT NUMBER

CALL          17,
EXIT          17,
I             10,     10,     11,     11,
IA            10,     11,     13,     15,
IDAYS          1,     13,     15,
IF             8,     12,     13,
INEW           1,      4,      5,      7,     11,
IOLD           1,      3,      4,      6,     10,
ISEGMT         1,      8,
ITEMP          3,      5,
JRINT         10,     11,
JSEGMT        10,     11,     12,     15,
JSIZE         10,     11,
JYR1          10,     11,
KSEGMT         1,     12,     15,
MONTH1        10,     11,
PRINT         15,
READ          10,
```

```
RETURN         9,      14,
REWIND         6,       7,
TPSWCH         1,
WRITE         11,
X              1,       2,     10,     11,
```

```
      SUBROUTINE ADJUST (X,Y,Z)                                         TWM  973
      X=X-Z                                                             TWM  974
      Y=Y+Z                                                             TWM  975
      RETURN                                                            TWM  976
      END                                                               TWM  977
```

```
     VARIABLE                    INDEX STATEMENT NUMBER


ADJUST        1,
RETURN        4,
X             1,     2,     2,
Y             1,     3,     3,
Z             1,     2,     3,
```

```
      SUBROUTINE DATAIN (RECORD,MONTH,NYEAR,INCRE,MASS,KSEGMT,IRECOD,IDATWM  978
     1YS,IFLAG)                                                         TWM  979
      COMMON MAT(16),SCRAP(31),IHOUR(15),TRS(1440)                      TWM  980
      DIMENSION RECORD(1440)                                            TWM  981
      DATA MDFSM/1H$/                                                   TWM  982
  400 FORMAT (1H  3I3,8(3X,I4,2X,F6.3))                                 TWM  983
      ISIZE=1440/INCRE                                                  TWM  984
      DO 1000 I=1,1440                                                  TWM  985
      RECORD(I)=0.                                                      TWM  986
 1000 CONTINUE                                                          TWM  987
      DELT=FLOAT(INCRE)                                                 TWM  988
      JDAY=1                                                            TWM  989
      IF (IRECOD-KSEGMT) 1340,1010,1340                                 TWM  990
 1010 READ 1480, N,UNIT,(MAT(I),I=1,16)                                 TWM  991
C***********************************************************************TWM
C         N IS THE NUMBER OF EVENTS PER CARD TO BE READ UNDER FORMAT MAT.TWM
C$**********************************************************************TWM
 1020 LMINUT=0                                                          TWM  992
      SAVE1=0                                                           TWM  993
 1030 READ MAT, IYEAR,IMONTH,IDAY,(IHOUR(I),SCRAP(I),I=1,N),MDF         TWM  994
C     PRINT 400, IYEAR, IMONTH, IDAY, (IHOUR(I), SCRAP(I), I= 1, N)     TWM
 1040 IF (JDAY-IDAY) 1050,1080,1050                                     TWM  995
 1050 CONTINUE                                                          TWM  996
      WRITE (3) MONTH,JDAY,NYEAR,KSEGMT,INCRE,ISIZE,(RECORD(IA),IA=1,144TWM  997
     10)                                                                TWM  998
      IF (IFLAG) 1055,1060,1055                                         TWM  999
 1055 WRITE (4) MONTH,JDAY,NYEAR,KSEGMT,INCRE,ISIZE,(RECORD(IA),IA=1,144TWM 1000
     10)                                                                TWM 1001
 1060 JDAY=JDAY+1                                                       TWM 1002
      LMINUT=0                                                          TWM 1003
      SAVE1=0.                                                          TWM 1004
      DO 1070 I=1,1440                                                  TWM 1005
      RECORD(I)=0.                                                      TWM 1006
 1070 CONTINUE                                                          TWM 1007
      IF (JDAY-IDAYS) 1040,1040,1080                                    TWM 1008
 1080 IF (IMONTH-MONTH) 1090,1100,1090                                  TWM 1009
```

```
 1090 RETURN                                                            TWM 1010
 1100 IF (MDF-MDFSM) 1110,1420,1110                                     TWM 1011
 1110 JDAY=IDAY                                                         TWM 1012
C***********************************************************************TWM
C         CONVERT UNITS WHEN NECESSARY                                  TWM
C***********************************************************************TWM
      IF (UNIT-1.) 1120,1140,1120                                       TWM 1013
 1120 DO 1130 I=1,N                                                     TWM 1014
      SCRAP(I)=SCRAP(I)*UNIT                                            TWM 1015
 1130 CONTINUE                                                          TWM 1016
C***********************************************************************TWM
C         IF THE DATA IS IN ACCUMULATED FORM, CONVERT TO RATE.          TWM
C***********************************************************************TWM
 1140 IF (MASS - 1) 1600, 1150, 1600                                    TWM 1017
 1150 IF (SCRAP(1)) 1160,1160,1170                                      TWM 1018
 1160 SAVE1=0.                                                          TWM 1019
 1170 DO 1230 I=1,N                                                     TWM 1020
      IF (I-1) 1190,1190,1180                                           TWM 1021
 1180 IF (IHOUR(I)-IHOUR(I-1)) 1240,1240,1190                           TWM 1022
 1190 CONTINUE                                                          TWM 1023
      SAVE=SCRAP(I)                                                     TWM 1024
      MINUT=(IHOUR(I)/100)*60+MOD(IHOUR(I),100)                         TWM 1025
      IF (MINUT-LMINUT) 1200,1220,1210                                  TWM 1026
 1200 IF (SAVE) 1210,1210,1330                                          TWM 1027
 1210 SCRAP(I)=(SCRAP(I)-SAVE1)/FLOAT(MINUT-LMINUT)*60.                 TWM 1028
      LMINUT=MINUT                                                      TWM 1029
 1220 SAVE1=SAVE                                                        TWM 1030
 1230 CONTINUE                                                          TWM 1031
 1240 CONTINUE                                                          TWM 1032
 1250 DO 1320 I=1,N                                                     TWM 1033
      MINUT=(IHOUR(I)/100)*60+MOD(IHOUR(I),100)                         TWM 1034
      IF (SCRAP(I)) 1270,1260,1270                                      TWM 1035
 1260 JMINUT=MINUT                                                      TWM 1036
      JSAVE=MINUT/INCRE+1                                               TWM 1037
      GO TO 1320                                                        TWM 1038
 1270 J=MINUT/INCRE+1                                                   TWM 1039
```

```
1280  IF (J-JSAVE) 1290,1310,1300                                       TWM 1040
1290  IF (J-JSAVE) 1330,1300,1300                                       TWM 1041
1300  NMINUT=JSAVE*INCRE                                                TWM 1042
      RECORD(JSAVE)=RECORD(JSAVE)+SCRAP(I)*FLOAT(NMINUT-JMINUT)/DELT    TWM 1043
      JMINUT=NMINUT                                                     TWM 1044
      JSAVE=JSAVE+1                                                     TWM 1045
      GO TO 1280                                                        TWM 1046
1310  RECORD(J)=RECORD(J)+SCRAP(I)*FLOAT(MINUT-JMINUT)/DELT             TWM 1047
      JMINUT=MINUT                                                      TWM 1048
1320  CONTINUE                                                          TWM 1049
      GO TO 1030                                                        TWM 1050
1330  PRINT 1490, I,IDAY,IHOUR(I),IMONTH,IYEAR,J,JDAY,JMINUT,JSAVE,LMINUTWM 1051
     1T,MINUT,N,NMINUT                                                  TWM 1052
      PRINT 1500, DELT,SAVE,SAVE1,SCRAP(I),UNIT                         TWM 1053
      CALL EXIT                                                         TWM 1054
C***********************************************************************TWM
C             RECORDER FOR THIS SEGMENT HAS ALREADY BEEN USED, AND IS ONTWM
C             TAPE 4, FIND IT, AND PLACE ON TAPE 3                      TWM
C***********************************************************************TWM
1340  CONTINUE                                                          TWM 1055
      NN=99999999                                                       TWM 1056
      WRITE (4) NN                                                      TWM 1057
      REWIND 4                                                          TWM 1058
1350  READ (4) JMONTH,KDAY,IYEAR,JSEGMT,JINCRE,JSIZE,(RECORD(I),I=1,1440TWM 1059
     1)                                                                 TWM 1060
      IF (JMONTH-MONTH) 1350,1360,1350                                  TWM 1061
1360  IF (JSEGMT-RECOD) 1350,1370,1350                                  TWM 1062
1370  IF (KDAY-JDAY) 1350,1380,1350                                     TWM 1063
1380  WRITE (3) MONTH,JDAY,NYEAR,KSEGMT,INCRE,ISIZE,(RECORD(IA),IA=1,144TWM 1064
     10)                                                                TWM 1065
      JDAY=JDAY+1                                                       TWM 1066
      IF (JDAY-IDAYS) 1350,1350,1390                                    TWM 1067
1390  REWIND 4                                                          TWM 1068
1400  READ (4) MM                                                       TWM 1069
      IF (MM-NN) 1400,1410,1400                                         TWM 1070
1410  BACKSPACE 4                                                       TWM 1071
```

```
      RETURN                                                            TWM 1072
C***********************************************************************TWM
C        DATA CARD IS FOR MEAN DAILY MEASUREMENT                        TWM
C***********************************************************************TWM
1420  DO 1460 I=1,N                                                     TWM 1073
      JDAY=IHOUR(I)                                                     TWM 1074
      IF (JDAY) 1430,1470,1430                                          TWM 1075
1430  X=SCRAP(I)*UNIT                                                   TWM 1076
      DO 1440 II=1,ISIZE                                                TWM 1077
1440  RECORD(II)=X                                                      TWM 1078
      WRITE (3) MONTH,JDAY,NYEAR,KSEGMT,INCRE,ISIZE,(RECORD(IA),IA=1,144TWM 1079
     10)                                                                TWM 1080
      IF (IFLAG) 1450,1460,1450                                         TWM 1081
1450  WRITE (4) MONTH,JDAY,NYEAR,KSEGMT,INCRE,ISIZE,(RECORD(IA),IA=1,144TWM 1082
     10)                                                                TWM 1083
1460  CONTINUE                                                          TWM 1084
      JDAY=JDAY+1                                                       TWM 1085
      GO TO 1020                                                        TWM 1086
1470  JDAY=IHOUR(I-1)+1                                                 TWM 1087
      GO TO 1020                                                        TWM 1088
C                                                                       TWM
1480  FORMAT (I4,F6.0,16A4)                                             TWM 1089
1490  FORMAT (1H 12I10)                                                 TWM 1090
1500  FORMAT (1H 5E20.6)                                                TWM 1091
1600  I = 1                                                             TWM 1092
1605  MINUT = (IHOUR(I)/100)*60 + MOD(IHOUR(I),100)                     TWM 1093
      IF (FLOAT(MINUT)+SCRAP(I)) 1710, 1710, 1610                       TWM 1094
1610  IF (SAVE1 + SCRAP(I)) 1705, 1705, 1620                            TWM 1095
1620  ISTART = LMINUT + 1                                               TWM 1096
      L = 0                                                             TWM 1097
      X = FLOAT(MINUT - LMINUT)                                         TWM 1098
      IF (X) 1330, 1705, 1650                                           TWM 1099
1650  CONTINUE                                                          TWM 1100
      DO 1700 K = ISTART, MINUT                                         TWM 1101
      L = L + 1                                                         TWM 1102
      J = K / INCRE + 1                                                 TWM 1103
```

```
 1700 RECORD(J) = RECORD(J) + ((SCRAP(I) - SAVE1)*FLOAT(L)/X + SAVE1)/   TWM 1104
     1        DELT                                                       TWM 1105
 1705 SAVE1 = SCRAP(I)                                                   TWM 1106
      LMINUT = MINUT                                                     TWM 1107
 1710 I = I + 1                                                          TWM 1108
      IF (I-N) 1605, 1605, 1030                                          TWM 1109
      END                                                                TWM 1110
```

```
     VARIABLE                      INDEX STATEMENT NUMBER


 CALL         73,

 COMMON        2,

 DATA          5,

 DATAIN        1,

 DELT         10,    63,    67,    72,   119,

 DO            7,    25,    34,    40,    53,    90,    94,   116,

 EXIT         73,

 FLOAT        10,    48,    63,    67,   109,   113,   119,

 GO           58,    66,    70,   101,   106,

 H             5,

 I             7,     8,    13,    13,    16,    16,    16,    25,
              26,    34,    35,    35,    40,    41,    42,    42,
              44,    45,    45,    48,    48,    53,    54,    54,
              55,    63,    67,    71,    71,    72,    78,    78,
              90,    91,    93,   102,   107,   108,   108,   109,
             110,   119,   120,   122,   122,   123,

 IA           19,    19,    21,    21,    82,    82,    96,    96,
              98,    98,

 IDAY         16,    17,    32,    71,

 IDAYS         1,    28,    84,

 IF           12,    17,    20,    28,    29,    31,    33,    37,
```

```
                38,     41,     42,     46,     47,     55,     60,     61,
                79,     80,     81,     84,     87,     92,     97,    109,
               110,    114,    123,

IFLAG            1,     20,     97,

IHOUR            2,     16,     42,     42,     45,     45,     54,     54,
                71,     91,    102,    108,    108,

II              94,     95,

IMONTH          16,     29,     71,

INCRE            1,      6,     10,     19,     21,     57,     59,     62,
                82,     96,     98,    118,

IRECOD           1,     12,

ISIZE            6,     19,     21,     82,     94,     96,     98,

ISTART         111,    116,

IYEAR           16,     71,     78,

J               59,     60,     61,     67,     67,     71,    118,    119,
               119,

JDAY            11,     17,     19,     21,     22,     22,     28,     32,
                71,     81,     82,     83,     83,     84,     91,     92,
                96,     98,    100,    100,    102,

JINCRE          78,

JMINUT          56,     63,     64,     67,     68,     71,

JMONTH          78,     79,
```

```
JSAVE         57,     60,     61,     62,     63,     63,     65,     65,
              71,

JSEGMT        78,     80,

JSIZE         78,

K            116,    118,

KDAY          78,     81,

KSEGMT         1,     12,     19,     21,     82,     96,     98,

L            112,    117,    117,    119,

LMINUT        14,     23,     46,     48,     49,     71,    111,    113,
             121,

MASS           1,     37,

MAT            2,     13,     16,

MDF           16,     31,

MDFSM          5,     31,

MINUT         45,     46,     48,     49,     54,     56,     57,     59,
              67,     68,     71,    108,    109,    113,    116,    121,

MM            86,     87,

MOD           45,     54,    108,

MONTH          1,     19,     21,     29,     79,     82,     96,     98,

N             13,     16,     34,     40,     53,     71,     90,    123,
```

```
NMINUT      62,     63,     64,     71,
NN          75,     76,     87,
NYEAR        1,     19,     21,     82,     96,     98,
PRINT       71,     72,
READ        13,     16,     78,     86,
RECOD       80,
RECORD       1,      3,      8,     19,     21,     26,     63,     63,
            67,     67,     78,     82,     95,     96,     98,    119,
           119,
RETURN      30,     89,
REWIND      77,     85,
SAVE        44,     47,     50,     72,
SAVE1       15,     24,     39,     48,     50,     72,    110,    119,
           119,    120,
SCRAP        2,     16,     35,     35,     38,     44,     48,     48,
            55,     63,     67,     72,     93,    109,    110,    119,
           120,
TO          58,     66,     70,    101,    106,
TRS          2,
UNIT        13,     33,     35,     72,     93,
WRITE       19,     21,     76,     82,     96,     98,
```

X 93, 95, 113, 114, 119,

```
      SUBROUTINE DATAMG (RECORD,IPREC,WFSG,IDAYS,MONTH,JYR,KSEGMT)      TWM 1111
      DIMENSION RECORD(1440)                                            TWM 1112
      COMMON MAT(16),SCRAP(31),IHOUR(15),TRS(1440)                      TWM 1113
      REWIND 1                                                          TWM 1114
      READ 200, LOOK,(MAT(I),I=1,16)                                    TWM 1115
      READ MAT, (SCRAP(I),I=1,IDAYS)                                    TWM 1116
      DO 10 I=1,IDAYS                                                   TWM 1117
      BACKSPACE 3                                                       TWM 1118
10    CONTINUE                                                          TWM 1119
      READ (3) MONTH1,IDAY1,IYR1,JSEGMT,JRINT,JSIZE,(RECORD(I),I=1,1440)TWM 1120
C***********************************************************************TWM
C       MERGE RECORD FROM MIDNIGHT OF FIRST TO OBSERVATION TIME ON      TWM
C             FIRST                                                     TWM
C***********************************************************************TWM
      LOOK=(LOOK/100)*60+MOD(LOOK,100)                                  TWM 1121
      K=LOOK/IPREC                                                      TWM 1122
      J=K+1                                                             TWM 1123
      SUM=0.                                                            TWM 1124
      DO 20 I=1,K                                                       TWM 1125
      SUM=SUM+RECORD(I)                                                 TWM 1126
20    CONTINUE                                                          TWM 1127
      IF (SUM-.0001) 50,50,30                                           TWM 1128
30    SUM=(SUM*FLOAT(IPREC)/60)                                         TWM 1129
      X=(SCRAP(1)/SUM-1.)*WFSG+1.                                       TWM 1130
      DO 40 I=1,K                                                       TWM 1131
      RECORD(I)=RECORD(I)*X                                             TWM 1132
40    CONTINUE                                                          TWM 1133
C***********************************************************************TWM
C        MERGE RECORD FROM OBSERVATION TIME ON FIRST DAY THROUGH        TWM
C             OBSERVATION TIME ON LAST DAY.                             TWM
C***********************************************************************TWM
50    K=1440/IPREC                                                      TWM 1134
      NEXT1=IDAYS-1                                                     TWM 1135
      DO 130 I=2,NEXT1                                                  TWM 1136
      READ (3) MONTH1,IDAY1,IYR1,JSEGMT,JRINT,JSIZE,(TRS(IA),IA=1,1440) TWM 1137
      SUM=0.                                                            TWM 1138
```

```
      L=J-1                                                             TWM 1139
      DO 60 M=J,K                                                       TWM 1140
      SUM=SUM+RECORD(M)                                                 TWM 1141
60    CONTINUE                                                          TWM 1142
      DO 70 M=1,L                                                       TWM 1143
      SUM=SUM+TRS(M)                                                    TWM 1144
70    CONTINUE                                                          TWM 1145
      IF (SUM-.0001) 110,110,80                                         TWM 1146
80    SUM=(SUM*FLOAT(IPREC)/60)                                         TWM 1147
      X=(SCRAP(I)/SUM-1.)*WFSG+1.                                       TWM 1148
      DO 90 M=J,K                                                       TWM 1149
      RECORD(M)=RECORD(M)*X                                             TWM 1150
90    CONTINUE                                                          TWM 1151
      DO 100 M=1,L                                                      TWM 1152
      TRS(M)=TRS(M)*X                                                   TWM 1153
100   CONTINUE                                                          TWM 1154
110   IB=I-1                                                            TWM 1155
      WRITE (1) MONTH,IB,JYR,KSEGMT,IPREC,K,(RECORD(IA),IA=1,1440)      TWM 1156
      DO 120 M=J,K                                                      TWM 1157
      RECORD(M-J+1)=TRS(M)                                              TWM 1158
120   CONTINUE                                                          TWM 1159
130   CONTINUE                                                          TWM 1160
C***********************************************************************TWM
C        MERGE RECORD FROM OBSERVATION TIME ON LAST DAY TO MIDNIGHT ON  TWM
C             LAST DAY.                                                 TWM
C***********************************************************************TWM
      SUM=0.                                                            TWM 1161
      DO 140 I=J,K                                                      TWM 1162
      SUM=SUM+RECORD(I)                                                 TWM 1163
140   CONTINUE                                                          TWM 1164
      IF (SUM-.0001) 170,170,150                                        TWM 1165
150   SUM=(SUM*FLOAT(IPREC)/60)                                         TWM 1166
      X=(SCRAP(IDAYS)/SUM-1.)*WFSG+1.                                   TWM 1167
      DO 160 I=J,L                                                      TWM 1168
      RECORD(I)=RECORD(I)*X                                             TWM 1169
160   CONTINUE                                                          TWM 1170
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```
 170   WRITE (1) MONTH,IDAYS,JYR,KSEGMT,IPREC,K,(RECORD(IA),IA=1,1440)    TWM 1171
       REWIND 1                                                           TWM 1172
       DO 180 I=1,IDAYS                                                   TWM 1173
       BACKSPACE 3                                                        TWM 1174
 180   CONTINUE                                                           TWM 1175
       DO 190 I=1,IDAYS                                                   TWM 1176
       READ (1) MONTH,IDAYS,JYR,KSEGMT,IPREC,K,(RECORD(IA),IA=1,1440)     TWM 1177
       WRITE (3) MONTH,IDAYS,JYR,KSEGMT,IPREC,K,(RECORD(IA),IA=1,1440)    TWM 1178
 190   CONTINUE                                                           TWM 1179
       RETURN                                                             TWM 1180
C                                                                         TWM
 200   FORMAT (I4,16A4)                                                   TWM 1181
       END                                                                TWM 1182
```

```
     VARIABLE                        INDEX STATEMENT NUMBER


 COMMON         3,

 DATAMG         1,

 DO             7,       15,      21,      26,      30,      33,      39,      42,
               47,       52,      58,      63,      66,

 FLOAT         19,       37,      56,

 I              5,        5,       6,       6,       7,      10,      10,      15,
               16,       21,      22,      22,      26,      38,      45,      52,
               53,       58,      59,      59,      63,      66,

 IA            27,       27,      46,      46,      61,      61,      67,      67,
               68,       68,

 IB            45,       46,

 IDAYS          1,        6,       7,      25,      57,      61,      63,      66,
               67,       68,

 IDAY1         10,       27,

 IF            18,       36,      55,

 IHOUR          3,

 IPREC          1,       12,      19,      24,      37,      46,      56,      61,
               67,       68,

 IYR1          10,       27,

 J             13,       29,      30,      39,      47,      48,      52,      58,

 JRINT         10,       27,
```

```
JSEGMT     10,   27,
JSIZE      10,   27,
JYR         1,   46,   61,   67,   68,
K          12,   13,   15,   21,   24,   30,   39,   46,
           47,   52,   61,   67,   68,
KSEGMT      1,   46,   61,   67,   68,
L          29,   33,   42,   58,
LOOK        5,   11,   11,   11,   12,
M          30,   31,   33,   34,   39,   40,   40,   42,
           43,   43,   47,   48,   48,
MAT         3,    5,    6,
MOD        11,
MONTH       1,   46,   61,   67,   68,
MONTH1     10,   27,
NEXT1      25,   26,
READ        5,    6,   10,   27,   67,
RECORD      1,    2,   10,   16,   22,   22,   31,   40,
           40,   46,   48,   53,   59,   59,   61,   67,
           68,
RETURN     71,
```

```
REWIND       4,    62,
SCRAP        3,     6,    20,    38,    57,
SUM         14,    16,    16,    18,    19,    19,    20,    28,
            31,    31,    34,    34,    36,    37,    37,    38,
            51,    53,    53,    55,    56,    56,    57,
TRS          3,    27,    34,    43,    43,    48,
WFSG         1,    20,    38,    57,
WRITE       46,    61,    68,
X           20,    22,    38,    40,    43,    57,    59,
```

```
      SUBROUTINE SHIFTT (JRINT,LRINT,REC1)                              TWM 1183
      DIMENSION REC1(1440)                                              TWM 1184
      COMMON MAT(16),SCRAP(31),IHOUR(15),TRS(1440)                      TWM 1185
C***********************************************************************TWM
C              SHIFTT CHANGES THE DATA IN REC1 FROM A TIME RASE OF LRINTTWM
C             MINUTES TO JRINT MINUTES.  TRS IS USES AS A SCRATCH ARRAY TWM
C        THE DATA IS IN REC1 , AND WILL BE RETURNED IN REC1.            TWM
C***********************************************************************TWM
      DO 10 I=1,1440                                                    TWM 1186
      TRS(I)=REC1(I)                                                    TWM 1187
      REC1(I)=0.                                                        TWM 1188
10    CONTINUE                                                          TWM 1189
      L=1                                                               TWM 1190
      J=1                                                               TWM 1191
      LTIME=LRINT                                                       TWM 1192
      JTIME=JRINT                                                       TWM 1193
20    IF (LTIME-JTIME) 30,50,40                                         TWM 1194
30    LTIME=LTIME+LRINT                                                 TWM 1195
      GO TO 20                                                          TWM 1196
40    JTIME=JTIME+JRINT                                                 TWM 1197
      GO TO 20                                                          TWM 1198
50    ICYCLE=LTIME/MIN0(JRINT,LRINT)                                    TWM 1199
      IC=(1440/LTIME)                                                   TWM 1200
C***********************************************************************TWM
C     C       IC IS THE NUMBER OF CYCLES IN THE DAY  , WHERE A CYCLE IS TWM
C          SHORTEST PERIOD FOR WHICH A*JRINT = R*IRINT(ISEG) FOR A AND BTWM
C          BOTH INTEGERS,                                               TWM
C***********************************************************************TWM
      IB=LRINT/JRINT                                                    TWM 1201
      IF (IB-1) 120,60,60                                               TWM 1202
C***********************************************************************TWM
C        CONDENSE RECORD   TO SHORTER TIME BASE                         TWM
C***********************************************************************TWM
60    J=1                                                               TWM 1203
      JTIME=JRINT                                                       TWM 1204
      DO 110 IA=1,IC                                                    TWM 1205
```

```
      LTIME=JTIME-JRINT+LRINT                                           TWM 1206
      L=LTIME/LRINT                                                     TWM 1207
      DO 100 ID=1,ICYCLE                                                TWM 1208
      IF (JTIME-LTIME) 70,70,80                                         TWM 1209
70    REC1(J)=REC1(J)+TRS(L)                                            TWM 1210
      GO TO 90                                                          TWM 1211
80    REC1(J)=REC1(J)+FLOAT(LTIME-JTIME+JRINT)/FLOAT(JRINT)*TRS(L)      TWM 1212
      REC1(J)=REC1(J)+FLOAT(JTIME-LTIME)/FLOAT(JRINT)*TRS(L+1)          TWM 1213
      L=L+1                                                             TWM 1214
      LTIME=LTIME+LRINT                                                 TWM 1215
90    J=J+1                                                             TWM 1216
      JTIME=JTIME+JRINT                                                 TWM 1217
100   CONTINUE                                                          TWM 1218
110   CONTINUE                                                          TWM 1219
      RETURN                                                            TWM 1220
C***********************************************************************TWM
C        EXPAND RECORD TO LONGER TIME BASE                              TWM
C***********************************************************************TWM
120   L=1                                                               TWM 1221
      LTIME=LRINT                                                       TWM 1222
      DO 170 IA=1,IC                                                    TWM 1223
      JTIME=LTIME-LRINT+JRINT                                           TWM 1224
      J=JTIME/JRINT                                                     TWM 1225
      DO 170 ID=1,ICYCLE                                                TWM 1226
      IF (LTIME-JTIME) 130,140,150                                      TWM 1227
130   REC1(J)=REC1(J)+FLOAT(LTIME-JTIME+JRINT)/FLOAT(JRINT)*TRS(L)      TWM 1228
      GO TO 160                                                         TWM 1229
140   REC1(J)=REC1(J)+FLOAT(LRINT)/FLOAT(JRINT)*TRS(L)                  TWM 1230
      GO TO 160                                                         TWM 1231
150   REC1(J)=REC1(J)+FLOAT(JTIME-LTIME+LRINT)/FLOAT(JRINT)*TRS(L)      TWM 1232
      REC1(J+1)=REC1(J+1)+FLOAT(LTIME-JTIME)/FLOAT(JRINT)*TRS(L)        TWM 1233
      J=J+1                                                             TWM 1234
      JTIME=JTIME+JRINT                                                 TWM 1235
160   L=L+1                                                             TWM 1236
      LTIME=LTIME+LRINT                                                 TWM 1237
170   CONTINUE                                                          TWM 1238
```

```
      RETURN                                                            TWM 1239
      END                                                               TWM 1240
```

```
VARIABLE                    INDEX STATEMENT NUMBER

COMMON       3,

DO           4,    23,    26,    41,    44,

FLOAT       30,    30,    31,    31,    46,    46,    48,    48,
            50,    50,    51,    51,

GO          14,    16,    29,    47,    49,

I            4,     5,     5,     6,

IA          23,    41,

IB          19,    20,

IC          18,    23,    41,

ICYCLE      17,    26,    44,

ID          26,    44,

IF          12,    20,    27,    45,

IHOUR        3,

J            9,    21,    28,    28,    30,    30,    31,    31,
            34,    34,    43,    46,    46,    48,    48,    50,
            50,    51,    51,    52,    52,

JRINT        1,    11,    15,    17,    19,    22,    24,    30,
            30,    31,    35,    42,    43,    46,    46,    48,
            50,    51,    53,

JTIME       11,    12,    15,    15,    22,    24,    27,    30,
            31,    35,    35,    42,    43,    45,    46,    50,
```

```
                      51,     53,     53,

          L            8,     25,     28,     30,     31,     32,     32,     39,
                      46,     48,     50,     51,     54,     54,

          LRINT        1,     10,     13,     17,     19,     24,     25,     33,
                      40,     42,     48,     50,     55,

          LTIME       10,     12,     13,     13,     17,     18,     24,     25,
                      27,     30,     31,     33,     33,     40,     42,     45,
                      46,     50,     51,     55,     55,

          MAT          3,

          MINO        17,

          REC1         1,      2,      5,      6,     28,     28,     30,     30,
                      31,     31,     46,     46,     48,     48,     50,     50,
                      51,     51,

          RETURN      38,     57,

          SCRAP        3,

          SHIFTT       1,

          TO          14,     16,     29,     47,     49,

          TRS          3,      5,     28,     30,     31,     46,     48,     50,
                      51,
ERROR IN I/O FROM COOP
```

```
      SUBROUTINE TAPCHK(IDAY,IDAY1,MONTH,MONTH1,JYR,JYR1,MSG)           TWM 1242
      IF (IDAY-IDAY1) 50, 10, 50                                        TWM 1243
   10 IF (MONTH - MONTH1) 50, 20, 50                                    TWM 1244
   20 IF (JYR - JYR1) 50, 30, 50                                        TWM 1245
   30 RETURN                                                            TWM 1246
   40 FORMAT (1H011HINSTEAD OF I2,1H/I2,1H/I2,6H READ I2,1H/I2,1H/I2,10XTWM 1247
     1,8HMESSAGE I3)                                                    TWM 1248
   50 PRINT 40,IDAY,MONTH,JYR,IDAY1,MONTH1,JYR1,MSG                     TWM 1249
      CALL EXIT                                                         TWM 1250
      END                                                               TWM 1251
```

```
        VARIABLE                      INDEX STATEMENT NUMBER


CALL         8,

EXIT         8,

IDAY         1,       2,       7,

IDAY1        1,       2,       7,

IF           2,       3,       4,

JYR          1,       4,       7,

JYR1         1,       4,       7,

MONTH        1,       3,       7,

MONTH1       1,       3,       7,

MSG          1,       7,

PRINT        7,

RETURN       6,

TAPCHK       1,
```

INPUT CARDS

Card Number	Variables	Format	Comment Code
1	ISEGMT, ITAPE, IYR, LRY, MASS	5I4	
2A, 2B.....	JPREC(1, 2,...ISEGMT)	20I4	
3A, 3B,....	IRECOD(1, 2,...ISEGMT)	20I4	a
4	ISTGAG, KSEGMT, WFSG	2I4, F4.3	a
5	N, UNIT, MAT(1, 2,...16)	I4, F6.0, 16A4	a, b
6A, 6B,....	IYEAR, IMONTH, IDAY, IHOUR(1), SCRAP(1), IHOUR(2), SCRAP(2) ...IHOUR(N), SCRAP(N), MDF	MAT	a, b
7	blank card to terminate Card 6 series		a, b
8	LOOK, MAT(1, 2,...16)	I4, 16A4	a, c
9A, 9B,....	SCRAP(1, 2,...IDAYS)	MAT	a, c
10	JRINT	I4	a, d
11	N, UNIT, MAT(1, 2,...16)	I4, F6.0, 16A4	a, b, d
12A, 12B...	IYEAR, IMONTH, IDAY, IHOUR(1), SCRAP(1), IHOUR(2), SCRAP(2) ...IHOUR(N), SCRAP(N), MDF	MAT	a, b, d
13	blank card to terminate Card 12 series		a, b, d
14	IRUN	I4	
15	XLAT, XLONG, CORTZ	3F10.0	
16	SCRAP(2, 3,...13)	12F6.0	e
17	TRANPO(1, 2,...12)	12F6.0	e

Card Number	Variables	Format	Comment Code
18	NEWVAL(1, 2,...12)	12I4	k
19	KSEGMT, KRINT, ISEG1, ISEG2, NRELEM, LAG, C(1, 2,... NRELEM)	I2, I4, 2(I2, 4X), I2, I4, 14F4.0	
20	PANFAC, ALPHA, RTZONE	3F10.0	f
21	IOPT1, IOPT2, IOPT3, IOPT4	5I4	f
22	BASE	F10.0	f, g
23	IFILM	I4	f, h
24	LTR, NAMSEG(1, 2,...19)	I2, 2X, 19A4	f, i
25A	ATOTAL, APERVS, AOLFSF, AOLFDS, DSMAX, VINSTM, DEPTHI, DEPTHU	8F10.0	f
25B	CHANLG, C1, C2, C3, C4, C5, C6, C7	8F10.0	f
25C	C8, C9, C10, C11, C12, C13, C14, C15	8F10.0	f
25D	ROUGH,SLOPE, VLENGH, SATPRM, UZST, VIZST, C16, SMMIN	8F10.0	f
26	TIZS1, BIZS1, OLS1, DS1, UZS1, GWS1, DELIN1, VINST1	8F10.0	f, j

Comments:

a. This card(s) should be omitted if ITAPE = 0

b. This card(s) read by subroutine DATAIN and is repeated for each month

c. This card(s) read by subroutine DATAMG and should be omited when ISTGAG ≥ 0

d. This card(s) should be omitted for IRECOD(KSEGMT) ≥ 0

e. This card contains the monthly pan evaporation

f. Omit for NEWVAL(MONTH) = 0 except for October of the first water year

Comments continued:

g. Omit for IOPT[illegible] ≠ [illegible]

h. Omit for IOPT3 ≠ 1

i. Omit when both IOPT1 and IOPT4 ≠ 1

j. Initial values for each segment

k. NEWVAL must not be zero when more than one segment is involved

PREPARATION OF RAINFALL DATA

Rainfall data may be supplied in either an accumulated amount for the day (as read from a weighing type rain gauge) or in intensity. The parameter MASS, read on card 1 signifies which type record is to be processed:

MASS = 1 for accumulated record

MASS $\neq$ 1 for intensity type record.

The Parameter UNIT, read on card 5 is the constant needed to convert the rainfall record to units of inches per hour. When an accumulated type record is supplied with volume in inches and time in hours and minutes (military time), the value of UNIT is one.

The month, day, and year occupy the first three fields of the precipitation card. The time of the beginning of the precipitation followed by a zero are next. Time of observation and amount of observation alternate until the end of the card is reached. The last column of the card must be read, and must not contain a $ symbol except for cards containing mean daily values (see section on Preparation of Streamflow Data). When a storm cannot be punched on one card, the following card must contain the month, day, and year information. The observation time and amount alternate across the card as for the first card.

When a storm extends past midnight, a value must be supplied at 2400 hours. The following day's amounts should start at zero for weighing type gauges.

A blank card terminates each month's data.

PREPARATION OF STREAMFLOW DATA

Subroutine DATAIN reads both precipitation and streamflow; consequently, the material in the preceeding section is also true for streamflow data. The parameter UNIT is the number needed to convert the input data into units of cubic feet per second.

Mean daily flows may be read in by means of a special symbol, the $ symbol, in the last field of the card. The first three fields must contain the month, the day corresponding to the first mean daily flow on this card, and the year. The remainder of the card to the last field may be filled with the day in the field normally occupied by the time and the day's mean daily flow values in the amount field. If the string of days for which mean daily flows are to be entered exceeds a single card, the next card must contain the same type information as the first. Cards containing mean daily flow and detailed streamflow may be mixed as desired. The special symbol differentiates between the two.

APPENDIX II

GLOSSARY OF MAIN PROGRAM VARIABLES

AD( )	An array containing the apparent declination of the sun
ALPHA	The input variable determining the ability of the soil to deliver moisture to the surface for evaporation
AOLFDS	Area producing overland flow to Depression Storage as a fraction of the total pervious area in the watershed
AOLFSF	Area producing overland flow to stream as a fraction of the total pervious area of the watershed
APERVS	Pervious area as a fraction of the total area in the watershed
ATOTAL	Total area in the watershed, negative if in square miles, positive if in acres
AVABER	Average absolute error
AVGERR	Average error
AVINFL	Average interval flow in inches per time interval
B	A symbol used in the on line plot operation
BASE	The value of stream flow, in c.f.s., below which everything is considered to be base flow; no storm analysis or plots are given for these low flows
BIZS	Bottom Intermediate Zone Storage, in inches
BIZS1	The value of Bottom Intermediate Zone Storage at the beginning of the month
BLANK	A symbol used in the on line plot operation
C( )	An array containing the elements of the time delay histogram
CARRYO(,)	An array containing the flow generated in one month but which occurs as stream flow during the next month
CHANLG	Channel lag, the ratio of this routing interval's flow to the last routing interval's flow

CHNLG( )	An array containing the flow lagged in the channel lagging operation during the last time increment of the day
COEFF	The coefficient of weighted absolute errors
CORRCO	The correlation coefficient for flow on a routing interval time base
CORREC	A correction for the rising and setting of the sun due to the location of the watershed with respect to the principal meridan
CORTZ	A correction for time zone when the basin is in the wrong time zone with respect to the actual location of the time zone boundaries
COSH	The cosine of the angle H in an equation for the rising and setting of the sun taken from page 403, Explanatory Supplement to the Ephemeris
C1, C2	Constants in the infiltration equation
C3, C4, C5	Constants in the equation for determining the unsaturated permeability
C7, C8, C9	Constants in the equation for defining the capillary potential
C10	The fraction of the Top Intermediate Zone which must be filled before transfer to Interflow Storage
C11, C12	Constants in the equation for flow from groundwater to the stream
C13	Constant in the equation for flow from groundwater to underflow
C14, C15	Constants in the equation used to lag flow through Interflow Storage
C16	Constant in the equation for transfer of water from Top Intermediate Zone to Interflow Storage
DAILYF( )	Simulated mean daily flow
DELINF	The volume of water stored in Interflow Storage
DELIN1( )	The volume of water in Interflow Storage at the beginning of the month

DELT	The time, in hours, of the basic operation cycle
DELTA	Angle of declination of the sun used in computing the time of sunrise and sunset, and is computed from AD( )
DEPTHI	Thickness of Intermediate Zone, in feet
DEPTHU	Thickness of Upper Zone, in feet
DS	Depression Storage, in inches
DSMAX	Maximum Depression Storage, in inches
DS1( )	The Depression Storage at the beginning of the month
EOMGW(,)	End of month Groundwater Storage
EOMINC(,)	End of month Interception Storage
EOMINF(,)	End of month Interflow Storage
EOMINT(,)	End of month Intermediate Zone Storage
EOMSUR(,)	End of month Surface Storage, the sum of Overland Flow Storage and Depression Storage
EOMUZ(,)	End of month Upper Zone Storage
ERR	The difference between simulated flow and recorded flow for the time interval
ET	The time of the day when the sun is directly overhead; used in computing sunrise and sunset
EVAPOT	Evaporation potential for period, in inches
EVAP1( )	A constant in a parabolic interpolation equation for evaporation from monthly data
EVAP2( )	See EVAP1( )
EVAP3( )	See EVAP1( )
E1, E2, E3, E4, E5	Constants in evaporation rate equation from van Bavel's data
FLOINT( )	Flow interval used in statistical analysis, based on logarithmic increments

FLOMAX	The maximum flow to be plotted
GWS	Groundwater Storage
GWS1( )	The Groundwater Storage at the beginning of the month
H	One half of the daylight hours, used in computing sunrise and sunset
HOUR	The hour of the day, used in computing the evaporation potential rate
I	An index
IA	An index
IAI	Dummy variable used in place of the day of the month when reading data from tape or disks
IB	An index
ICASE(,)	The number of cases of flow within each class for each segment
IDAY	An index corresponding to days of the month
IDAYS	The number of days in the month being processed
IFILM	A flag used to signal use of film for plotting (IFILM = 1)
IFIRST	A flag used to indicate if the current month is October of the first year (IFIRST = 1)
IFLAG	A flag which is set to 1 if flow above BASE is encountered during the month in the simulated flow
IHOUR( )	An array used to store on a temporary basis the time of occurrence of rainfall and runoff events being read from cards
IHOURS	The time of beginning of runoff from a storm
II	An index
IK	An index
IMIN	The minutes portion of the time

IND	An index used to classify the flow into the proper interval for statistical analysis
INEW, IOLD	Tape or disk numbers, alternates between units 2 and 4
IOPT1	If 1, print out simulated flow on a time base of JRINT for all flows above a base flow, BASE
IOPT2	If 1, print statistical data
IOPT3	If 1, plot storm hydrographs on Calcomp plotter
IOPT4	If 1, plot monthly stream flow
IOPT5	If 1, recorded streamflow available on tape 3
IPREC( )	The time base, in minutes, to be used in preparing the precipitation tape
IR	Variable denoting position of the recorded flow in the on line plot routine
IRECOD( )	A flag indicating whether there is recorded streamflow to read (+, 0, no streamflow data) and whether the rainfall data for this segment has already been read (IRECOD(KSEGMT) = KSEGMT, data not yet read in; IRECOD(KSEGMT) ≠ KSEGMT, data for KSEGMT was read for segment IRECOD(KSEGMT) and is on tape 4)
IRINT	A dummy variable used in place of JRINT when reading tape or disk
IRINT1	The routing interval, in minutes, of the segment just upstream of the segment being processed
IRUN	A flag to indicate if a run is to be made (IRUN = 1)
IS	Variable denoting position of the simulated flow in the on line plot routine
ISCRTH	The scratch tape number, specified as unit 1
ISEGMT	The number of segments to be processed each month
ISEG1	Segment number of upstream segment
ISEG2	Segment number of upstream segment
ISIZE	The number of IPREC time units in the month

ISTGAG	The number of storage gauges in the segment
IT	The time period, in minutes, of the basic cycle
ITAPE	If ITAPE is 1, the precipitation tape is to be prepared
IYR	The first year of the first water year to be processed
J	An index
JAD	An index
JDPM( )	An array containing the days of the months
JDPY	Days per year
JDTD	Days to Date
JFIRST	A dummy variable used to protect the value of KFIRST during the printing of the individual storms
JJ	The number of values of simulated flow to be printed on one line
JPLOT( )	The array used to store the symbols for printing the on line plot
JPREC( )	The time base, in minutes, to be used in preparing the precipitation tape
JRINT	The time period, in minutes, to be used in simulating the streamflow, hence the routing interval
JRINT1	A dummy variable used in place of JRINT when reading tape or disc
JSEGMT	The counter for the number of segments which have been processed
JSIZE	A dummy variable used in place of ISIZE when reading tape or disks
JYR	The year being processed
JYR1	A dummy variable used in place of JYR when reading tape or disks
K	An index

KFIRST	The location in the SIMFLO array of the first element of a string of elements characterized by magnitudes greater than BASE
KSECND	The location of the last element in the string described under KFIRST
KSEGMT	The number of the segment being processed
LAG	The time of flow through the segment in units of JRINT minutes
LINE	The counter of the number of lines printed in the on line plot
LOOP	The number of basic cycles in a day
LTR	The number of letters to be plotted as the name of the segment
LYR	The second year of the last water year to be processed
MASS	Equal 1 if precipitation data is from weighing gauge and hence is in form of sum of rain to date
MAT( )	A variable format used to read in data
MONTH	The month being processed, January equal 1
MONTH1	A dummy variable used in place of MONTH when reading tape or disks
NAMSEG( )	The array containing the name of the segment to be plotted under the plot of stream flow
NEWVAL( )	An array used to control the reading of new data. When NEWVAL is zero for a particular month, the physical parameters from the last month will be used. Can be used only when one segment is being modeled
NRELEM	The number of routing elements, C
OFSAVG	Average Overland Flow Storage for the period
OFSEQU	Equilibrium Overland Flow Storage
OLF	Overland Flow, in inches
OLS	Overland Flow Storage, in inches

OLSI	Overland Flow Storage at beginning of current period, in inches
OLS1( )	Overland Flow Storage at the beginning of the month
PANFAC	A coefficient to be multiplied by the monthly pan evaporation to obtain monthly evaporation potential
POTEVP	The potential evaporation for a day
PREC( )	The array containing the precipitation data, sometimes used for scratch storage
PSI1, PSI2	The capillary potential in the various soil zones
R	The symbol used for recorded flow in the on line plot routine
RAIN	The volume of water falling in the time period, in inches
RECFLO( )	The recorded stream flow, may be any units, convert with UNIT, of the subroutine DATAIN
RO	The volume of runoff generated in the segment during the current time period
ROUGH	Manning's roughness factor for overland flow
RTZONE	The thickness of the root zone in inches
S	The symbol used for simulated flow in the on line plot routine
SABSER(,)	The sum of the absolute value of the error for the segment for the flow interval
SATPRM	The saturated permeability of the soil, in inches per hour
SCRAP( )	An array used for temporary storage when reading data cards
SDAYFL	The volume of runoff for one day, in inches
SEEP	The infiltration volume for the time period in inches
SERRSQ(,)	The sum of the square of the errors for the segment for the flow interval

SEVAP(,)	The sum of the evaporation for the segment for the month, in inches
SGWF(,)	The sum of the groundwater flow for the segment for the month, in inches
SIF(,)	The sum of infiltration for the month, in inches
SIMFLO( )	The volume of stream flow in acre-inches for the time period
SLOPE	The slope of overland flow
SMMIN	The minimum soil moisture for all zones, in inches^3 per inch^3
SOLF(,)	The sum of overland flow for the segment for the month, in inches
SRAIN(,)	The sum of precipitation for the segment for the month, in inches
SSEVAP	A dummy variable used to accumulate the monthly sum of evaporation, and again to accumulate the annual sum of evaporation
SSF( )	Monthly sum of streamflow for the segment, initially in inches, converted to second-feet days, and then to acre-feet
SSGWF	Dummy variable used to accumulate groundwater flow for month and later for year
SSIF	Dummy variable used to accumulate monthly sum and then annual sum of interflow
SSOLF	Dummy variable used to accumulate monthly sum and then annual sum of overland flow
SSRAIN	Dummy variable used to accumulate monthly sum and then annual sum of precititation
SSSF	Dummy variable used to accumulate monthly sum and then annual sum of stream flow
SSUF	Dummy variable used to accumulate monthly sum and then annual sum of underflow
STDERR	Standard error of estimate of the simulated flow

SUF(,)	The monthly sum of underflow for the segment
SUMERR(,)	The sum of the error for the segment for the flow interval
SUMX( )	The sum of the simulated flow for the segment for the year
SUMY( )	The sum of the recorded flow for the segment for the year
SWEIFL( )	Sum of the weighted absolute error for the segment for the year
TB	The time of beginning of evaporation, in hours
TE	The time of ending of evaporation, in hours
TM	The time of maximum evaporation, in hours
TIZS	Top Intermediate Zone Storage, in inches
TIZS1( )	The Top Intermediate Zone Storage at the beginning of the month, in inches
TRANPO( )	The difference between pan evaporation and consumptive use for each month
TRS( )	A scratch array used at various parts of the program to hold precipitation or streamflow data temporarily
UNDFLO	Accumulator for water assigned to underflow
UZMIN	Minimum moisture in Upper Zone Storage, in inches
UZD	Upper Zone Storage, in inches
UZST	The total Upper Zone Storage available, in inches
UZS1( )	The Upper Zone Storage at the beginning of the month, in inches
VINFLO	The volume of water transferred from Intermediate Zone Storage to Interflow Storage in any time period, in inches
VINSTG	Interception Storage, in inches
VINSTM	Maximum Interception Storage, in inches

VINST1( )	Interception storage at the beginning of the month, in inches
VIZMIN	Minimum Moisture in either half of Intermediate Zone, in inches
VIZST	Maximum intermediate Zone Storage, in inches
VLENGH	The length of overland flow, in feet
WEIGH( )	The weighting factors assigned to each flow interval in the statistical analysis. Defined as the logarithm of the midpoint of the interval plus one
WFSG	Weighting factor for the storage gauge
X	A dummy floating point variable
XK	The unsaturated permeability in the various soil zones, in inches per hour
XLAT	The latitude of the basin, in degrees
XLONG	The longnitude of the basin, in degrees
XTCKS	The spacing of tick marks on the time axis of the plot (Calcomp plot routine)
XP	One of the scale values printed on the on line plot
XX( )	The sum of the square of the simulated stream flow
XY( )	The sum of the product of the simulated stream flow and the measured flow
X1	The volume of rain reaching the two areas producing overland flow; the accumulator for individual storm simulated flow
X11	The accumulator for the monthly simulated flow
X12	The accumulator for the monthly recorded flow
X2	The accumulator for the individual storm recorded flow
X4	A dummy floating point variable
Y	A dummy floating point variable

YESDAY	The value of the lagged portion of the streamflow generated during the last time increment of the previous day
YP	One of the scale values printed on the on line plot
YY( )	The sum of the square of the measured stream flow
Y1	A factor used in converting inches per time period to c.f.s.
ZP	One of the scale values printed on the one line plot

VITA

Billy Joe Claborn was born in Brown County, Texas, on June 17, 1930, the son of Pearl Leona Chambers Claborn and Garnet Weldon Claborn. Upon completion of his work at Leverett's Chapel High School, Overton, Texas, in 1948, he studied for one year at Draughon's Business College in Dallas, Texas. He spent his freshman year at East Texas State Teachers College, and was drafted into the Army in February, 1951, after completing one semester of work at Kilgore Junior College. Discharged in February 1953, he entered Texas Technological College that fall, and received a Bachelor of Science in Civil Engineering in May, 1956. He married Nancy Ann Keele in 1954. Following a summer of employment with the City of Lubbock, he entered Stanford University in the fall of 1956 and received a Master of Science degree in June, 1957. Employment with Kern County Land Company in Bakersfield, California, was accepted following graduation from Stanford and continued until 1961. During this period two sons were born, Garnett Weldon II, and Forrest Jay. The next two years were spent in Denver, Colorado, in the employ of Tipton and Kalmbach, Inc., Consulting Engineers. During this period a third son, Mitchell Lee, was born. Appointment to the faculty of Texas Technological College, School of Engineering, Department of Civil Engineering with the rank of Assistant Professor became effective September, 1963. A leave of absence was obtained for the academic years 1966-67, 1967-68 to pursue the doctoral degree at The University of Texas at Austin. Course work was completed during this two year period. A daughter, Alison Jane was added to the family. Teaching duties at Texas

Technological College were resumed in September, 1968, with the rank of Associate Professor. Publications consists of the following:

"Testing and Maintaining Deep Wells" with Mel Jans. Presented at Northwest Well Drillers Association Meeting, 1959.

"Tolerable Water Shortages During Droughts for Various Uses" Texas Water Commission Bulletin 6512, 1965.

"The Stanford Watershed Model as a Tool for Estimating Continuous Streamflow Hydrographs" with Walter L. Moore. Presented at the Spring Meeting Texas Section, American Society of Civil Engineers, Houston, Texas, 1968.

"Application of Continuous Accounting Techniques to Evaluate the Effects of Small Structures on Mukewater Creek, Texas" with Erdal Coskun and Walter L. Moore. Presented at the Conference on The Effects of Watershed Changes on Streamflow, Austin, Texas, 1968.

"Numerical Simulation of Watersheds Using Physical Soil Parameters" with Walter L. Moore. Presented at the Thirteenth Congress of the International Association of Hydraulic Research, Kyoto, Japan, 1969.

"Numerical Model of the Ogallala as a Management Tool" with T. Al Austin and D. M. Wells. Presented at the Ogallala Aquifer Symposium at Lubbock, Texas, 1970.

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