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Simulation modeling of erosion processes on small agricultural watersheds

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SIMULATION MODELING OF EROSION PROCESSES ON SMALL AGRICULTURAL WATERSHEDS

Iowa State University PH.D. 1980

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Simulation modeling of erosion processes on small agricultural watersheds

by

Ebrahim Shahghasemi

A Dissertation Submitted to the
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DOCTOR OF PHILOSOPHY

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Iowa State University
Ames, Iowa

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INTRODUCTION

One of the basic problems facing the world is the pressure of an increasing population with higher living standards on land resources. Not only the availability of land resources, but also the quality of the environment is a major public concern. In recent years, sediment has been recognized as the major water pollutant in rural areas. In general, soil erosion diminishes the fertility and aesthetic quality of the land, while sedimentation degrades the quality of streams.

The effects of loss of soil by erosion are discussed by Beasley (1972). Erosion reduces the production potential by removing the nutrients needed for crop production, reduces the quality of crop produced, reduces the quality of water by increasing turbidity and carrying pollutants like nutrients and pesticides, deteriorates the soil structure by deposition, and increases flood hazards by reducing the infiltration rate and water holding capacity of the soil.

Sedimentation reduces the capacity of downstream channels and reservoirs, reduces value of land and streams for wildlife habitat and recreation, reduces the potential for water power, reduces the carrying capacity of irrigation and drainage systems, increases cost of maintaining navigable channels and harbors, increases cost of maintaining irrigation and drainage systems, roads, and highways, and increases damage to flooded cities and homes.

The loss of an estimated 4 billion tons of soil from land in the United States each year affects many people, but primarily the land owners. It is estimated that 3 billion tons of this total are lost from agricultural and forested land (Beasley, 1972). Increased export demands for farm products brought many stabilized acres back into cultivation (Wischmeier, 1977). Mining and construction activities have been accelerated to meet increasing needs.

Recent developments in the field of agricultural technology have intensified erosion hazards and have made some previously effective control practices less acceptable. Tractor power increased, farm and construction equipment became larger, and sod based rotation was replaced by single crop farming. Due to these activities, productivity of the soil, vital to human existence, is depleted. It seems relevant to mention the statement by Carter and Dale (1974) which says "One man has given a brief outline of history by saying that civilized man has marched across the face of the earth and left a desert in his footprint...."

Development and application of erosion control techniques in the United States in the past few decades have successfully reduced erosion on much of the cropland and nonagricultural lands. However, erosion and sediment are still major national problems (Wischmeier, 1977).

Recent research in erosion and sediment transport has helped to narrow the gap that has existed between the information needed and that which is available for use by planning agencies, regulatory groups, and researchers. Rapidly expanding interest in water quality control brought new dimensions to erosion control objectives and soil loss predictions. Additional research in erosion and sediment transport has achieved high priority because of recent congressional legislation which requires the protection and improvement of the nation's water quality. In an effort to control and regulate nonpoint sources of pollution, section 208 of this law (PL 92-500) requires a measurement of the source and amount of sediment by land use and an evaluation of the integrated effects of a mix of land use activities on water quality (Ross and Contractor, 1978).

At the National Conference on Soil Erosion, Wischmeier (1977) stated

> "Agriculturalists recognized the need for environmental protection long before the term became widely popular. Between the early 1930s and mid-1950s, the United States Department of Agriculture, in cooperation with land grant colleges, established erosion research stations at 48 locations in 26 states. Researchers at these stations studied and quantified effects of topography, crop systems, various management techniques, and potential erosion control practices by measuring runoff and soil losses from experimental field plots and small single-crop watersheds under natural rain...."

Research accelerated after 1960 by making use of rainfall simulators. One valuable outcome of these activities is the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1965). The main attributes of the equation are its simplicity and its broad data base of more than 10,000 plot years of data from natural runoff plots and the equivalent of 1,000 plot years of rainfall simulator data (Foster, 1978). The equation was originally developed as a tool for soil conservation technicians to use to develop farm management plans for erosion control. Related uses for which the equation and factor-value charts are specifically designed include: quantitatively estimating the long-term soil loss from a particular field or construction area, estimating the reduction in soil loss attainable from various changes that a farmer might make in his crop system or cultural practices, and determining how much more intensively a given field could be safely cropped if contoured and terraced or strip cropped (Wischmeier, 1977).

Because of the limitations involved with use of the USLE in predicting short-term sediment yield, as from an individual rainstorm, basic mathematical models are being developed that combine fundamental principles, concepts, and relationships of erosion mechanics, hydrology, hydraulics, soil science, and meteorology to simulate the erosion and sedimentation processes. Substantial progress has been made in developing models capable of predicting spatial and temporal variations in erosion and sedimentation. To the extent that these simulation models reflect direct and interacting effects of more of the uncontrolled and secondary variables, they will enhance analysis of erosion systems and control practices (Wischmeier, 1977). These models have not become field operational because additional research is needed to bridge certain information gaps. However, they have already improved the understanding of erosion processes, helped explain some of the seeming inconsistencies in field-plot data, and improved the accuracy of some factor evaluations for the USLE. This study uses the basic principles and relationships of erosion mechanics and tests the applicability of these concepts on a field basis.

OBJECTIVES

The general objective of this study is to develop a deterministic model to simulate the surface runoff and sediment yield from small, single-cropped agricultural watersheds. The water balance model developed by Anderson (1975) is modified to predict rate of surface runoff. A deterministic erosion model is developed to be used with the hydrologic model to simulate erosion and sediment yield.

The specific objectives of this study are:

1) To develop a deterministic erosion model based on principles of erosion mechanics to predict sediment yield from upland areas.

2) To simulate sediment yield from small agricultural watersheds continuously over a growing season and for any individual storm event. To meet the above mentioned objectives, a hydrologic model is required to simulate the factors involved in deterministic modeling of erosion. This requirement dictates the third objective.

3) To modify Anderson's (1975) water balance model, by adding an overland flow routing component to be used for erosion and sediment yield prediction on upland areas.

4) To calibrate the hydrology and erosion model with data from small agricultural watersheds in western Iowa.

5) To test the accuracy of the model with independent data from western Iowa.

LITERATURE REVIEW

Introduction

Sediment yield has been defined as "the total sediment outflow from a watershed or drainage basin measurable at a point of reference and in a specified period of time," ASCE (1970). At present, many sediment yield models are available for use or have been used for various purposes. In general, the models can be grouped into four categories. The first category is composed of models derived from statistical analysis. These are statistically fitted equations relating sediment yield to one or more watershed and climatic factors involved in the process. The second category is developed from modified forms of statistically derived models. These are usually modified forms of the Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1965). The third category is derived from stochastic analysis. In these models, rainfall and runoff are stochastic input to a probabilistic fluvial system, and sediment yield is a stochastic output. The fourth category of models is the deterministic simulation model. These models combine fundamental principles, concepts, and relationships of erosion mechanics, hydrology, hydraulics, soil science, and meteorology to simulate the erosion and sedimentation process. The purpose of this section is to review briefly these approaches to sediment yield prediction.

Sediment yield predictions which utilize models are needed for several purposes. Models are used to extend a short-term sampling program to provide an adequate data base. This is frequently done to predict watershed response to various land use treatment activities. They enable evaluation of the effectiveness of alternative plans on a basin, whether for pollution control, economic analysis, or conservation needs. A third purpose is related to research. Because deterministic modeling is an ordered sequence of steps in time and space representing a complex process, information gaps can be identified. This provides research personnel a framework to define a large research program. Modeling develops an improved understanding of the erosion and sedimentation process, provided good field data are available.

In the available literature, the units of hydrologic and sediment yield components are expressed in different ways. Since a large number of equations are derived empirically, they are not homogenous in dimensions. The nonhomogeneity limits the use of an equation to the same system from which it was originally derived. In this study, in reviewing the literature, the units are expressed as they have been published. The units in the hydrologic model are expressed mainly in the English system. The units in the erosion and sediment yield model are expressed in the metric system. The predicted rainfall intensity, overland flow runoff depth, and velocity from hydrologic model are converted to metric units to be used in the erosion and sediment yield model.

Statistical Approaches to Watershed Sediment Yield

Watershed sediment yield may be defined as the amount of sediment transported per unit of time at a given cross section of a river by runoff from upstream source areas. The sediment yield is dependent on the upstream gross erosion and factors responsible for transport of the eroded material to the downstream point. The ratio of the sediment yield to the gross erosion is expressed by the term, sediment delivery ratio. Statistical models have been used to estimate sediment yield either by computing gross erosion and sediment delivery ratio, or by use of regression equations. These methods will be discussed separately.

Regression models

These models are statistically fitted equations expressing the sediment yield from a watershed as a function of watershed characteristics and climatic factors. The delivery ratio concept is, therefore, incorporated implicitly in the model. They require much data on watershed parameters and on sediment discharge. Consequently, considerable time and expense are needed to collect adequate data. Several empirical formulas have been derived by use of multiple correlation. Some of these models will be presented here.

To estimate probable silting of government-owned ponds and reservoirs in South Dakota, Gottschalk (1946) developed the following equation:

$$S = 0.0573C + 0.0029A + 0.0125D + 0.2283T - 2.1194 \qquad 1$$

where S = total sediment accumulation, acre-ft

C = capacity of pond or reservoir, acre-ft

A = net drainage area, acres

D = drainage density, ft/acre

T = age, years.

In the same study, Gottschalk (1946) substituted precipitation for age and an equally good correlation was obtained. In this case, the formula developed was:

$$S = 0.0570C + 0.0029A + 0.0124D + 0.0176P - 2.6494. \qquad 2$$

The formula accounted for 89 percent of variability in sedimentation.

Another equation was developed by Anderson (1949) to relate reservoir sedimentation to characteristics of forest cover watersheds in southern California. The relationship is:

$$\text{Log } e_D = 1.041 + 0.866 \log q + 0.370 \log A_{CH} - 1.236 \log C \qquad 3$$

where e_D = annual sediment accumulation, ac-ft/sq mi

q = maximum yearly peak discharge, cfs/sq mi

A_{CH} = area of main channel of the watershed, ac/sq mi

C = cover density on the watershed, percent.

In this formula, the multiple correlation coefficient, R, was 0.953.

Gottschalk and Brune (1950) developed the following equation for estimating sedimentation rates needed for design of small detention and desilting reservoirs in the Missouri Basin Loess Hills of western Iowa. The watersheds ranged from 0.038 to 41.3 square miles in area and represented a variety of land use, land management, and slope conditions. The model developed was:

$$\text{Log } S = 0.7664 \log 100W + 0.7867 \log T + 1.0545 \log E + 0.3701 \log C_T/W - 2.9127 \qquad 4$$

where S = total sediment accumulation in the reservoir, tons

W = net watershed area, sq mi

T = age, years

E = rate of gross erosion, tons/sq mi/yr

C_T/W = capacity - watershed ratio of combined flood and conservation storage, ac-ft/sq mi of drainage area.

The variable E (rate of gross erosion) included in this equation represents the annual rate of sheet, gully, channel, and other erosion processes in the watersheds. The standard deviation of the above formula is ± 0.124 log units, and the multiple correlation coefficient, R, is 0.967.

Another equation was developed by Glymph *et al.* (1951) and cited in Glymph (1954) for estimating the annual sediment yield from watersheds in eastern Nebraska. Their study included records of 36 watersheds varying in size from 0.036 to 2,800 square miles. Statistical analysis of the data indicated that the following formula for estimating annual sediment yield was the best:

$$\text{Log } S = 1.0078 \log E + 0.6460 \log 10N - 0.1354 \log 100W - 1.4130 \qquad 5$$

where S = sediment yield tons/sq mi/yr

E = gross erosion, tons/sq mi/yr

N = number of rainfall events, average annual number of events equal to or exceeding one inch per day during the growing season, April 1 to October 15

W = net drainage area, sq mi.

The standard deviation was ± 0.141 log units, and the multiple correlation coefficient, 0.907.

Maner and Barnes (1953), using statistical analysis, developed a relationship between annual sheet erosion and annual sediment yield in the Texas Blackland Prairies. The relationship is:

$$\text{Log } S = 0.9898 \log E - 0.1407 \log W - 0.2400 \qquad 6$$

where S = sediment yield, tons/sq mi/yr

E = gross erosion, tons/sq mi/yr

W = drainage area, sq mi.

The standard deviation in the above equation was ± 0.053 log units, the multiple correlation coefficient, 0.963.

Another equation was developed by Kohler and cited in Glymph (1954) which utilized sediment yield records from several sources, including field size watersheds at Clarinda, Iowa, and Bethany, Missouri, and data from selected reservoir sedimentation surveys. The following relationship was established by regression analysis:

$$\begin{aligned}\text{Log } T = {} & 3.0858 \log N + 1.8896 \log 100\,Q + 0.7029 \log E \\ & + 0.0908 \log P - 0.013 \log 1000\,A - 0.0563 \\ & \log S - 4.6646\end{aligned} \qquad 7$$

where T = sediment yield, tons/sq mi/yr

N = number of rainfall events per year equal to or greater than one inch per day during the growing season

Q = average annual runoff, inches

E = erosion factor

P = precipitation, inches/yr

A = drainage area, sq mi

S = average slope of watershed, percent.

The watersheds ranged in size from 2.5 to 13,700 acres and represented a range in slope, cover, and farming practices. The accuracy of the equation is almost the same as the previously mentioned equations.

Branson and Own (1970) used geometric variables, watershed cover, and hydrologic variables to develop an equation for predicting sediment yields from watersheds near Grand Junction, Colorado. Geomorphic parameters, such as angle of stream junction, mean slope, drainage density, relief ratio, length-width ratio, and watershed area, and percent of bare slope were more highly correlated with sediment yield. A stepwise multiple regression analysis was used to determine which variables had the stronger relationship to sediment yield and is presented in the following equation:

$$y = 40.97\ X_1 + 0.03X_2 - 1.27 \qquad 8$$

where y = estimated sediment yield, acre-ft per sq mi

X_1 = the relief ratio

X_2 = percent bare soil.

The multiple correlation coefficient was 0.86.

This equation explained about 91 percent of variance in average annual sediment yield from 27 watersheds ranging in size from 12 to 54 mi^2 in 10 western states.

Anderson (1976) used data from 48 forested northern California watersheds to devise a regression equation with 34 independent variables. He used the general form of the model:

Reservoir Deposition = f (topography, geology, roads, forest fires, streamflow, precipitation, soil, land sides, and geologic faults).

The data were analyzed by reduced rank principal component techniques. The final regression equation had an R^2 of 0.86.

Herb and Yorke (1976) used similar techniques to predict sediment yield transport from construction sites in the Washington, D.C. area. The computer analysis of various combinations of independent variables produced regression equations of the form:

$$\text{Log } S_L = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3 + \ldots. + b_n X_n \qquad 9$$

where S_L = sediment load

b_o = regression coefficient

b_n = regression coefficient for the corresponding variable X_n.

Each model for an individual situation was analyzed, and the best equations with one, two, three, and four independent variables were selected based on the multiple correlation coefficient and standard error of estimate. Multiple correlation coefficients for regression equations with four independent variables ranged from 0.85 to 0.96 in this study.

Dendy and Bolton (1976) related deposition in about 800 reservoirs to drainage area size and mean annual runoff. Watershed areas ranged from 1 mi^2 to 30,000 mi^2, and runoff ranged from nearly zero to about 50 in/yr. For areas where runoff is less than 2 inches, they derived the equation:

$$S = 1280\ Q^{0.46}\ (1.46 - 0.26 \log A) \qquad 10$$

and for other areas:

$$S = 1958e^{-0.055Q}\ (1.43 - 0.26 \log A) \qquad 11$$

where S = sediment yield, tons/mi^2/yr

Q = runoff, inches

A = watershed area, mi^2.

The coefficient of determination for these two equations is 0.75.

Hindall (1976) developed a statistical method to predict sediment yields at any point on 95 percent of Wisconsin streams. The method involves equations that relate sediment yield to the geographic or physical factors that control sediment production and transport. The general form of the equation is as follows:

$$Q_s = a.\ A^{b_1} \cdot Q_a^{b_2} \cdot Q_{25}^{b_3} \cdot S^{b_4} \cdots \qquad 12$$

where Q_s = sediment yield in tons/sq mi/yr

a = regression constant

A = drainage area, mi^2

Q_a = average discharge, ft^3/sec

Q_{25} = twenty-five year flood discharge, ft^3/sec

S = main channel slope, ft/mi.

b_1, b_2, b_3, and b_4 are coefficients obtained by regression analysis. Four different areas in the state (Wisconsin) were specified, and regression models for each area were derived. The standard error of estimate is ranged between 28 to 38 percent for a level of statistical significance of higher than 95 percent.

Sediment flow rating curve

The sediment rating curve procedure can be considered a subdivision of the statistical methods also. The procedure was suggested by Straub in 1935 (cited in Glymph (1954)), further developed by Campbell and Bauder (1940), and later improved by Miller (1951). The procedure requires voluminous data to develop runoff flow durations and sediment rating curves for a watershed. It is inherently weak since it relates sediment yield to only one contributing factor. In most watersheds the discharge of a stream is merely the vehicle of sediment transportation and not necessarily a major cause of sediment yield. Therefore, a close relationship between the two need not be expected (Glymph, 1954). Shape of drainage basin, channel density, rainfall distribution, topographic configuration among others have a bearing upon sediment yield, and, unless they are uniform from watershed to watershed, the ratio of sediment yield to erosion may be expected to show considerable variation for equal size drainage areas even within the same physiographic area. Long-term sediment yield can be estimated for a particular watershed, but results cannot be extrapolated to other watersheds.

Gross erosion models

To determine average annual sediment yield by use of the delivery ratio, the first step is to determine the average annual gross erosion from all sources in the watershed area above the point where the yield estimate is needed. Multiplication of gross erosion and delivery ratio provides an estimate of sediment yield.

One of the first and most well-known models of this type is the result of an analysis to establish the effects of various factors upon the rate of sheet erosion by Musgrave (1947). Based on this model, the soil loss by sheet erosion can be expressed by the following equation:

$$E = F(R/100)(S/10)^{1.35}(L/72.6)^{0.35}(P_{30}/1.25)^{1.75} \qquad 13$$

where E = the probable soil loss, tons/ac/yr

F = a soil factor based upon the erodibility of soil and other physical factors

R = a cover factor, which may be the product of several factors related to the use of the land

S = the steepness of the slope, percent (with 10 percent as the base)

L = the slope length, ft (with 72.6 ft as the base), and

P = the rainfall. The amount used is the maximum 30-minute rainfall expected in the locality from a 2-year frequency, inches.

The above equation, referred to as the Musgrave equation, was used by the Soil Conservation Service for several years to estimate sheet erosion. A modification of Musgrave's equation with a form of delivery ratio concept was used by Beer _et_ _al_. (1966) in a study of sediment yield in western Iowa, and is:

$$E = 0.59\ (KR/150)P(R/100)(S/10)^{1.35}(L/72.6)^{0.35} \qquad 14$$

where E = the average annual soil loss, in/yr

KR = the product of soil erodibility factor and the rainfall factor from the Universal Soil Loss Equation (USLE)

P = the supporting conservation practice factor from the USLE equation

R = the cover factor (fallow or continuous row crop = 100)

S = the degree of land slope, percent (with 10 percent as the base)

L = the length of land slope, ft (with 72.6 ft as the base), and 150 and 0.59 are constants for annual soil loss in tons and for the cropping factor for continuous row crop, respectively.

Some other modified forms of Musgrave's equation were used by the Soil Conservation Service (Renfro, 1975). The most known and most widely used statistically derived model to estimate gross erosion is the Universal Soil Loss Equation (Wischmeier and Smith, 1965), which is the more advanced form of the Musgrave (1947) equation.

The Universal Soil Loss Equation was originally devised as a tool for soil conservation technicians to develop farm management plans for erosion control. With recent developments, the equation can now be applied in most parts of the country although originally limited to areas east of the Rocky Mountains (Wischmeier and Smith, 1978). The main attributes of the equation are its simplicity and its broad data base of over 10,000 plot-years of data from natural runoff plots and the equivalent of 1,000 plot-years of rainfall simulator data (Foster, 1978).

The USLE is:

$$A = RKLSCP \qquad 15$$

where A is the computed soil loss per unit area expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in tons per acre per year.

R, the rainfall and runoff factor, is the number of rainfall erosion index units plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow.

L, the slope length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions.

S, the slope steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

D, the support practice factor, is the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down the slope.

Since the USLE is based on extensive data, it has been used as a basis for many of the parametric or deterministic erosion model developments. This will be discussed in the following section.

Neibling and Foster (1977) have developed an average annual sediment transport capacity function based on the Yalin's (1963) sediment transport equation that can be used with the USLE to estimate average annual sediment yield from overland flow areas. The USLE in this model is written as follows:

$$A_i = 0.0459\ RK_i\ S_iC_iP_i(X_i^{n+1} - X_{i-1}^{n+1})\ 172.6^n \qquad 16$$

where A_i = average annual soil erosion for segment i, lbs/ft width

R = storm R factor, EI units.

Factors K_i, S_i, C_i are the same as USLE factors for the segment i. The term $X_i^{n+1} - X_{i-1}^{n+1}$ gives the slope length effect of each segment. The slope length exponent, n, is normally 0.5.

Stochastic Models

Watershed sediment yield processes are closely related to other hydrologic processes such as rainfall, runoff, and snowmelt. As these hydrologic processes are stochastic, stochastic models of sediment yield seem promising for solving sediment related problems (Sharma, 1977). Rodriguez-Iturbe and Nordin (1968) performed time series analysis of monthly runoff and suspended sediment yield for four stations on the Rio Grand River, New Mexico, to pioneer in use of such stochastic models. Woolhiser and Blinco (1975) have developed stochastic models of sediment yield on an event basis by considering the probabilistic relationships among sediment yield, rainfall, and runoff processes. Rendard and Lane (1975) proposed a stochastic-deterministic model of sediment yield. The flow was generated by a stochastic model on an event basis. For each generated runoff event, the sediment yield was computed by use of the Laursen (1958) sediment transport equation.

Unit Sediment Graph Models

In addition to the previously mentioned methods of erosion and sediment yield modeling which have been reviewed, the "unit sediment graph" idea has been used to model sediment yield from a watershed. One of the assumptions on which the so-called unit hydrograph theory is based states that for a given drainage basin the hydrograph of runoff due to a given period of rainfall reflects all the combined physical characteristics of the basin. It was proposed in 1972 by Rendon-Herrero (1978) that "in watersheds where the loci of hydrograph and the sediment graph 'parallel' each other, the same assumption is imposed on the unit sediment graph." A relationship was developed by Rendon-Herrero (1978) between total sediment mobilized and surface runoff for single storm events. The model has been tested on the data of Bixter Run Watershed, a 15 mi^2 area in Pennsylvania. The model produced encouraging results with rainfall and snowmelt events.

Runoff Based Models

The Universal Soil Loss Equation is intended to estimate average annual soil loss, but it can also be used to predict sediment yield from watersheds when a delivery ratio is applied (Williams and Berndt, 1972). The delivery ratio is not necessary if the rainfall energy factor of the USLE is replaced by a runoff factor. Watershed characteristics such as drainage area, stream slope, and watershed shape influence runoff rates and delivery ratios in a similar manner (Williams, 1975). The committee on Sedimentation of the Hydraulics Division, American Society of Civil Engineers (ASCE, 1970), stated that runoff is the best single indicator of sediment yield. Some other studies (Williams _et_ _al_., 1971; Dragoun and Miller, 1964) have shown that a runoff factor is superior to rainfall factor in predicting the sediment yield.

Based on these findings and the fact that runoff is the only agent to transport sediment, Williams (1975) devised a set of equations to replace the rainfall energy factor in the USLE in order to predict sediment yield from a watershed for an individual storm. The equation which is known to be the Modified Universal Soil Loss Equation (MUSLE) was developed:

$$y = 95(Q \times q_p)^{0.56}\ LKSCP \qquad 17$$

where y = sediment yield in tons

Q = volume of runoff in acre-ft

q_p = peak flow rate in cfs

The K, LS, C, and P factors, from USLE, were weighted according to drainage area so that the source erosion can be computed for the entire watershed in one solution of the equation. The general form of the weighting function is:

$$X = \frac{\sum_{i=1}^{n} X_i\ DA_i}{DA} \qquad 18$$

where X = weighted factor

X_i = value of the factor covering the drainage area DA_i

DA = total drainage area of the watershed.

To use USLE as a tool to predict sediment yield from an individual storm from a watershed, Onstad and Foster (1975) replaced the rainfall energy term in the USLE to read:

$$R_m = 0.5\ R_{st} + 15\ Q\ q_p^{1/2}. \qquad 19$$

They have modified the USLE and defined the detachment capacity of a storm as follows:

$$A_i = \frac{R_m\ (KCPS)_i}{185.58}\ (X_i^{1.5} - X_{i-1}^{1.5}) \qquad 20$$

where R_m = combined rainfall and runoff erosivity factor

R_{st} = storm rainfall factor, EI units

Q = storm runoff volume, inches

q_p = storm peak runoff rate, in/hr

A_i = detachment capacity on segment i, tons/acre

X_i = downslope distance of segment i, ft.

The factors K, C, P, and S for each segment are the same as for USLE.

Foster _et_ _al_. (1977a), using basic erosion principles and USLE as a criteria to evaluate the coefficients, developed the following equation:

$$A = [K_r F_t (430S^2)(X/\lambda) C_r P_r + K_i I_t (305 + 0.43) C_i P_i] 16.574 \qquad 21$$

where A = average soil loss for a slope length x, mass/unit area/time period of erosivity factor

X = slope length, ft

λ = length of a unit plot, 72.6 ft

S = slope steepness, percent

F_t = runoff erosivity factor, $15\ Qq_p^{1/3}$

I_t = rainfall erosivity factor, $0.5\ R_{st}$.

K_r, C_r, P_r, K_i, C_i, and P_i are soil erodibility, cropping management, and supporting practices for rill and interrill erosion, respectively.

Deterministic Models

The importance and recognition of fundamental principles involved in erosion and sediment transport were noted by Ellison in 1947. Ellison has defined erosion as follows: "Soil erosion is a process of detachment and transportation of soil materials by erosive agents." This definition describes the erosion process as consisting of two principal sequential events. In the first process, soil particles are torn loose (detached) from the soil mass and made available for transport. In the second process, detached soil materials are transported. For erosion by water, these agents are rainfall and runoff. Ellison has pointed out that each has both a detaching and transporting capacity and that these must be studied separately. Using these ideas, Meyer and Wischmeier (1969) proposed a physically based mathematical model of erosion processes which treats (a) soil detachment by rainfall, (b) transport by rainfall, (c) detachment by runoff, and (d) transport by runoff, as separate but interrelated parts of soil erosion processes (Figure 1). In this model the detachment by rainfall is represented by equation

$$D_R = S_{DR}\, A_i I^2 \tag{22}$$

where D_R = detachment by rainfall

A_i = area of increment i

I = rainfall intensity

S_{DR} = a coefficient related to soil effect on rainfall detachment.

Detachment by runoff is represented by equation 23:

$$D_F = S_{DF} A_i\ 1/2 (S_s^{2/3}\ Q_s^{2/3} + S_E^{2/3}\ Q_E^{2/3}) \tag{23}$$

where D_F = detachment by runoff

S_s = slope steepness at the beginning of increment i

Q_s = flow rate at the beginning of increment i

S_E = slope steepness at the end of increment i

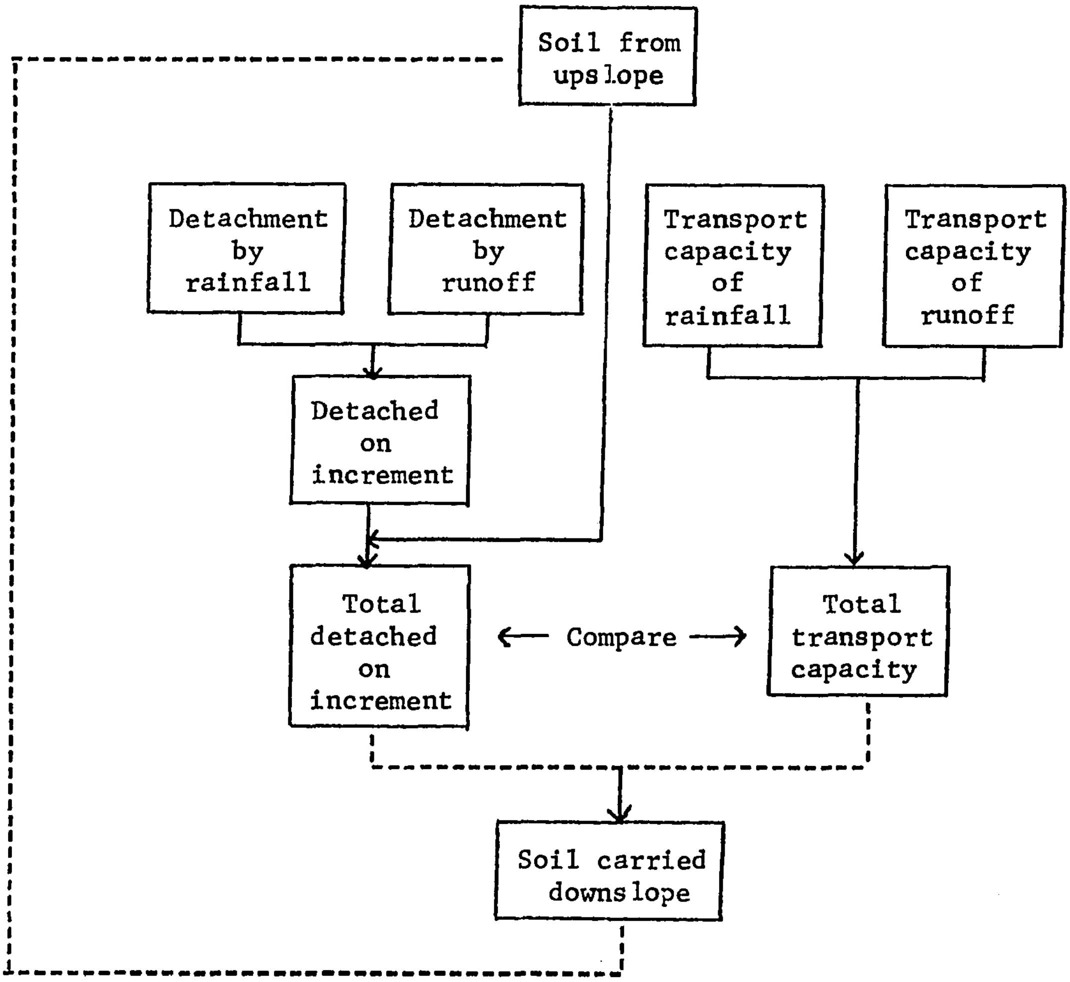


Figure 1. Deterministic approach to simulate the processes of soil erosion and sediment yield by water

Q_E = flow rate at the end of increment i

S_{DF} = a coefficient, soil effect on runoff erosion.

Transport capacity of rainfall and runoff are shown as equations 24 and 25, respectively.

$$T_R = S_{TR} SI \qquad 24$$

$$T_F = S_{TF}\, S^{5/3}\, Q^{5/3} \qquad 25$$

where T_R = transport capacity of rainfall

S = slope steepness

I = intensity of rain

T_F = transport capacity of runoff

Q = overland flow rate

S_{TR} and S_{TF} are coefficients for transportability of soil by rain and runoff, respectively.

Another deterministic but lumped model was assembled by Negev (1967) and combined with Stanford model to predict sediment yield. In Negev's model, the quantity of fine soil particles produced by the splash process is computed as follows:

$$PER = KRER * HPP(t)^{JRER} \qquad 26$$

where PER = hourly quantity of soil splash, tons

HPP = hourly rainfall during hour t, inches

kRER = a parameter that varies with soil type and cover

JRER = an exponent.

The hourly quantity of fine soil pickup in this model is computed by the relationship:

$$SER = KSER * SRER(t-1)\ OVQ(t)^{JSER} \qquad 27$$

where SER = hourly quantity of splash soil pickup, tons

OVQ(t) = hourly overland flow during hour t, inches

KSER = a parameter that varies with soil type and surface roughness

SRER(t-1) = the accumulated deposits of fine soil particles at the end of hour t-1, tons

JSER = an exponent.

Crawford and Donigian (1973) used the erosion model developed by Negev (1967) in PTR (pesticide transport and runoff) model. In contrast to Negev's model, they have assumed that rill formation and erosion is to be included in the sheet erosion process. Donigian and Crawford (1976), with some modification, used the PTR model. They modified the transport capacity equation as follows:

$$SER(t) = KSER * OVQ(t)^{JSER} \text{ subject to } SER(t) < SRER(t) \qquad 28$$

where SRER(t) = reservoir of soil fines at the beginning of time interval, t.

A more comprehensive vegetal cover function and an attempt to simulate the effect of tillage operations were included also.

Another model in this series is one by David and Beer (1975). In this model, the total sheet erosion is given by the following equation:

$$E = T' + E_r + E_s + E_i \qquad 29$$

where E = total erosion rate for the specific period

$T' = T;\ T \leq D$

$T' = D;\ T > D$

T = transport capacity of overland flow

D = total detachment storage at the end of time interval

E_r = overland flow scour

E_s = soil splashed directly into the stream

E_i = sediment picked up from impervious area.

The transport capacity in the model is:

$$T = n\ S^a\ y^k \qquad 30$$

where n = soil and surface roughness factor

S = average overland flow surface slope

a = an exponent

k = a constant

y = the overland flow depth.

The other components of the model are as follows:

$$E_r = c'\ y^{\beta} \qquad 31$$

where β = an exponent

c' = a constant representing the soil characteristics and overland flow surface slope,

and

$$E_s = AS\ E_d \qquad 32$$

where A = area representing the total land surface within a splashing distance to a stream surface

E_d = amount of soil splash.

$$E_d = SC_F\ LS_F\ I^{\alpha}\ e^{-ky} \qquad 33$$

where SC_F = soil and soil cover factor

LS_F = land slope factor

I = rainfall intensity

k = exponent greater than 1.0

α = exponent $\simeq$ 2.0.

$$E_i = k'aE_d \qquad 34$$

where k' = empirical constant

a = fraction of the watershed being impervious.

Another model, based on Negev's model, is presented by Fleming and Leytham (1976). In this study, they tried to generalize Negev's model and define the parameters in terms of some measurable quantities by use of the Universal Soil Loss Equation criteria.

Bruce et al. (1975) developed a model to describe the rate and quantity of runoff water from separate rainfall events on a watershed and the rate and quantity of sediment and pesticides transported. In this model, the concept of rill and interrill erosion is conceptually distinguished. It is a two-stage convolution model. Even though the model produces good results in terms of amount of sediment yield and distribution of sediment with time, as compared to field data, because of many undefined constants in the model, it is somewhat abstract.

Another model which uses the concept of rill and interrill erosion is the one by Smith (1977). Detachment by rainfall is assumed proportional to the square of the rainfall rate modified by the mean depth of water on the surface:

$$D_r = k_r\, r^2\, [e^{-Hh^2}] \qquad 35$$

where D_r = detachment rate by rainfall

r = rainfall rate

H = a parameter

h = mean depth of surface flow

k_r = a constant parameter.

Erosion rate due to overland flow is represented as follows:

$$D_f = k_f \ (C_{max} - C) \qquad 36$$

where D_f = detachment rate by overland flow

k_f = a parametric coefficient

C_{max} = concentration of sediment that can be carried by the flow at any instant

C = actual sediment concentration.

Sediment carrying capacity, C_{max}, in the model, is the one proposed by Kilinc and Richardson (1973) as follows:

$$C_{max} = \frac{k_o \ [U(\tau_o - \tau_c)]^{1.58}}{\gamma U h} \qquad 37$$

where U = local velocity

τ_o = tractive force

τ_c = critical tractive force, a parameter

γ = unit weight of sediment

k_o = a parameter.

A mathematical model simulating water and sediment hydrographs from small watersheds has been developed by Li et al. (1976). This model is designed to simulate the response of the basin to individual storms. The model includes a water balance on the single storm basis, loose soil detachment by raindrop impact and by moving water, and water and sediment routing features for both overland flow and channel systems.

The approach of rill and interrill erosion by runoff and rainfall was adapted to the overland flow component of a model by Ross and Contractor (1978). Detachment by raindrop impact in this model is estimated by the following equation:

$$D_R = 0.027\ CKAI^2 \qquad 38$$

where D_R = rainfall impact detachment rate, kg/min

C = cropping and management factor (from USLE)

K = soil erodibility factor (from USLE), tons/acre/EI unit

A = area increment in m^2

I = rainfall intensity, mm/min.

Detachment due to overland flow is expressed as:

$$D_F = 0.018\ C\ K\ ASq \qquad 39$$

where D_F = overland flow detachment rate in kg/min

S = slope, percent

q = flow rate per unit width, m^2/min.

Soil transport by overland flow was described by the relationships:

$$T = 146\ S\ q \qquad q \leqslant 0.74\ m^2/min \qquad 40$$

$$T = 14600\ S\ q^2 \qquad q > 0.74\ m^2/min \qquad 41$$

T = transport capacity, kg/min

Solomon and Gupta (1977) have used the relationship given by Meyer and Wischmeier (1969) with some modification of the model. The model is a distributed one (both in time and space) which estimates sediment discharge of ungraded rivers.

Foster _et_ _al_. (1977b), using the basic erosion principles, have derived the following equation:

$$G_T = X^2 K_r (as^e) F_t + X K_i (bs + c)I_t \qquad 42$$

where G_T = total rill and interrill erosion from a storm event

X = slope length

F_t = runoff erosivity factor

I_t = rainfall erosivity factor

s = slope steepness

K_r and K_i = soil erodibility for rill and interrill erosion, respectively

a, e, b, and c = constants.

If the effect of cropping, management, and supporting practices factor is considered, the equation is as follows:

$$G_T = X^2K_r(as^e)F_t C_rP_r + X K_i(bs+c)I_t C_iP_i \qquad 43$$

where C_r, P_r, C_i, and P_i are cropping and supporting practices factor from USLE for rill and interrill erosion.

Foster (1978) divided the upland erosion into rill and interrill process and has suggested the following equation for interrill detachment.

$$D_i = 1.38 K_i i^2 [2.96(\mathrm{SIN}(\theta))^{0.79} + 0.56]C_i \qquad 44$$

where D_i = detachment rate (kg/m^2 hr)

K_i = soil erodibility factor for detachment by raindrop

i = intensity of rainfall units

θ = angle of the slope

C_i = combined effect of crop canopy and residue on detachment by rainfall.

This equation is the basic equation for interrill detachment and applies to 9 percent slope to be consistent with the USLE, K (Foster, 1978). Parameters to represent the effect of slope and cover should be added.

Rill erosion is assumed to be represented by a Duboys type sediment transport equation or:

$$D_{rc} = a\ (\tau - \tau_{cr})^{b} \qquad 45$$

where D_{rc} = rill erosion capacity rate (mass/unit total surface area/ time)

τ = the flow shear stress assuming broad shallow flow

τ_{cr} = a critical shear stress

a = a constant coefficient

b = an exponent.

Assuming critical shear stress to be zero, and using the data by Wischmeier _et al_. (1971), Foster (1978) derived the following equation for rill erosion

$$D_{rc} = 83.7\ K_r\ \tau^{1.5} \qquad 46$$

where D_{rc} = rill erosion rate, kg/m^2 of total area/hr

τ = average shear stress assuming broad shallow flow, N/m^2

K_r = soil erodibility factor for rill erosion, kg hr/N m^2.

The effect of crop cover should be considered too.

Summary of Literature Review

From this brief review, one can conclude that sediment yield of a watershed is the result of many causal factors. Variation in the significance of the individual causal factors from one physiographic area to another probably accounts for the observed differences in sediment yield over the country.

All of the statistically derived models have a common characteristic. They are all used for a specific purpose in a local area. As a result, use by extrapolation to other areas is limited. An obvious hazard in a method which relies solely upon historical data is the magnitude of the error that may be encountered in data collection and extrapolation.

Stochastic principles and unit sediment graph method may be useful in predicting sediment yield. They do not define the way each factor involved in the process affects the sediment yield. As a result, like statistical models, they have the same disadvantages as statistical models.

Deterministic models, which are based on principles involved, are more appropriate to understanding the process. In these models, sources of erosion and the quantity of eroded materials from each source as well as the transporting capacity of runoff have to be defined, considering conditions at any time. As a result, they are more general and applicable to other areas if the assumptions underlying the development of the model are considered. The general trend of erosion and sediment yield research is in this direction. In the present study, the writer has made use of the most recent findings to develop a deterministic sediment yield model.

HYDROLOGIC MODEL

Introduction

As previously discussed, the basic requirement for a deterministic and mathematically based erosion model is a hydrologic model. Many different models have been developed to serve different purposes. Since the early 1960's, hydrologic modeling has become an accepted branch of scientific hydrology. The first attempt to bring the many component processes together into a more detailed model resulted in the Stanford Watershed Model (Crawford and Linsley, 1966).

In 1965, the Department of Agricultural Engineering at Iowa State University began development of a deterministic hydrologic model. To serve different purposes, different versions of the Iowa State University Hydrologic Model were developed (Haan and Johnson, 1968; DeBoer and Johnson, 1971; Saxton _et_ _al_., 1974a; and Campbell and Johnson, 1975).

The I.S.U. Watershed Model was developed for a particular type of soil and topography (flatland of central Iowa, characterized by numerous depressions, high natural watertables, and extensive artificial drainage) and was not directly applicable to other areas. Anderson _et_ _al_. (1978) modified the I.S.U. Hydrologic Model components to predict evapotranspiration, soil moisture storage, and runoff volumes from deep, well-drained soil with rolling topography of western Iowa. The present study is the continuation of Anderson's work. Anderson's model is a one-dimensional one. The model predicts the volume of runoff (depth). To be used as a basis for erosion prediction, an overland flow routing component is added to predict the rate of runoff at any time during a rainfall runoff event. An erosion model is also added to the new version of the hydrologic model to predict sediment yield from small agricultural watersheds.

Model Components

In this section, the components of the hydrologic model will be discussed briefly unless modifications have been made.

The soil-plant-air system to be modeled is shown schematically in Figure 2. The major processes involved are: precipitation, interception, evapotranspiration, infiltration, soil moisture redistribution, and surface runoff. The flow chart of the main program and subroutines associated with different components are provided in Appendix A. The main computer program was designed to call each process in its logical sequence and update the watershed conditions based on the results of that process. The time period required for each individual process to be executed is varied by the main program.

At the beginning of each day, as is shown in Figure 3, plant (PLANT) and potential evaporation (PEVAP) subroutines are called. Then the day is divided into six, four-hour periods, the longest time increment used in the model. If rain occurred during the day, the precipitation (PRECIP) subroutine is called for that day. The second major loop, which is a four-hour one, determines whether there is any rainfall during the first four hours. If no rainfall has occurred during the first four-hour period, infiltration, redistribution, and evapotranspiration components will be executed to update the soil moisture conditions.

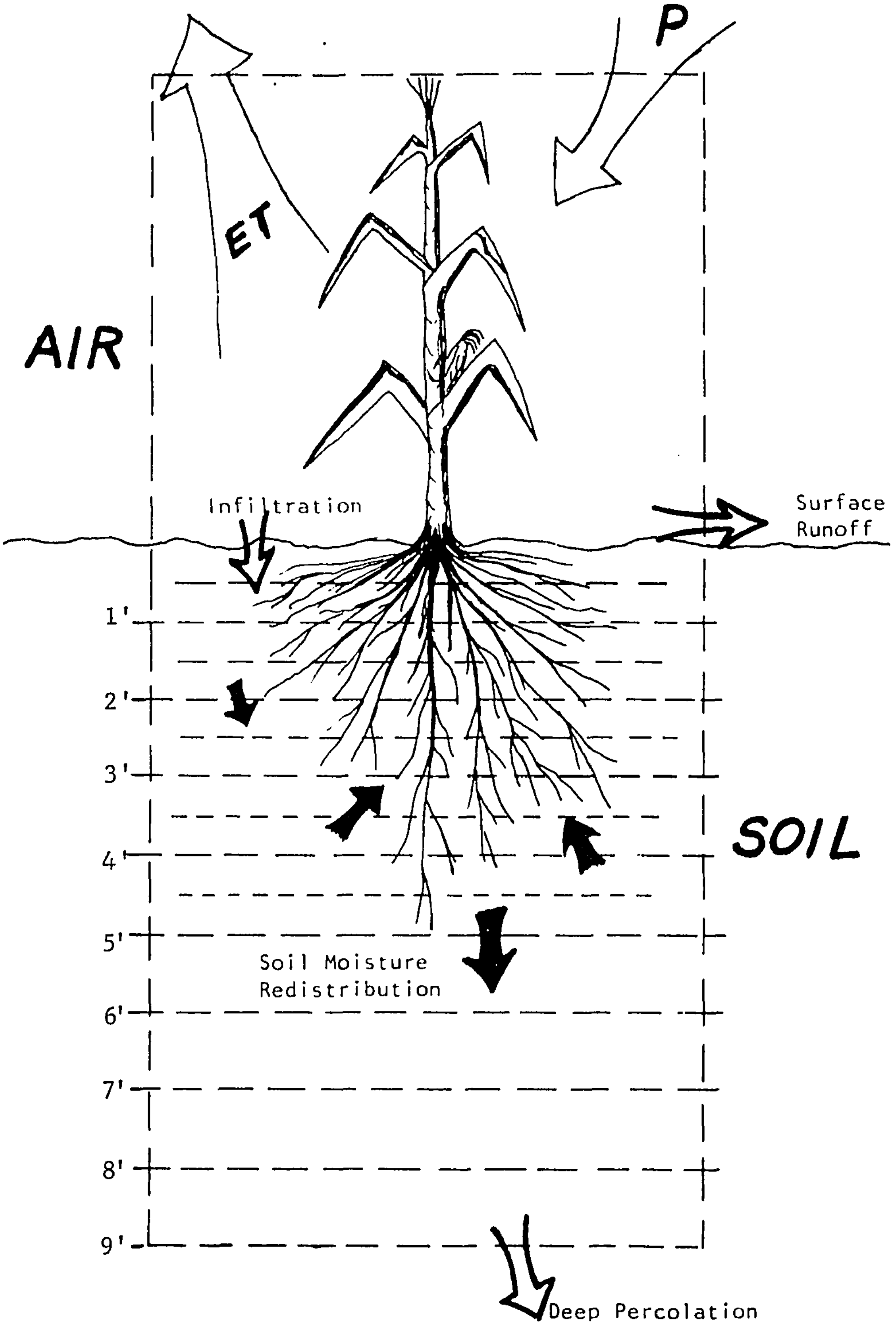
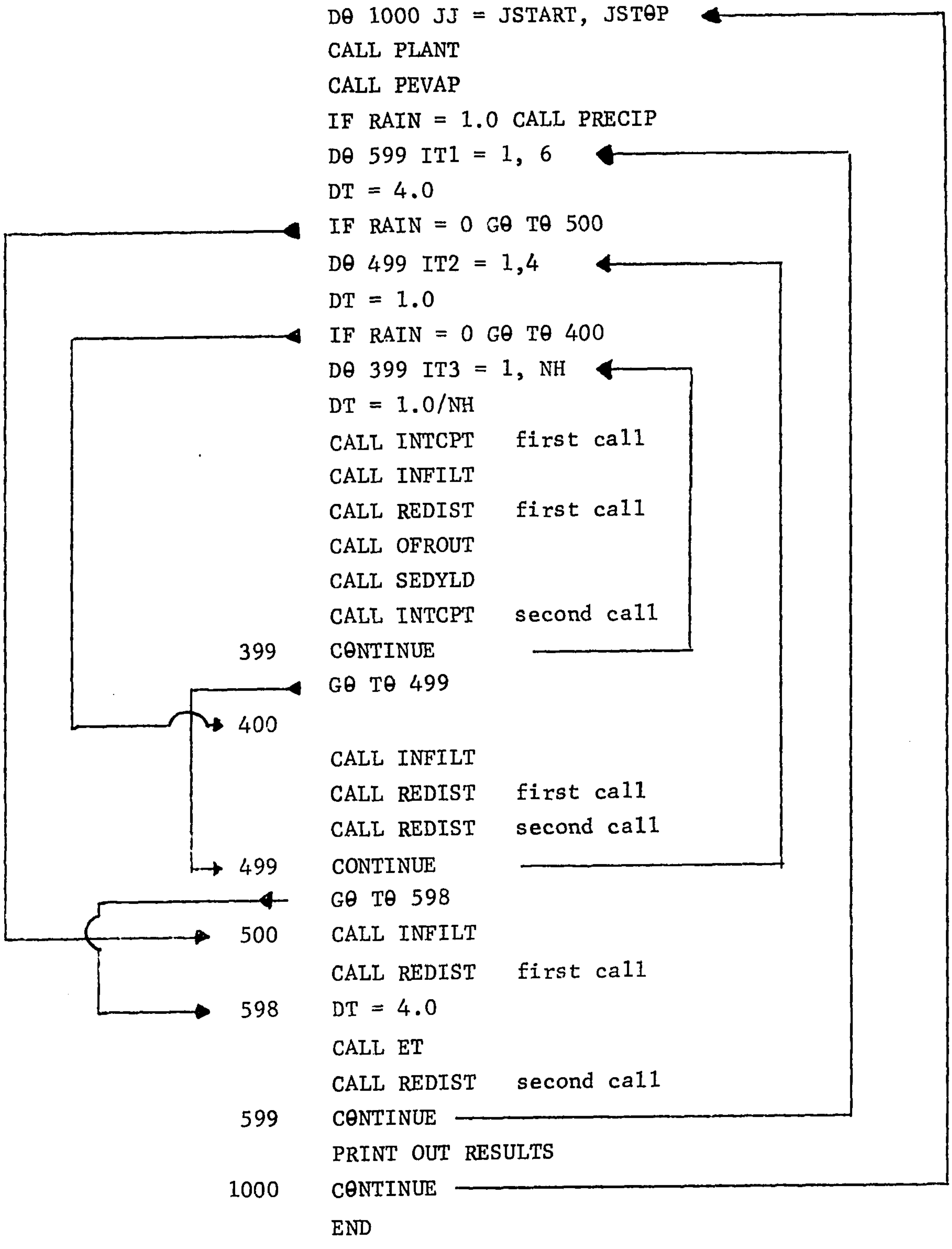


Figure 2. Schematic model of soil-plant-air system (Anderson, 1975)



```
      DO 1000 JJ = JSTART, JSTOP
      CALL PLANT
      CALL PEVAP
      IF RAIN = 1.0 CALL PRECIP
      DO 599 IT1 = 1, 6
      DT = 4.0
      IF RAIN = 0 GO TO 500
      DO 499 IT2 = 1,4
      DT = 1.0
      IF RAIN = 0 GO TO 400
      DO 399 IT3 = 1, NH
      DT = 1.0/NH
      CALL INTCPT   first call
      CALL INFILT
      CALL REDIST   first call
      CALL OFROUT
      CALL SEDYLD
      CALL INTCPT   second call
 399  CONTINUE
      GO TO 499
 400
      CALL INFILT
      CALL REDIST   first call
      CALL REDIST   second call
 499  CONTINUE
      GO TO 598
 500  CALL INFILT
      CALL REDIST   first call
 598  DT = 4.0
      CALL ET
      CALL REDIST   second call
 599  CONTINUE
      PRINT OUT RESULTS
1000  CONTINUE
      END
```

Figure 3. General flow chart of the main model program

Then the next four-hour period will be tested to see if rainfall has occurred. If rainfall has occurred, the third major loop will divide the four-hour period into four one-hour periods. For those hours during which rainfall has not occurred, the infiltration and redistribution will be called. If rainfall has occurred within an hour, the major loop number 4, which is the most detailed one, will divide the one-hour period into NH number of periods. The value of NH will determine the shortest period of time over which different components of the model will be called to be executed. Components that will be called within this loop are interception (INTCPT), infiltration (INFILT), redistribution (REDIST), overland flow routing (OFROUT), and sediment yield (SEDYLD).

Precipitation

A detailed flow chart for precipitation subroutine is shown in Appendix A. No change has been made in this subroutine. The reader is referred to Anderson (1975). The model uses rain gage charts consisting of time and accumulated rainfall. The accumulated rainfall at the break points of a rain gage chart and the corresponding time are input to the model. Thus, the precipitation subroutine reduces the volume of precipitation input data to a great extent. This is especially true when very small time increments are used. The method allows the use of time increments smaller than those found on rain gage charts.

Infiltration

Anderson (1975) pointed out "If one process in the model can be singled out as being the key to successful simulation of surface runoff and soil moisture, infiltration is that process." Holtan's equation (1961), which is modified by Huggins and Monke (1968), is used in the model. The main reasons for using this equation are its ability to determine infiltration during periods of intermittent water supply, to predict infiltration capacity recovery during dry periods, and ease of computation. The equation to be used is:

$$f = fc + A\left(\frac{S-F}{T}\right)^{P} \qquad 47$$

where f = average infiltration capacity during any period, in/hr

fc = wet soil infiltration capacity, in/hr

S = soil water storage potential above any impeding strata, in

F = accumulated infiltrated water, in

T = total pore volume above any impeding strata, in^3/in^2

A = a parameter representing the maximum potential increase of infiltration capacity above the wet soil value, in/hr = ASOIL in computer program

P = an exponent reflecting the steepness of the slope of the infiltration capacity curve at the beginning of infiltration process = PSOIL.

The procedure for solving the equation is given by Anderson (1975); the flow chart is shown in Appendix A.

Even though the parameters in Holtan's equation are theoretically independent of initial soil moisture, based on findings of Anderson

(1975), these parameters are a function of plant cover, rainfall intensity, and initial soil moisture.

At the beginning of each day, the A parameter in equation 47 (ASOIL in computer program) is adjusted based on the soil moisture of the first layer of the soil at the beginning of that day. The function used for this purpose is

$$\mathrm{ASOIL} = \mathrm{ASOILM}[e^{\mathrm{AM}(\mathrm{AMC}-\mathrm{FCS})}] \qquad 48$$

where ASOILM = maximum value of parameter ASOIL

AM = an input parameter to be calibrated

AMC = moisture content in the top soil layer at the beginning of the day, percent by volume

FCS = field capacity of the top soil layer, percent by volume.

The relation between parameter A(ASOIL) and moisture content of the top soil layer (AMC) is shown as Figure 4.

To consider the effect of crop growth on infiltration capacity, one-half of the crop leaf area index for crop leaf area index less than or equal to 3.0 at the beginning of each day is added to the adjusted ASOIL.

The effect of rainfall intensity on infiltration is estimated by using the rainfall kinetic energy. According to Moldenhauer and Kemper (1969), infiltration reduces exponentially with increasing rainfall kinetic energy. This reduction in infiltration is primarily due to the compacting effect of rainfall kinetic energy, destruction of soil

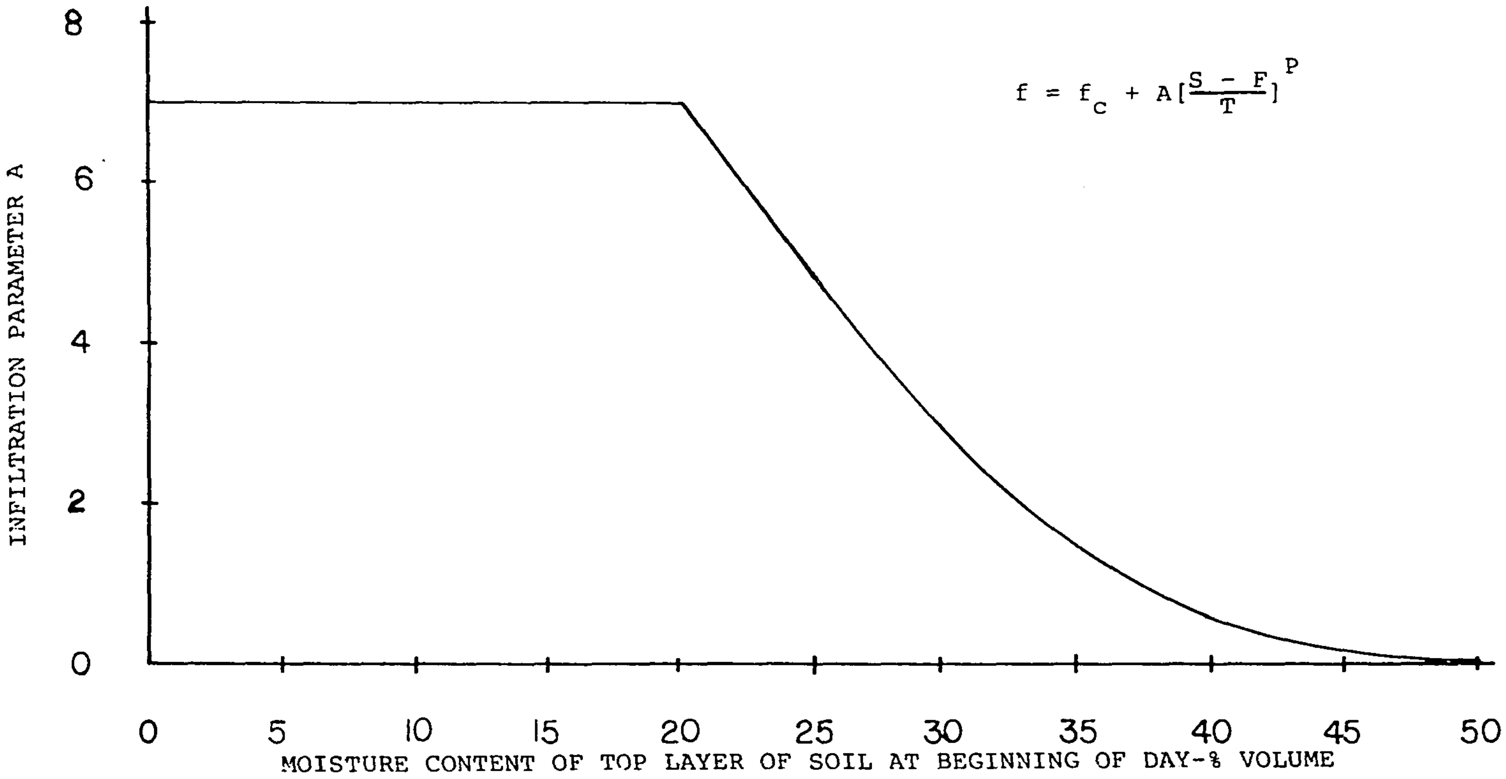


Figure 4. Curve used in the model to describe the relationship between parameter A in the infiltration equation and the moisture content of the surface soil layer at the beginning of each day (Anderson, 1975)

structure and consequent soil dispersion, and the blocking of pores by fine soil particles. The equation used to estimate the reduction factor, which is called rainfall energy factor (REF), is:

$$REF = CE1 * SRKE^{-CE2} \qquad 49$$

where CE1 and CE2 are constant either to be determined or estimated by calibration

SRKE = summation of rainfall kinetic energy from the time of tillage, Joules/cm^2.

Rainfall kinetic energy for each time increment is calculated as follows (Wischmeier and Smith, 1978):

$$RKE = DDP\ (0.06133 + 0.02216 \log DINT) \qquad 50$$

where DDP = direct precipitation (unintercepted by the crop canopy) in the period of calculation, in

DINT = intensity of rainfall during the period of calculation, in/hr

RKE = rainfall kinetic energy in period of calculation, Joules/cm^2.

The rainfall energy factor (REF) varies between 0 and 1. To consider the effect of tillage and cultivation on infiltration, the model assigns the value of zero to SRKE when tillage or cultivation occur. This means that by disturbing the soil surface, the previous effects of rainfall kinetic energy on compacting and blocking the pores are removed, and infiltration of water takes place at its maximum value insofar as affected by the rainfall energy factor. The rainfall kinetic energy is assumed to be zero in the model if the depth of water in depressional storage is greater than 0.5 inch. This value is an arbitrary value and can be changed for any other condition.

The parameter P (PSOIL in computer program) is also a function of moisture content of top soil layer (Anderson, 1975). The function which is used to adjust the PSOIL at the beginning of each day is:

$$\mathrm{PSOIL} = \mathrm{PSFC}(\mathrm{AMC}/\mathrm{FCP})^{\mathrm{PM}} \qquad 51$$

where PSFC = PSOIL value for AMC equal to field capacity of top soil layer, percent by volume

FCP = field capacity of top soil layer, percent by volume

PM = exponent on the PSOIL vs AMC function (Figure 5).

Soil moisture redistribution

A detailed flow chart for the soil moisture redistribution subroutine is shown in Appendix A. This subroutine is divided into two parts. The first distributes infiltrating water throughout the soil profile. The second redistributes moisture according to potential gradients.

In the first part of this subroutine, each layer is assumed to fill to a certain level of saturation before any infiltrating water is drained to the next lower layer. Anderson (1975) assumed this value to be 80 percent. In the present version, other values were tried to determine the effect on the response of the model. It was concluded that 80 percent produced better results than the other tested values, at least for the present condition. That part of the water which passed below the bottom of the soil profile is assumed to be deep percolation.

In the second part of the subroutine, moisture content (percent by volume) and saturation ratio for each layer is calculated. Using concepts by Saxton et al. (1974a), Campbell (1974), and Ghosh (1977), Anderson (personal communication)[1] adopted the following equations to

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[1] Department of Agricultural Engineering, Iowa State University, Ames, Iowa, September, 1979.

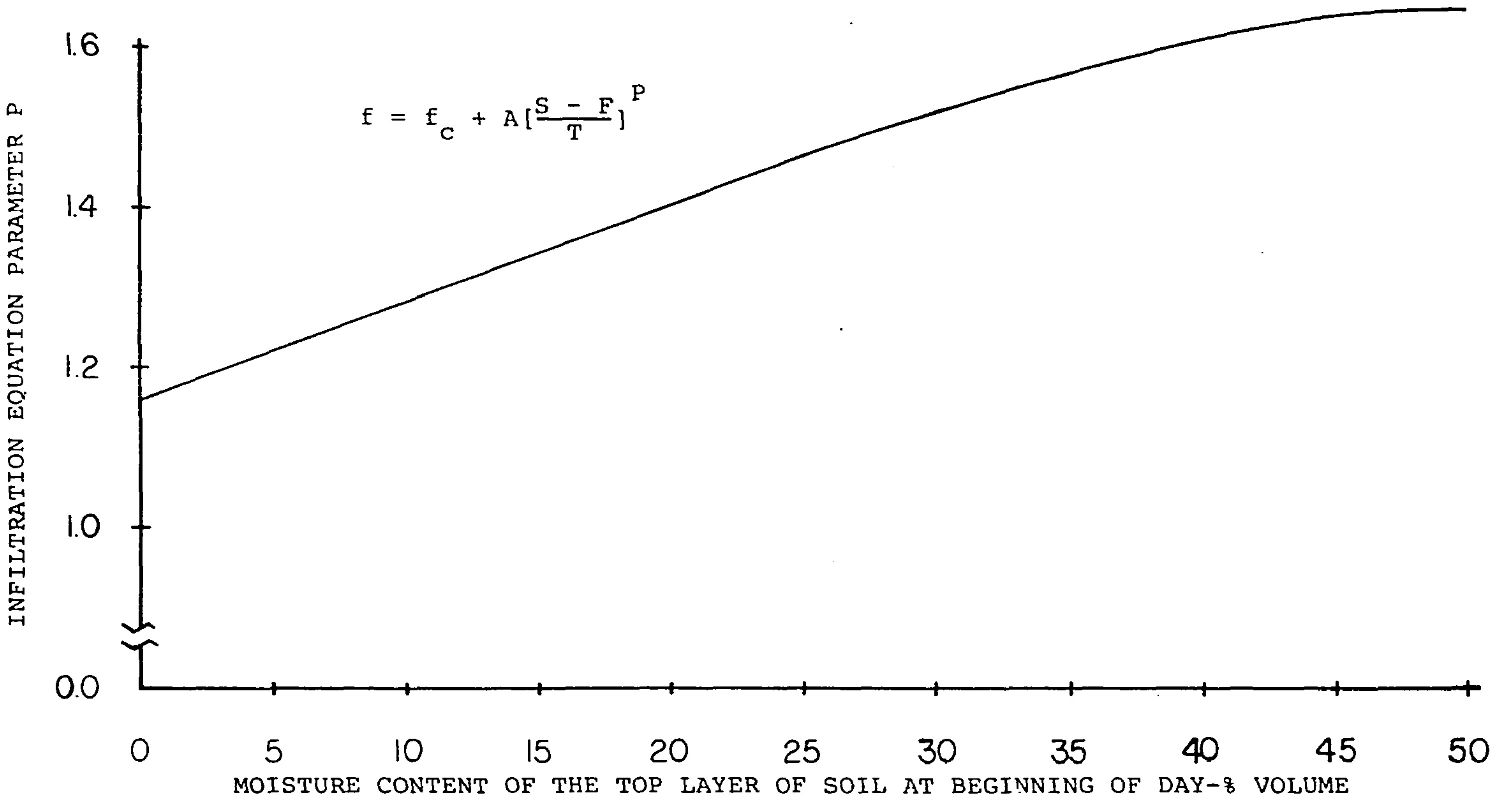

Figure 5. Curve used in the model to describe the relationship between the exponent P in the infiltration equation and the moisture content of the surface soil layer at the beginning of the day (Anderson, 1975)

estimate moisture tension and unsaturated hydraulic conductivity for each layer.

If the saturation ratio (ratio of estimated soil moisture in percent by volume to the moisture content at saturation) is less than 90 percent, moisture tension in each layer is:

$$TENZ(JI) = AEWP(JI)*SR^{-SMTC(JI)} \qquad 52$$

and unsaturated hydraulic conductivity is:

$$UHC(JI) = SHC(JI)*SR^{1.5SMTC(JI)+3.0} \qquad 53$$

where TENZ(JI) = tension in layer JI, cm
AEWP(JI) = air entry water potential of layer JI, cm
SR = saturation ratio
SMTC(JI) = slope of moisture-tension curve for layer JI
UHC(JI) = unsaturated hydraulic conductivity of layer JI, cm/hr
SHC(JI) = saturated hydraulic conductivity of layer JI, cm/hr.

If SR is greater than 1, tension is zero and unsaturated hydraulic conductivity is the same as saturated hydraulic conductivity. When SR is between 0.9 and 1.0, UHC is assumed to be the same as SHC, and tension is calculated as follows:

$$TENZ(JI) = (10SR - 9.0)AEWP\ (0.90)^{-SMTC(JI)}. \qquad 54$$

Knowing the tensions in two adjacent layers and thickness of each layer, the potential gradient between the two layers is calculated. By use of the one-dimensional Darcy equation, with the known gradient and hydraulic conductivity, the flow between layers is calculated.

When a drainage system is present, change in soil moisture storage with respect to time, due to flow of water to the tile, is assumed to be:

$$\frac{dS}{dt} = KS = -Q \qquad 55$$

where S = soil moisture storage, inches

K = a proportionality constant

Q = rate of flow to the tile, inches/day

t = time, days.

Change in volume of water flowing into the tile is assumed to be

$$\frac{dQ}{dt} = kQ \qquad 56$$

where k = a proportionality constant.

Integrating Equation 56 and applying the specified conditions results

$$Q = Q_o e^{-kt}, \text{ at } t = 0.0, Q = Q_o. \qquad 57$$

The term e^{-k} is daily recession rate of inflow to the tile and is assumed to be k_r. Change in soil moisture storage, as a function of daily recession rate of inflow, k_r, will be:

$$\frac{dS}{dt} = -Q_o\ k_r^{\ t}. \qquad 58$$

The integration of Equation 58 yields

$$S = -Q_o \frac{k_r^{\ t}}{\ln k_r}. \qquad 59$$

Substituting Q for $Q_o\ k_r^{\ t}$, daily flow to the tile will be as follows:

$$Q = S(-\ln k_r). \qquad 60$$

The volume of flow to the tile for any time increment to be used in a day is:

$$Q = -S\ \ln(k_r^{\ DT/24.0}) \qquad 61$$

where DT = time increment to be used, hour.

Potential evapotranspiration

The present version of the model can use either the Penman equation with some modifications by Anderson et al. (1978), or pan evaporation data to calculate potential evapotranspiration. It is generally believed that the Penman equation gives better results when the required data are available. The data required by the Penman equation include: daily values of air temperature, relative humidity, wind velocity, and solar radiation. These data are not always available. Pan evaporation data are more apt to be available.

In the present version of the model, the regression equation developed by Saxton et al. (1974b) relating pan data and potential evapotranspiration is used. This regression equation is:

$$PE = 0.01 + 0.83*PAN \tag{62}$$

where PE = potential evapotranspiration for the day, in

PAN = pan evaporation data for the day, in.

To check the use of Equation 62, the model was run for the year of 1968 on the NE Gingles Watershed for which the required data are available for use of the Penman equation. For the same year, the model was run using the pan evaporation data to predict the potential evapotranspiration. Soil moistures of the top 5 ft and 9 ft were taken as criteria to compare the results of the two methods (see Figures 6 and 7). On both 5 and 1 percent level of probability, the difference between the two methods was not significant. Predicted depth of surface runoff using Penman equation and pan evaporation data is compared with the measured depth of runoff in Table 1.

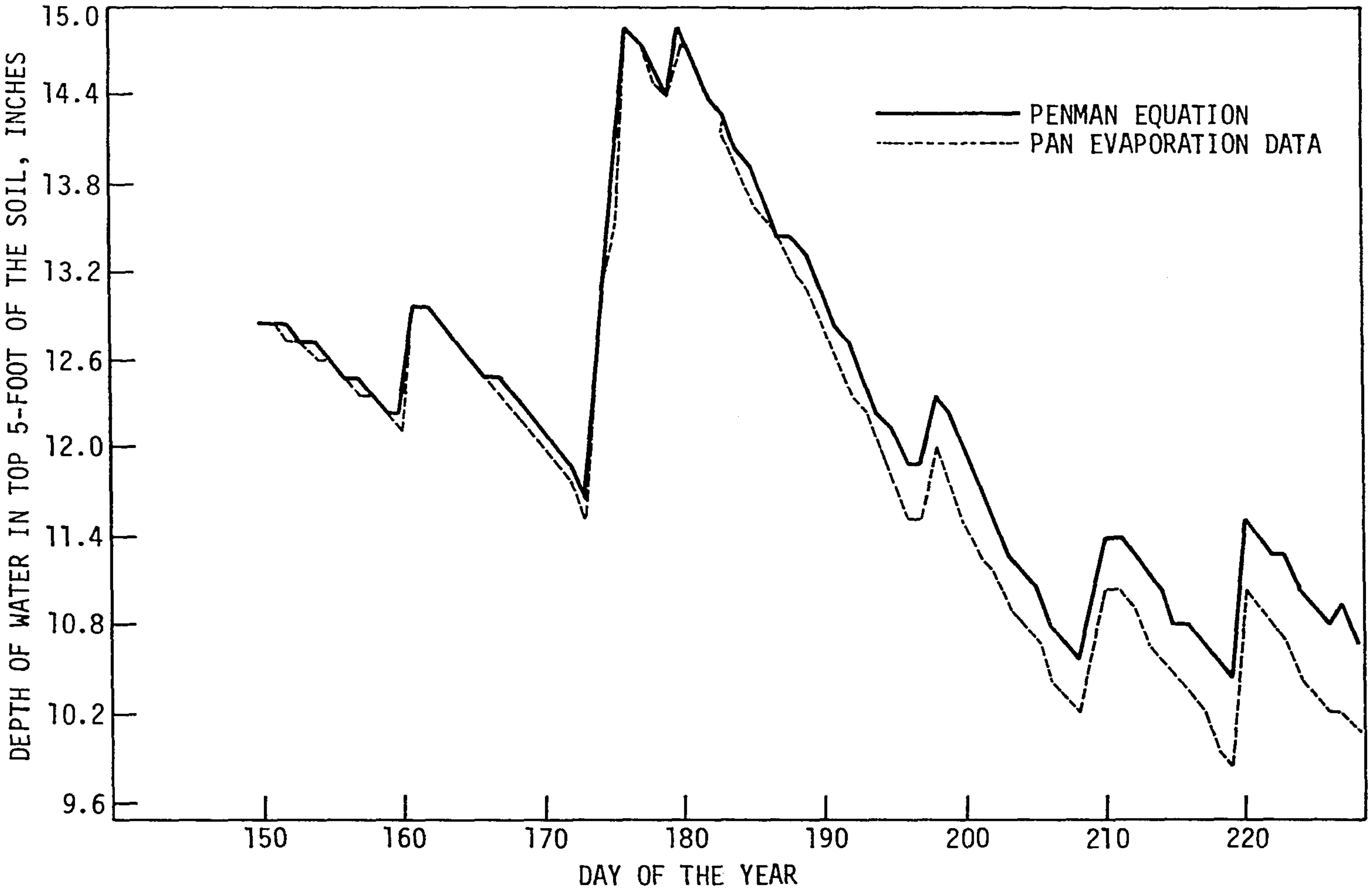

Figure 6. Predicted soil mositure in the top 5-foot root zone under corn, using Penman equation and pan evaporation data, during the 1968 growing season on the North-East Gingles watershed

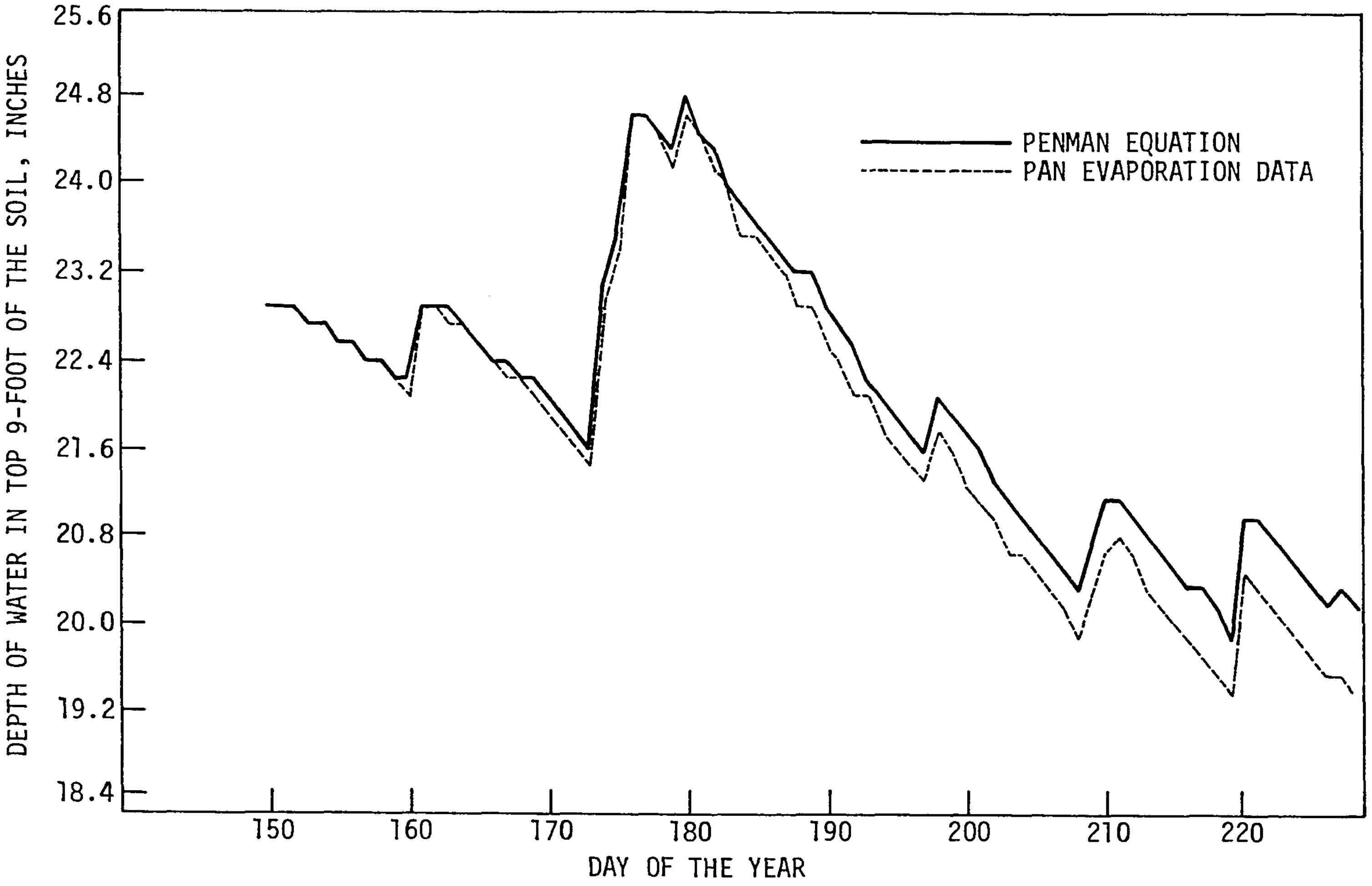

Figure 7. Predicted soil mositure in the top 9-foot root zone under corn, using Penman equation and pan evaporation data, during the 1968 growing season on the North-East Gingles Watershed

Table 1. Comparison of measured and predicted depth of surface runoff using Penman equation and pan evaporation data for the year 1968 on Gingles NE Watershed

Date	Measured runoff (centimeters)	Predicted runoff (centimeters)	
		Penman equation	Pan data
6/23	trace	0.09	0.12
6/24	0.61	0.72	0.74
6/25	0.96	0.99	0.98
6/29	0.30	0.19	0.22
8/8	0.68	0.73	0.84
Total	2.55	2.72	2.90

Based on these results, Equation 62 is used in the model to predict daily potential evapotranspiration.

Distribution of potential evapotranspiration over 24 hours of the day is assumed (Anderson, 1975) to be:

Midnight to 4:00 a.m., 2.4% of total daily potential

4:00 a.m. to 8:00 a.m., 4.8% of total daily potential

8:00 a.m. to 12:00 noon, 29% of total daily potential

Noon to 4:00 p.m., 39.7% of total daily potential

4:00 p.m. to 8:00 p.m., 19.5% of total daily potential

8:00 p.m. to Midnight, 4.6% total daily potential.

Evapotranspiration

A detailed flow chart for evapotranspiration component is given in Appendix A. The procedure used is the one developed by Saxton (1972) and modified by Anderson (1975). Since no modification of this subroutine was made and it is well-described by Saxton (1972) and

Anderson (1975), the reader is referred to the original works for more details.

Interception

The interception component which was originally developed by Anderson (1975) was used with no modification. A detailed flow chart of the component is shown in Appendix A.

Plant model

In contrast to hydrologic models originally developed for very large watersheds where streamflow is the main concern, the plant growth has to be considered if the model is supposed to simulate the hydrology of the area continuously. The present model was developed to simulate the surface runoff, evapotranspiration, soil moisture storage, and the flow to tile drains or deep percolation over a growing season. On a small agricultural watershed, the components of the hydrologic cycle of over-riding importance for simulating long-term water yield and soil moisture are infiltration and evapotranspiration. These two components are interrelated through the plant system, since the amount of soil moisture stored in the root zone affects both the infiltration rate and evapotranspiration rate, and the evapotranspiration rate depends upon seasonal changes in crop canopy and root system.

Considering these facts, the importance of having a plant growth model to simulate hydrologic processes over a long period of time is obvious. Three factors in the plant system development are of primary importance to the water balance model (Saxton, 1972, and Anderson, 1975). They are crop canopy development, crop root system development, and fraction of the existing crop canopy which is actively transpiring. In the present version of the model, the value of these factors at different stages of the growing season is input to the system. At the beginning of each day, the main program calls the subroutine plant (PLANT) to interpolate the value of crop canopy, root distribution system, and the percent of the existing crop canopy which is actively transpiring to be used in evapotranspiration subroutine (ET).

Variation of crop canopy and fraction of the existing crop canopy which is actively transpiring, over the growing season, are shown in Figures 8 and 9, respectively. Crop root distribution system in each layer of the soil and its variation with time is shown as Table 2.

The presence of a plant growth model in any continuous watershed modeling is essential. However, lack of data related to the plant system development, considering different conditions which may exist from one year to another or from one location to another location, makes it difficult to develop an exact model of plant growth. It is known that any modification in crop canopy and root system will have a distinct effect on interception, evapotranspiration, and soil moisture distribution throughout the soil profile, and, consequently, on surface runoff and sediment yield. Considering these facts, the plant growth component is probably the weakest element in the hydrologic modeling of an agricultural watershed.

Overland flow routing component

Overland flow is defined as the movement of water over the land surface to the stream channel system. Overland flow is sometimes

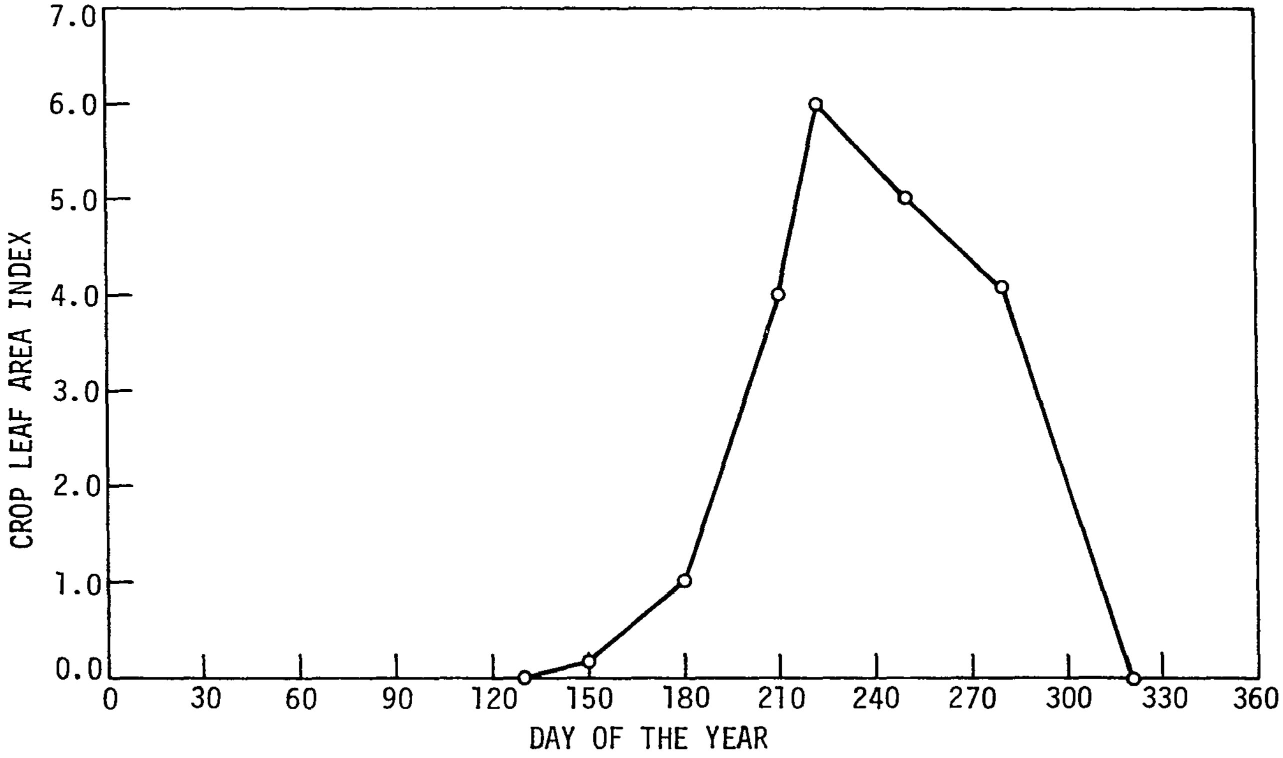

Figure 8. Crop leaf area development curve for corn used in the plant system development subroutines

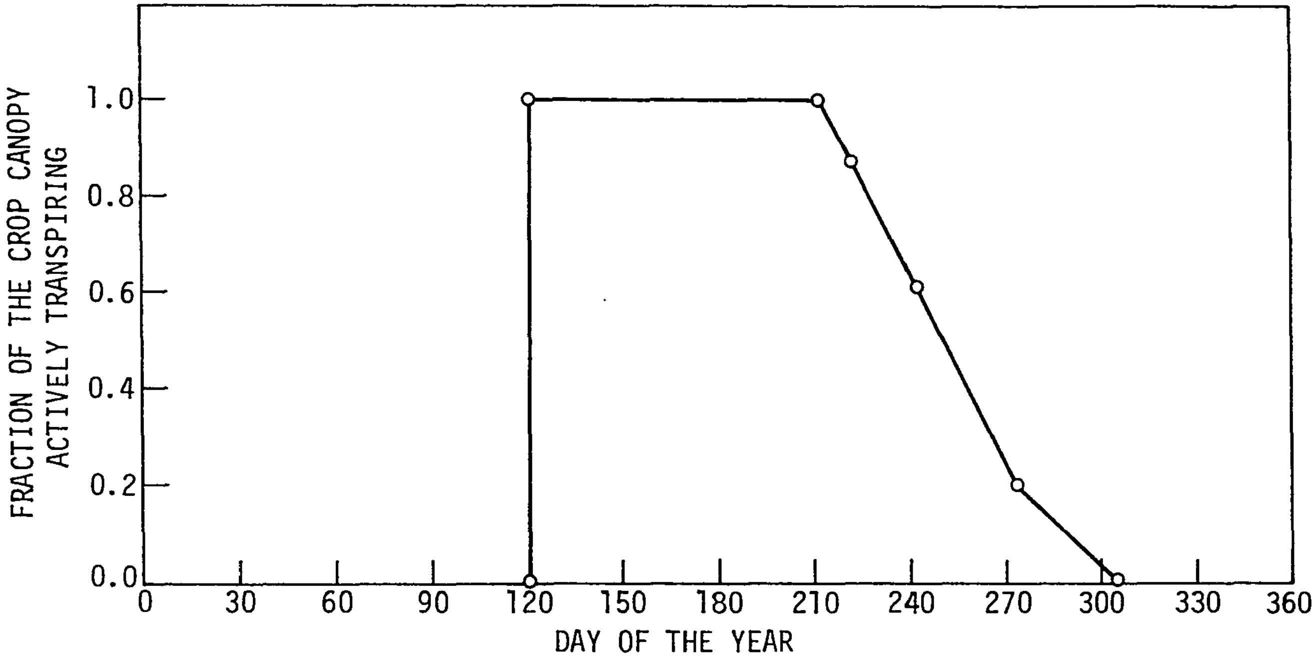

Figure 9. Curve showing the fraction of the crop canopy actively transpiring at any time during the growing season as used in the plant system development subroutines

Table 2. Distribution of root system of corn for each soil layer and period of the growing season as used in the model (percent of total)

Soil depth meters (feet)	Day of the year									
	1-130	130-158	158-165	165-178	178-185	185-192	192-199	199-206	206-213	213-
0.0 -0.15 (0.0 -0.5)	0.0	100.0	50.0	40.0	35.0	34.0	33.0	32.0	31.0	30.0
0.15-0.30 (0.5 -1.0)	0.0	0.0	50.0	27.0	26.0	25.0	25.0	25.0	25.0	25.0
0.30-0.46 (1.0 -1.5)	0.0	0.0	0.0	18.0	17.0	16.0	12.0	10.0	8.0	6.0
0.46-0.61 (1.5 -2.0)	0.0	0.0	0.0	13.0	10.0	9.0	8.0	7.0	6.0	5.0
0.61-0.76 (2.0 -2.5)	0.0	0.0	0.0	2.0	6.0	7.0	6.0	5.0	4.0	4.0
0.76-0.91 (2.5 -3.0)	0.0	0.0	0.0	0.0	4.0	5.0	5.0	4.0	4.0	4.0
0.91-1.07 (3.0 -3.5)	0.0	0.0	0.0	0.0	2.0	3.0	4.0	4.0	4.0	4.0
1.07-1.22 (3.5 -4.0)	0.0	0.0	0.0	0.0	0.0	1.0	4.0	4.0	4.0	4.0
1.22-1.37 (4.0 -4.5)	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.0	4.0	4.0
1.37-1.52 (4.5 -5.0)	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	4.0	4.0
1.52-1.83 (5.0 -6.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0	4.0
1.83-2.13 (6.0 -7.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0
2.13-2.44 (7.0 -8.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
2.44-2.74 (8.0 -9.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

referred to as sheet flow, since it is characterized as a thin sheet of water flowing over the land surface (Fleming, 1975). Interactions between overland flow and infiltration need to be considered, since both processes occur at the same time. During overland flow, water held in detention storage remains available for infiltration. Surface conditions such as roughness (irregularity) made by tillage or cultivation activities, heavy turf, or very mild slopes that restrict the velocity of overland flow tend to reduce the total quantity of runoff by allowing more time for infiltration. The storage capacity of a watershed acts as a reservoir which attenuates the short high intensity rainfall bursts and reduces the peak outflow rate from overland flow. Since the storage capacity is limited, and in any rainfall-runoff event the available storage changes as a function of time, continuous estimates of detention storage as well as the continuous outflow rates from overland flow are required.

The overland flow process has been studied by many investigators. A wide range of methods for estimating the overland flow depths and velocities over a rough land surface has been applied. The only rigorous general methods for simulating unsteady overland flow are finite difference techniques for the numerical solution of the governing partial differential equations, the continuity and momentum equations (Crawford and Linsley, 1966). To apply this method, the watershed has to be divided into small elements. For each element the excess precipitation has to be calculated, and then using the numerical solutions of continuity and momentum equations, the calculated excess precipitation has to be routed. One of the disadvantages of this method, especially for continuous simulation of hydrologic processes over a long period of time, is the computer time required to simulate overland flow. In addition, even though the method is good mathematically, the accuracy to be gained by using finite difference methods for overland flow is still subject to question because of the limited accuracy of the basic data. In the last decade there have been significant advances in the science of surface water hydraulics which have resulted in the development of a substantial simplification of the flow equations. This simplification is called the kinematic wave approximation. "With further advances in computer technology and measurement techniques and with further increases in the need for more detailed information, a time will come when the rigorous solution will be justified in deterministic simulations" (Fleming, 1975).

Present deterministic simulation techniques attempt to approximate the process of overland flow by use of a combination of semiempirical equations based on average values of the land surface parameters governing the process. These parameters include the length, slope, and roughness of overland flow paths and the depth of surface detention.

Average values of lengths, slopes, and roughness of overland flow in the Manning and continuity equations are used in the Stanford Watershed Model (Crawford and Linsley, 1966) to continuously calculate the surface detention storage D_e. The overland flow discharge rate is then related to D_e. This approach is followed in this study with modifications to take into account the changes in surface conditions over time.

In a very large watershed, the channel system and its hydraulic properties govern the shape of the hydrograph; in a small agricultural watershed, where overland flow is the source of the storm hydrograph (neglecting the effect of interflow), surface conditions have to be considered in more detail. Overland flow is assumed to be a sheet of water flowing over the whole watershed. However, this is not the case. As soon as precipitation starts, infiltration of water into the soil will occur. If the rate of precipitation is greater than the rate of infiltration which is calculated by infiltration (INFILT) subroutine, the excess water, which is called precipitation excess after infiltration (PEAI), will be collected in the depressions. When the depressions are filled with water, the water in excess to depressional storage will start to run off. The runoff water will not flow as a thin sheet layer of water, but tends to concentrate in small rills and continue to flow to the channel system. Thus, changes in the surface conditions will have pronounced effects on the overland flow rate and volume.

Early in the spring, when the soil is tilled before planting, surface storage is at its maximum. As the time passes, under the action of rainfall kinetic energy and overland flow runoff, the surface irregularities tend to break down, and surface storage produced by tillage reaches its minimum value.

Small rills which have developed from runoff water are not very well-established at the beginning of the event. As the time passes and more water runs into the rills, they become established, and resistance to flow reduces to its minimum value. Surface water storage at any time is assumed to be:

$$SWS = VOLDPR + PEAI - PUDLE \qquad 63$$

where SWS = depth of surface water storage, in

VOLDPR = depth of water in depressional storage, in

PEAI = depth of precipitation excess after infiltration, in

PUDLE = depth of water held in excess of VOLDPR, due to tillage, in.

Depth of water held in excess of VOLDPR, due to tillage at any time, is assumed to be a function of depth of overland flow from the time of tillage and a maximum runoff depth which is required to smooth the roughness resulting from tillage.

$$PUDLE = PUDLE1 - \frac{TRST}{TRSTM} (PUDLE1 - PUDLE2) \qquad 64$$

where PUDLE1 = initial depth of water held by puddles just after tillage, in

PUDLE2 = final depth of water held by puddles, which is assumed to be zero in most cases, in

TRST = depth of overland flow runoff from the time of tillage, in

TRSTM = (maximum) depth of overland flow required to remove the irregularities, in.

Probably, the rate of reduction of PUDLE is not only a function of overland flow volume but is a function of the rate of runoff as well. Because of the lack of information, rate of reduction is assumed to be a function of overland flow volume.

Manning's roughness coefficient, n, is assumed to be a variable. Right after tillage, when the rills are not well-formed, Manning's n has its maximum value and is assumed to be reduced to its minimum value in the same way that PUDLE is reduced.

$$\mathrm{OFMN} = \mathrm{OFMN1} - \frac{\mathrm{TRST}}{\mathrm{TRSTM}} (\mathrm{OFMN1} - \mathrm{OFMN2}) \qquad 65$$

where OFMN = Manning's n, at any time

OFMN1 = initial value of Manning's n

OFMN2 = final value of Manning's n.

Values of PUDLE1, PUDLE2, OFMN1, OFMN2, TRST, and TRSTM are to be evaluated by calibration.

Manning's equation is used (Crawford and Linsley, 1966) to derive a relation between surface detention storage at equilibrium, the supply rate to overland flow, Manning's n, and the length of slope of the flow surface. The amount of surface detention storage at equilibrium is:

$$D_e = \frac{0.000818\ i^{0.6}\ n^{0.6}\ L^{1.6}}{S^{0.3}} \qquad 66$$

where D_e = the surface detention storage at equilibrium, ft^3/ft

i = the rainfall rate, in/hr

S = the slope, ft/ft

L = the length of overland flow, ft.

The overland flow discharge rate is next determined as a function of detention storage from

$$q = \frac{1.486}{n} S^{1/2} (D/L)^{5/3} \left(1.0 + 0.6\left(\frac{D}{D_e}\right)^3\right)^{5/3} \qquad 67$$

where q = the overland flow discharge rate per ft of width, $ft^3/sec/ft$

D = the average detention storage during the time interval, ft^3/ft.

The equation also applies during the recession that occurs after rain ceases, but the ratio D/D_e is assumed to be 1.0.

For each time interval, ΔT, an end-of-interval surface detention, D_2, is calculated from the initial value, D_1, plus any water added, ΔD, to surface detention storage during the time interval, less any overland flow discharge $\bar{q}$ that escapes from detention storage during the time interval and the water which is held in depressions due to tillage. This is simply an expression of continuity, or

$$D_2 = D_1 + \Delta D - \bar{q}\,\Delta t - \mathrm{PUDLE}. \qquad 68$$

The discharge $\bar{q}$ is found from Equation 67 using a value of $D = (D_1 + D_2)/2$. Equations 63-68 allow the complete determination of overland flow by use of basin-wide values of the average length, slope, and roughness of overland flow. Flow chart for overland flow subroutine (OFROUT) is shown in Appendix A.

EROSION AND SEDIMENT YIELD PROCESSES UTILIZED IN THE MODEL

Introduction

In order to model the erosion and sediment transport processes, researchers have conceptualized the system in different ways. One of the recent ideas is that of dividing the erosion sources into rill and interrill erosion. Hydrologically, a watershed may be conceptualized as having overland flow, channel flow, and subsurface flow components, with overland flow component being the major one as far as upland erosion and sedimentation are concerned. Although overland flow is usually analyzed as a broad shallow flow, it usually concentrates in many small definable channels (Foster, 1971, 1978). Erosion in these small channels (rills) is rill erosion, while erosion on areas between the rills is interrill erosion (Meyer *et al*., 1975). The idea of rill and interrill erosion is used in this study to simulate the sources of erosion. A flow chart for the erosion and sediment transport model is shown in Appendix A.

Interrill Erosion

Interrill erosion is known as that part of erosion which takes place on surface area between the small definable channels (rills). The source of energy to detach the soil particle is the rainfall energy. Many of the rainfall characteristics, raindrop size and mass, drop impact velocity, orientation of rainfall to the soil surface, and the depth of accumulated water over the soil surface should be considered conceptually in an ideal interrill erosion simulation. Because of the difficulties involved in estimating these parameters on a field basis, researchers have tried to relate the erosion due to rainfall to its intensity, which can be measured with good accuracy by using a recording rain gage.

Laboratory studies by different researchers (Moldenhauer and Long, 1964; Meyer and Wischmeier, 1969; Bubenzer and Jones, 1971; Foster and Meyer, 1975) show that detachment due to the rainfall is proportional to the intensity of rainfall to a second power. Based on these findings, Foster (1978) suggested Equation 44 for interrill detachment. The functional form of this equation with intensity to the second power is a good representation of detachment by rainfall. Therefore, the equation used in this study to simulate the interrill erosion is:

$$Di = C_1 K_i i^2 \qquad 69$$

where Di = rate of detachment by rainfall, $kg/m^2.hr$

K_i = soil erodibility factor for detachment by raindrop impact, $kg.hr/N.m^2$

i = rainfall intensity, cm/hr

C_1 = a parameter to be evaluated by calibration.

Other important factors to be considered in interrill erosion are slope steepness and length, crop cover, crop residue, soil surface roughness (tillage effect), and depth of accumulated water on the soil surface.

Effect of slope length and steepness on interrill erosion

The slope length, which is the length the overland flow water moves to the channel, seems not to be a major factor in estimating the interrill erosion. A study by Meyer *et al*. (1975) showed that interrill detachment is not a function of slope length, even though detachment increased as slope length increased for the first few feet of the slope length. Foster *et al*. (1977b) suggested that interrill detachment is not a function of slope length. In the present study, it is accepted that slope length has no effect on detachment by rainfall.

Interrill detachment has proven to be a function of slope steepness. Data by Young and Mutchler (1969) showed that an increase in interrill slope increased soil loss. Data of Meyer *et al*. (1975) indicated that the relationship of interrill detachment to slope steepness was linear for slopes less than 15 percent. Using experimental data, Foster (1978) suggested the following equation, which is used in the model to evaluate the effect of slope steepness on the detachment by rainfall.

$$S_i = 2.96(\mathrm{Sin}\ \theta)^{0.79} + 0.56 \qquad 70$$

where S_i = factor representing the effect of slope steepness

θ = angle of slope, degree.

Effect of crop canopy on interrill erosion

Crop canopy is one of the important factors to be considered in detachment by rainfall. Leaves and branches that do not directly contact the soil have little effect on amount and velocity of runoff from prolonged rains, but they reduce the effective rainfall energy by intercepting falling raindrops (Wischmeier and Smith, 1978).

Water drops falling from the canopy may regain appreciable velocity but less than the terminal velocity of free-falling raindrops.

The effect of crop canopy on interrill erosion can be described by modifying the rainfall intensity to be an effective rainfall intensity. To modify the rainfall intensity to its effective rainfall intensity, Foster (1978) suggested the following equation:

$$i_{eff}^2 = i^2 \, [a + (1-a)(m_{ca}V_{ca}^2/m_pV_p^2)(i_{can}/i)] \qquad 71$$

where i_{eff} = the effective rainfall intensity

a = fraction of open area where drops may strike the ground unintercepted by the canopy

i_{can}/i = the fraction of the total rainfall reaching the ground by falling from the canopy as reformed drops

m_{ca} = mass of the drops falling from the canopy

m_p = mass of the drops passing unhindered through the canopy

V_{ca} = impact velocity of the drops falling from the canopy

V_p = impact velocity of the unhindered drops.

According to the above equation, the amount by which energy expended at the soil surface is reduced depends on the height and density of the canopy. Since it is difficult to obtain the factors required by the above equation, the canopy effect is evaluated using the data by Wischmeier and Smith (1978). Assuming an average fall height of drops from canopy of 1 meter, the following relationship is obtained:

$$\mathrm{INTFAC} = 1.0 - 0.70 \left(\frac{\mathrm{PCC}}{100}\right) \qquad 72$$

where INTFAC = factor for canopy effect on intensity of rainfall

PCC = percent of ground covered by the canopy, obtained from hydrologic model.

Effective intensity is then assumed to be the product of intensity of rainfall and INTFAC. The effective intensity (EFFINT) is to be used in Equation 69 rather than intensity to calculate the detachment by rainfall.

Effect of crop residue on interrill erosion

Crop residue, with its mulching effect, dissipates the energy of raindrops striking the cover directly. Crop residue is one of the most efficient ways of reducing erosion. Erosion by rainfall theoretically would be negligible if 100 percent of the soil surface were covered by the crop residue. A first approximation of detachment by raindrop impact is to assume Di as proportional to the fraction of the soil surface left exposed to direct raindrop impact (Foster, 1978). Data by Lattanzi *et al.* (1974) and Sloneker and Moldenhauer (1977) were used to develop a relationship between the percent area exposed and the amount of crop residue left on the ground. The relationship which was obtained is as follows:

$$RESFAC = e^{-0.37(RESIDU)} \tag{73}$$

where RESFAC = reduction factor due to the crop residue (for corn)

RESIDU = amount of residue left on soil surface, T/HA.

The detachment by rainfall as affected by crop residue is the product of Di and the reduction factor related to the residue (RESFAC).

Effect of surface roughness (tillage) on interrill erosion

It is assumed that tillage has no effect on interrill erosion (Foster, 1978). The major effect of tillage on interrill erosion is that of transport capacity of interrill flow. Tillage increases the soil surface roughness and creates numerous small puddles which trap part of the detached particles. This effect is a reduction factor for interrill detachment. As discussed previously in the hydrology section related to overland flow, the depressions created by tillage tend to diminish with time as a function of volume of runoff. This concept is used to obtain a relationship to define the effect of tillage on interrill transport capacity. The relationship used is:

$$RF = RF1 + \frac{TRST}{TRSTM}(1.0 - RF1) \qquad 74$$

where RF = roughness factor to be used as a reduction factor

RF1 = initial roughness factor

TRST = volume of overland flow since last tillage, in

TRSTM = maximum volume of overland flow required to reduce the created puddles to a minimum value, in.

The above relationship states that the reduction factor immediately after tillage, when TRST is zero, is at its minimum value, RF1. This means some of the particles, in proportion to RF1, will be trapped. As TRST increases, the roughness created by tillage reduces. The roughness factor will be at its maximum value of 1.0 when TRST is the same or greater than TRSTM, the time that PUDLE is at its minimum value, and all of the detached particles are assumed to be available for transport.

Effect of surface water depth on interrill erosion

It is generally believed that surface water depth affects the erosion by rainfall. Study by Mutchler and Young (1975) indicated that raindrop impact was most erosive when a very thin layer of water was present (approximately one-fifth drop diameter) and was relatively nonerosive when the soil was covered with a water depth of three drop diameters or greater. Some researchers have tried to include the effect of surface water depth in their model to estimate the interrill erosion (David and Beer, 1975; Smith, 1977; Yoo, 1979). It is generally assumed that interrill erosion decreases exponentially as the depth of surface water increases. The same assumption was made in the present study. The relationship assumed to represent this effect is:

$$\text{DEPTHF} = e^{-\text{DF}(\text{VOLDPR})} \qquad 75$$

where DEPTHF = depth factor

DF = a decay constant, 1/in

VOLDPR = volume of water in depressional storage, in.

It is assumed that total energy of rainfall is dissipated when VOLDPR is equal or greater than 0.5 inches (1.27 centimeters), which means DEPTHF would be zero.

The effect of crop canopy, crop residue, surface roughness created by tillage, and surface water depth is calculated in any time period and is multiplied by detachment by rainfall, Di, to obtain the corrected interrill erosion.

Rill Erosion

Rill erosion is that part of erosion which takes place on the overland flow areas from small definable channels under the degrading forces of running water. Interrill erosion can go unnoticed, because it removes sediment in a uniform layer. However, for a susceptible soil, rill erosion is immediately obvious, because flow concentrates in many small eroded channels (rills), and, therefore, rill erosion is the most identifiable characteristic indicative of serious erosion on a particular area (Foster, 1978).

Total rill erosion on an upland area is the sum of the erosion in each individual rill. The complexity of the erosion processes in a single rill leads to the assumption that the total of the erosion rates for all rills on a cross section of some distance downslope can be estimated. Foster (1978) suggested Equation 46 to estimate rill erosion. The functional form of the equation is accepted in this study; the relationship used in the model is:

$$Dr = C_2 \, K_r \, \tau^{C_3} \qquad 76$$

where DR = rill erosion rate, kg/m^2 of total area.hr

C_2 = a constant to be calibrated

K_r = soil erodibility factor for rill erosion, $kg.hr/N.m^2$

C_3 = an exponent to be calibrated

τ = flow shear stress, N/m^2.

The flow shear stress, τ, is replaced in the model as follows:

$$\tau = \gamma dS \qquad 77$$

where γ = unit weight of water, N/m^3

d = depth of flowing water, m

S = slope of the overland flow, percent.

If any crop residue is left on the soil surface, Foster (1978) suggested replacing τ in the above equation with

$$\tau = \frac{\gamma V^2 f_s}{8g} \qquad 78$$

where V = flow velocity with cover, m/sec

f_s = friction factor due to the soil

g = acceleration due to gravity, m/sec^2

γ = unit weight of water, N/m^3.

This equation permits estimation of the potential detachment rate (capacity) of the rill erosion, assuming that the transport capacity of flow to transport both sediment yields from interrill and rill areas is not a controlling factor. In other words, rill erosion is assumed to be dependent on interrill erosion and occurs at its capacity rate if no sediment is present in the flow or transport capacity is not limiting. For this reason, Foster and Meyer (1972a) believed that if the flow transport capacity is partially filled, a reduction may be assumed for rill erosion rate. If the transport capacity is the same as interrill erosion, rill erosion is assumed to be zero, and in the case that transport capacity is less than interrill erosion, the difference is assumed to be deposited. Besides the reductions in rill erosion due to crop residue and the limitations of transport capacity, the effect of the other factors involved has to be considered.

Effect of tillage and rill stabilization on rill erosion

One of the important factors that should be considered in estimation of rill erosion is the effect of tillage and rill stabilization. Tillage increases the soil susceptibility to rill erosion. Erosion on undisturbed plots at Zanesville, Ohio, decreased in 5 years to 0.44 of that immediately after the last tillage on the plots (Wischmeier, 1975). All of the reduction in this case is credited to a reduction in rill erosion (Foster, 1978). The effect of tillage on rill erosion is also believed to be a function of type of tillage and moisture content at tillage time (Foster, 1978).

As rills deepen, they may tend to stabilize and decrease the rill erosion. This is especially true if the bottom of the rills reach dense restricting layers like a plow sole. Because of this, rill erosion decreases with further erosion. The stabilizing, with consequent decreasing amounts of material removed, was treated as an exponential decay process in a model by Bruce _et al_. (1975). The reduction factor used in their model is:

$$P = e^{(f1 + f2 \, . \, TR)} \qquad 79$$

where P = rill reduction factor

TR = total rill erosion.

f1 and f2 are parameters. In the present model, the reduction in rill erosion due to stabilization is also assumed to be an exponential decay function, and the relationship used is as follows:

$$RILLF = e^{-RC(TRILL)} \qquad 80$$

where RILLF = rill reduction factor

TRILL = total rill erosion since last tillage, T/HA

RC = a coefficient to be determined by calibration.

Total rill (TRILL) is assumed to be zero immediately after tillage. During each rainfall event, for each time increment, actual rill erosion is calculated and TRILL is updated for the next time increment. Total rill erosion (TRILL) at the end of a rainfall event is the initial value of TRILL for the next event.

Transport Capacity

Different relationships have been used by researchers to describe transport capacity. Few of these relationships have been presented. All of these relationships have an adequate functional form and, given proper parameter values, generally can be used to adequately simulate deposition (Foster, 1978). The Yalin equation (1963) seemed most applicable based on the assumptions used for its derivation (Foster and Meyer, 1972b). Of the other bed load type equations, the Yalin equation best fits data for deposition of sand and coal by overland flow from the studies of Foster and Huggins (1977) and Davis (1978), and deposition of soil aggregates on a 35 foot long concave field plot (Foster, 1978).

The Yalin equation, as used in the present model, is:

TC = C * DELTA*(1.0-(1.0/SIGMA)*ALOG(1.0+SIGMA))*WD* 81
DIA*SHVEL*SG

SIGMA = A * DELTA 82

DELTA = (Y/YC) - 1.0 (when Y < YC, SIGMA = 0.0) 83

$$A = 2.45\ (SG)^{0.4}\ (YC)^{0.5} \quad 84$$

$$Y = (SHVEL)^{2.0}\ /\ (SG-1.0)*G*DIA \quad 85$$

$$SHVEL = (G*OFRCM*OFSS)^{1/2} \quad 86$$

where OFSS = slope of the soil surface, assumed to be the same as slope of energy gradeline

OFRCM = depth of overland flow, assumed to be the same as hydraulic radius, cm

G = acceleration due to gravity, 980 cm/sec^2

DIA = particle diameter, cm

SG = particle specific gravity

YC = ordinate from the Shield's diagram

WD = mass density of water, 1.0 gm/cm^3

SHVEL = shear velocity, cm/sec

TC = transport capacity of overland flow, gm/cm.sec

C = a coefficient.

The constant coefficient, C, was empirically derived by Yalin (1963) to be 0.635. The empirical constant was 0.8 when the equation was calibrated to Young and Mutchler's data, when assuming a DIA of 0.2 mm and an SG of 2.0 (Neibling and Foster, 1977).

Sediment in overland flow is a mixture of particles having different sizes and densities. Either a representative size and density must be selected or the sediment transport equation must be modified. In the present study, a representative diameter size of 0.15 cm and specific gravity of 2.0 was selected.

At the end of each time increment, calculated transport capacity and total available detachment are compared. If transport capacity is greater than or equal to the total available detached particles, rill erosion will occur at its full capacity considering reductions due to above mentioned factors, and no deposition will occur. If transport capacity is less than total available detachment, rill erosion which is assumed to be dependent on interrill erosion will be less than its full capacity and is assumed to be the same as the difference between transport capacity and interrill erosion. At the beginning of each rainfall-runoff event, when rainfall has started but runoff has not yet resulted, detachment by rainfall is assumed to be deposited. Some of the deposited material is assumed to be trapped by puddles created by tillage and will not be available for transport at the next time increment. The relationship for estimates of that part of the deposited material which is available for transport is a function of availability of puddles and is assumed to be:

$$\mathrm{TDEPOS} = \mathrm{TDEPOS}\ (1.0 - \frac{\mathrm{PUDLE}}{\mathrm{PUDLE\ 1}}) \tag{87}$$

where TDEPOS = total deposited material from previous time increments, T/HA.

The terms PUDLE and PUDLE 1 have been defined.

In case any deposited material is left at the end of rainfall-runoff event, all of deposited material, reduced for the PUDLE effect, will be available to be transported if another rainfall event occurs the same day. For the following days, or the next day, if the soil moisture of the first layer is the same or greater than the saturation soil moisture, the same assumption is made. Otherwise, deposited material tends to attach to the soil body. The rate of attachment may depend on soil moisture, soil texture and structure, percent of organic matter, and other factors. In this study, it is assumed that total deposited material decreases exponentially as a function of soil moisture of the top layer. At the beginning of each day, soil moisture of the first layer is estimated, and total deposited material is updated for that day. The relationship used to serve this purpose is:

$$\text{TDEPOS} = \text{TDEPOS}\ (1-e^{-\text{ALPHA*ESOILM}}) \qquad 88$$

where ALPHA = a coefficient

ESOILM = estimated soil moisture of the first layer of the soil, in.

If it is assumed that at field capacity of the top layer of soil, 50 percent of deposited material is attached to the bulk of the soil, the constant ALPHA would be about 0.25, the value which is used in the model.

CALIBRATION AND EVALUATION OF THE MODEL

Introduction

In this section, the general information related to the experimental watersheds from which calibration and evaluation of the hydrologic and sediment yield models were made is given. Availability of data required for the model, adjustment and procedures for parameter calibration, and their calibrated values, are discussed.

Description of Experimental Watersheds

A research program was initiated on Gingles Watersheds in 1963 by the Departments of Agricultural Engineering and Agronomy at Iowa State University to better describe the hydrology of the area. The six experimental watersheds, commonly referred to as the Gingles Experimental Watersheds, are located one mile west of the Western Iowa Experimental Farm (Experimental Farm hereafter) near Castana in Monona County, Iowa (see Figure 10). Detailed information describing data that were taken during the period from 1963 through 1975 were provided by DeBoer *et al*. (1971) and files of the Agricultural Engineering and Agronomy departments.

These watersheds are located in the loess hills near the Missouri River Valley and range in size from 0.55 to 1.75 hectares (see Figure 11). The north and south drainage areas were divided by dikes centered in the natural waterways. The north drainage area is divided into North-West (NW) and North-Middle (NM); the south drainage area is divided into South-West (SW) and South-Middle (SM) watersheds. The east drainage areas are natural watershed areas defined as the

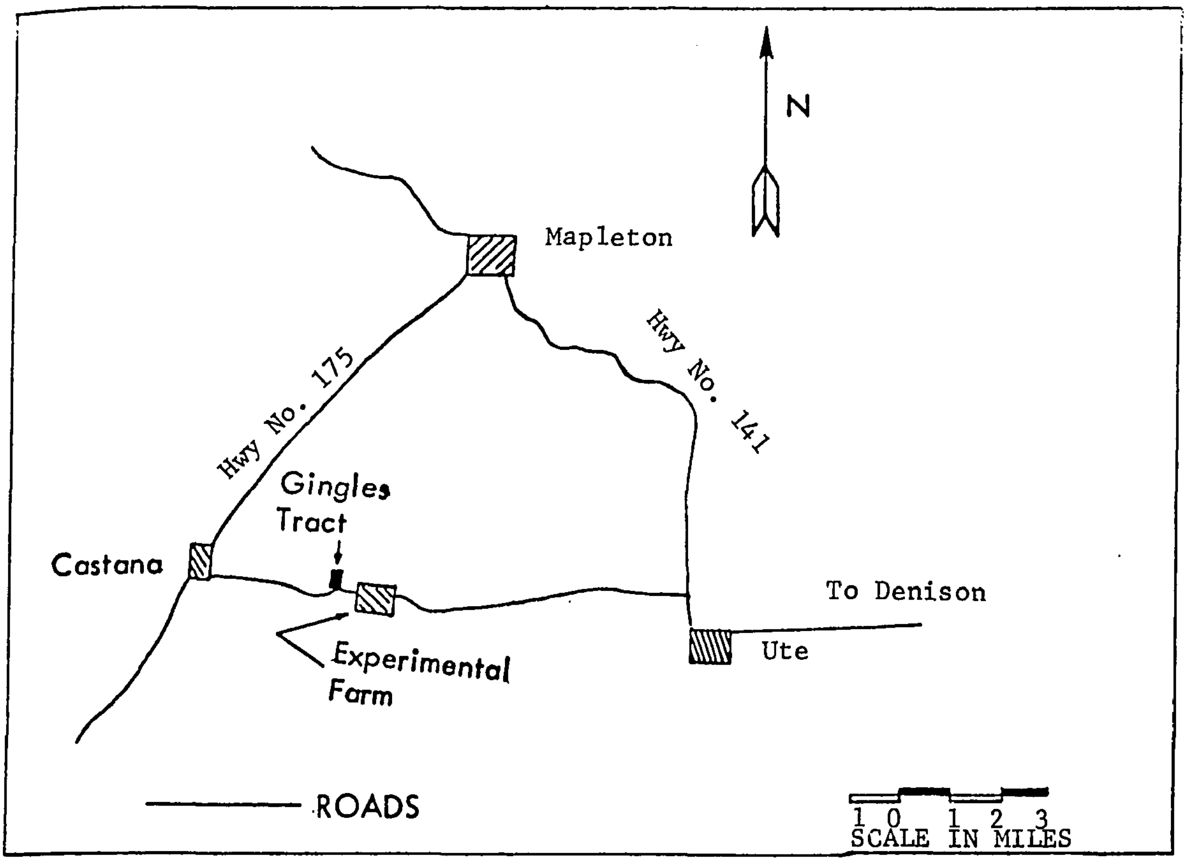

Figure 10. Location of Gingles Experimental Watersheds

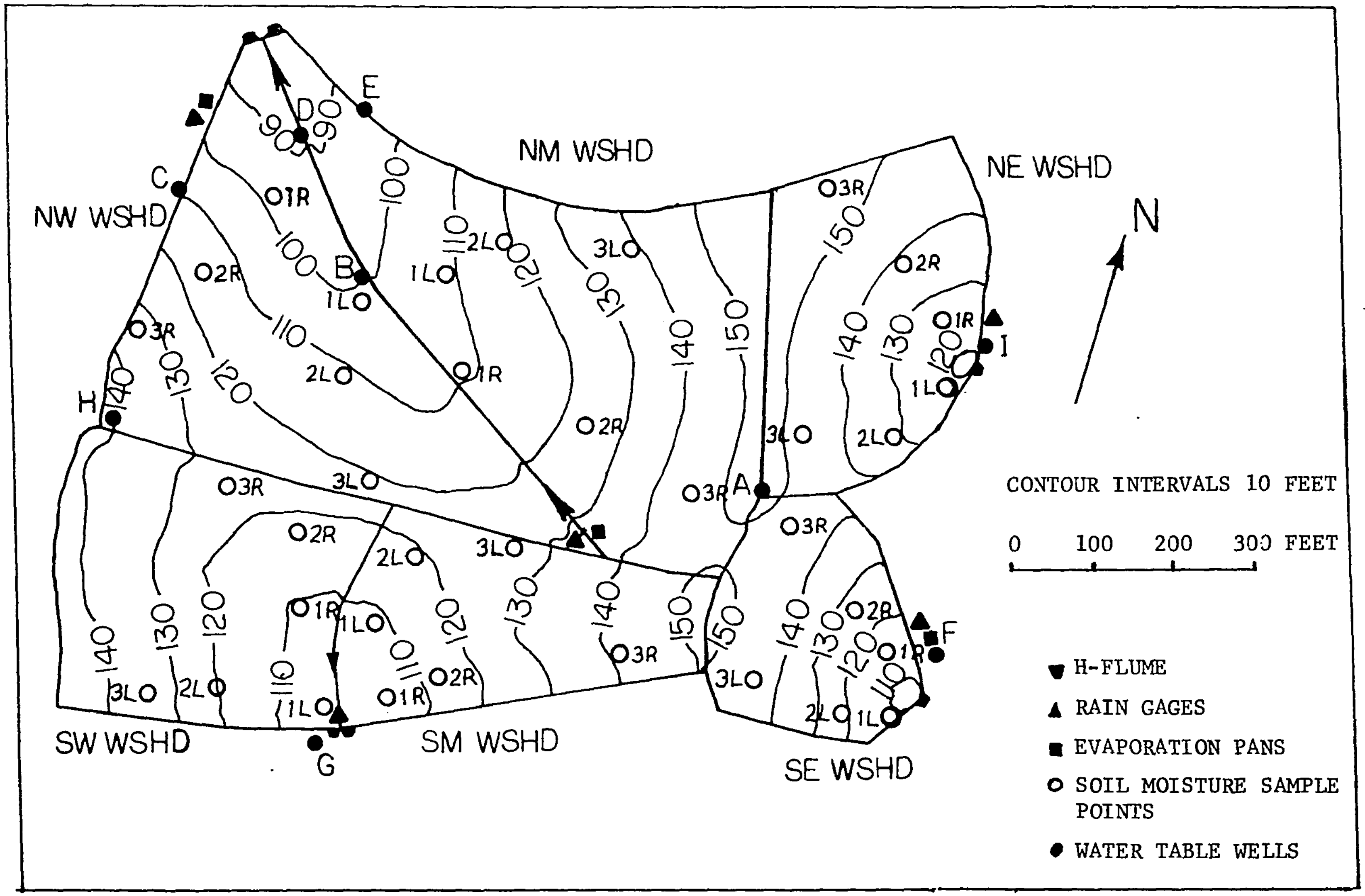

Figure 11. Gingles Experimental Watersheds

North-East (NE) and South-East (SE) watersheds making a total of six research watersheds.

The deep loess soils on the watersheds cover a glacial till plain, are high in silt content, and have relatively uniform textural composition with depth. The Monona soil type is found on the upper areas of the watersheds, the Ida soil type on the eroded soil slopes, and the Napier soil type at the footslopes (Baker and Johnson, 1978).

During the study period of 1972 through 1975, the watersheds were in continuous corn. The watersheds were paired to provide two replications of tillage methods. Watersheds NE and SM were conventionally plowed and planted, NW and SE were buffalo-till planted, and SW and NM were ridge planted. Table 3 shows the size of each watershed and the tillage treatment on each of them.

Table 3. Watershed description and treatments for the period of 1972-1975

Watershed	Size (hectares)	Cropping	Land treatment
NE	0.90	Corn	Contour surface plant
SM	0.78	Corn	Contour surface plant
NW	1.43	Corn	Buffalo till plant
SE	0.55	Corn	Buffalo till plant
SW[a]	1.10	Corn	Ridge plant
NM[a]	1.75	Corn	Ridge plant

[a] The data collected for these watersheds in 1972 should be included with conventional plowing (Baker and Johnson, 1978).

Data Availability

Rainfall data

Two non-recording standard and three recording rain gages were located on the watersheds providing data on the distribution of storm rainfall with respect to both time and space. The location of each of the three recording rain gages is shown in Figure 11. Data from the NE rain gage were used for the NE watershed. For the SM watershed, data from the rain gage located at the border between SM and SW watersheds, known as SW station, were used. In case the rainfall distribution data were missing from either of the two stations for any specific storm, the rainfall distribution data from the other recording station, known as Central Station, were used.

Even though the distances between different stations were a matter of a few hundred feet, the amount and distribution of rainfall with time sometimes differed during the summer months. Some of the difference may be due to weighing mechanism variations in the recording rain gages and also their sensitivity to wind effects. The rest suggests that for this part of the country and this time of the year, the rainfall intensity may be different from one point to another even though not far from each other. This is a key point to be considered in any successful deterministic hydrologic modeling.

Runoff data

Surface runoff was measured by use of six 3-ft H-flumes equipped with water level gages. The gages recorded the depth of water in the flume continuously during the runoff event. The data were used to calculate the rate of runoff and, therefore, to construct the storm hydrograph for any individual storm. It was assumed that no ponding of water above the flumes occurred; no correction was made for the ponding effect.

In many cases, drastic reductions in the sediment transport capacity of flow above and in the flumes occurred near the end of rainfall event and sediment deposited in the flumes. The deposited sediment prevented the recorder from returning to the initial "zero" level. Therefore, that part of the measured hydrograph had to be estimated for those cases. Some sediment deposited above the flumes during severe storms.

Sediment yield data

Sediment samples from each watershed were collected in one liter glass bottles at ports in the sides of H-flumes during the rising stage of runoff. Up to six samples were taken per watershed for each runoff event, the first being taken at a flow of about 1 mm/hr and the last at a maximum of about 75 mm/hr. Sample concentrations collected on the rising side of the runoff hydrograph were combined with flow data to calculate sediment loads associated with that point of the hydrograph. No samples were taken on the receding side of the hydrograph. Using Treynor watershed data (also in the loess soil area of western Iowa), where flow and sediment concentration data for complete runoff events were available, Baker and Johnson (1978) developed a procedure for calculation of sediment concentration for use with flow data from the receding stages, based on the known maximum flow and the sediment concentration for that flow. The relationship developed is:

$$C_t = 0.212C_p + 0.668Q_t/Q_p \qquad 89$$

where C_t = sediment concentrations at any time, t, after peak flow, ppm

C_p = sediment concentration at peak flow, ppm

Q_t = flow rate at any time, t, after peak flow, unit volume/unit time

Q_p = peak flow rate, unit volume/unit time.

The equation had an R^2 value of 0.68 for 65 data points.

Soil moisture data

Soil moisture data on Gingles Watersheds for the years of 1972 through 1975 were not available. Some measurements were made by Shaw[1] on the Experimental Farm one mile east of Gingles Watersheds. The soil moisture on Gingles Watersheds was assumed to be the same as that measured at the Experimental Farm. The measured soil moisture for the top 5 ft of the soil and the date of measurements are shown in Table 4.

Data on soil moisture properties for the Gingles Watersheds were included in Melvin's dissertation (1970). The data included the variation in bulk density throughout the profile and curves for soil moisture content as a function of matric potential and unsaturated hydraulic conductivity. Additional data on moisture content at the wilting point, field capacity, and saturation for western Iowa soils were available from Shaw *et al*. (1959).

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[1] From the file of Dr. Robert H. Shaw, Agronomy Department, Iowa State University, Ames, Iowa, March 1979.

Table 4. Measured soil moisture in inches and the date of measurements on Experimental Farm as used in the model

Soil zone meters (ft)	1972		1973	1974		1975	
	Apr. 11	Oct. 15	Oct. 27	July 27	Oct. 23	Apr. 21	Oct. 24
0-0.30 (0-1)	2.0	2.3	1.9	0.0	0.6	2.40	0.40
0.30-0.61 (1-2)	1.7	1.8	1.6	0.0	0.5	1.70	0.0
0.61-0.91 (2-3)	1.4	1.7	1.6	0.0	0.2	1.30	0.0
0.91-1.22 (3-4)	0.7	1.4	1.8	0.0	0.1	0.50	0.0
1.22-1.52 (4-5)	0.2	1.1	1.6	0.3	0.2	0.70	0.0

Pan evaporation data

Use of pan evaporation data to calculate potential evaporation has already been discussed. For the year 1972 the daily pan evaporation data were measured at three different locations in Gingles Watersheds from late May through August, except for unexplained gaps in the data. An average value of evaporation at these stations was used as a representative pan evaporation for the same period measured at Experimental Farm. For the years 1973, 1974, and 1975, pan evaporation data from Experimental Farm were used.

Calibration of the Model

Data for the year of 1972, the year soil moisture measurements were made at the beginning of the growing season (at Experimental Farm) and pan evaporation data were available at Gingles Watersheds, were used to calibrate the model. The NE watershed of Gingles, which was under conventional tillage, was used for this purpose. Average slope steepness of the watershed, obtained from a contour map, is about 15 percent.

Calibration of hydrologic model

The hydrologic model was calibrated to simulate the overland flow runoff by use of the measured volumes and rates of surface runoff. A trial and error procedure was used to calibrate the parameters. The main objective was to minimize the differences between the measured and predicted volume and rate of runoff. In any trial run, the parameter under study was varied over a reasonable range, while the other parameters were held constant. The predicted volume and rate of runoff were compared with the measured volume and rate of runoff for each individual storm. Considering the other variables, this procedure was continued until a set of calibrated parameters was obtained.

One of the most important components governing the surface runoff is the infiltration process. Parameters related to the infiltration component have major effects on the response of the model and were considered prior to other parameters. The infiltration equation used in the model was the Holtan equation as modified by Huggins and Monke (1968) and presented as Equation 47. Parameters A and P in the Holtan equation are a function of soil moisture; variations in A and P parameters with soil moisture are shown as Figures 4 and 5. Parameter A is also a function of crop canopy and rainfall intensity.

When the model was run with 1972 data and simulated surface runoff was compared with the measured surface runoff, the model was overpredicting at the beginning and underpredicting at the end of the growing season. Part of this difficulty is believed due to surface storage created by the tillage, which is considered in the overland flow routing component, and part due to the effect of tillage on parameter A. Parameter A represents the maximum potential increase of the infiltration capacity above the wet soil value. Immediately after plowing and planting, when the soil is disturbed, the storage and consequently the maximum potential increase of the infiltration capacity increases. This means that the infiltration rate is at its maximum level as associated with this parameter immediately after spring plowing and later, cultivation. As the growing season advances, the compacting effects of rainfall energy, settlement of soil particles, and washed-in fine materials decrease the infiltration rate and increase the surface runoff for equivalent storm events. Data by Moldenhauer and Kemper (1969) were used to evaluate this effect; Equation 49 was developed to meet this need. By appropriate changes of the parameters CE1 and CE2 in this equation, and related parameters in the overland flow component, the problem of overpredicting runoff at the beginning and underpredicting at the end of the growing season was solved.

Other parameters related to infiltration processes are ASOILM, AM, PSFC, and PM. Calibrated values by Anderson (1975) for the year of 1968 on Gingles Watersheds were used. Parameter FCINF, representing wet soil infiltration capacity, was assumed to be constant over the growing season. Infiltration parameter definitions and calibrated values are tabulated in Table 5.

The other set of parameters to be calibrated is that related to the overland flow component which have been used to evaluate the effects

Table 5. Infiltration parameter definitions and calibrated values as used in the model

Parameters	Parameter definition	Calibrated values
CE1	Intercept of the line, plotting the rainfall energy factor (Equation 49) against the summation of rainfall kinetic energy on a semi-log paper, with rainfall energy factor on log scale.	0.125
CE2	Slope of the line plotting the rainfall energy factor (Equation 49) against the summation of rainfall kinetic energy on a semi-log paper, with rainfall energy factor on log scale.	1.25
ASOILM	Maximum value of ASOIL (see Figure 4).	7.00
AM	Exponent coefficient used in Equation 48 to calculate ASOIL. Slope of the curve of ASOIL plotted against AMC (moisture content of the first layer of the soil, percent by volume) on a semi-log paper, with ASOIL on log scale.	-0.160
PSFC	Value of PSOIL at the field capacity of the surface layer. Used in Equation 51 to calculate PSOIL.	1.480
PM	Slope of the PSOIL-AMC curve on log-log paper. Exponent used in Equation 51 to calculate PSOIL.	0.199
FCINFL	Wet soil infiltration capacity, in/hr.	0.14

of surface roughness and surface storage created by tillage on overland flow. Manning's coefficient, which represents the effect of surface roughness on overland flow, was assumed to vary from its maximum value immediately after tillage to its minimum value after a certain amount of surface runoff has occurred. This assumption was made partially to overcome the problem of overpredicting the surface runoff right after the tillage. The functional relationship used to serve this purpose was discussed and then presented as Equation 65. To overcome the problem of overpredicting the surface runoff immediately after tillage, a large unreasonable value of OFMNI, the maximum value of Manning's coefficient, had to be used. It was concluded that another function had to be incorporated in the overland flow component to take care of the surface storage created by tillage. This function was also discussed and presented as Equation 64. The reasoning behind this idea derives from the fact that the depressions created by tillage retain a certain depth of water which will not contribute to the overland flow directly, but is available to infiltration. The amount of surface water retained by depressions was also assumed to vary from its maximum immediately after tillage to its minimum later in the season in the same fashion as Manning's coefficient.

The accumulated depth of surface runoff required to remove the storage created by tillage and reduce OFMN (Equation 65) and PUDLE (Equation 64) to their minimum values was another parameter requiring calibration. These parameters, their definitions, and calibrated values are summarized in Table 6.

The soil moisture content at saturation, which is related to soil porosity, was quite variable according to the data in Melvin's dissertation (1970). Adjustments made within the ranges reported greatly influenced the soil moisture distribution as well as infiltration and surface runoff in the model. The data on soil moisture properties as used in the model are shown in Table 7.

Table 6. Overland flow parameters definitions and calibrated values as used in the model

Parameter name	Parameter definition	Parameter value
TRSTM	Accumulated depth of surface runoff required to remove the puddles created by tillage and reduce OFMN and PUDLE to their minimum values, inches.	0.50
OFMNI	Maximum value of Manning's coefficient. The value used immediately after tillage when TRST (accumulated depth of surface runoff since last tillage) = 0.0.	0.15
OFMN2	Minimum value of Manning's coefficient for overland flow. Manning's coefficient when TRST TRSTM.	0.10
PUDLE1	Maximum depth of water held in puddles immediately after the tillage, inches.	0.50
PUDLE2	Minimum depth of water held in puddles when TRST TRSTM.	0.00

The shortest time period used in the model was 2 minutes, which approached the limit of accuracy of the rain gages. Longer time periods were tested. The effect of length of time periods on the response of the model is discussed separately under sensitivity analysis.

Calibration of erosion and sediment yield model

Parameters related to the erosion and sediment yield model were calibrated after the calibration of hydrologic model was completed. The same procedure which was used to calibrate the hydrologic model was used. The constants of soil erodibility factor, KI and KR, were treated as parameters to be varied over the limited range of

Table 7. Soil moisture content at saturation (SAT), field capacity (FC), wilting point (WP), and saturated hydraulic conductivity (SHC) used in the model

Soil zone meters (feet)	SAT percent by volume	FC percent by volume	WP percent by volume	SHC (cm/hr)
0-0.15 (0.05)	53.0	27.0	9.0	0.50
0.15-0.30 (0.5-1.0)	52.0	26.0	9.5	0.48
0.30-0.46 (1.0-1.5)	50.0	26.0	9.5	0.46
0.46-0.61 (1.5-2.0)	50.0	26.0	9.5	0.44
0.61-0.76 (2.0-2.5)	50.0	26.0	9.5	0.40
0.76-0.91 (2.5-3.0)	48.0	26.0	9.0	0.35
0.91-1.07 (3.0-3.5)	46.0	25.0	9.0	0.30
1.07-1.22 (3.5-4.0)	44.0	25.0	9.0	0.30
1.22-1.37 (4.0-4.5)	44.0	24.0	9.0	0.30
1.37-1.52 (4.5-5.0)	46.0	23.0	8.5	0.30
below 1.52 (5.0)	45.0	23.0	8.5	0.30

published values. It was assumed that soil susceptibility to rill and interrill detachment was the same; values used for KI and KR were equal.

The exponential decay constant, ALPHA, used in Equation 88 represents the rate at which the deposited particles from previous storms attach to the soil body in the field. In other words, the parameter represents the rate at which detached particles become unavailable for transport due to aggregate formation and attachment to the soil body. This parameter was assumed to be a constant throughout the growing season and was evaluated on the basis that 50 percent of detached particles are aggregated and attached to the soil body when the moisture content of the first layer of the soil is reduced to its field capacity. However, the model was not sensitive to this parameter, because the amount of deposited material left at the end of each runoff event was insignificant.

Another parameter representing the effect of roughness created by tillage on transportability of interrill erosion is the initial roughness factor, RF1. The roughness factor, RF, varies from its minimum value immediately after tillage to a maximum of 1.0 according to Equation 74. The RF1 was assumed to be 0.75 based on information by Foster (1978) and was unchanged during the calibration period.

The effect of surface water depth on interrill erosion was considered. Detachment by rainfall was assumed to be zero for surface water depth equal or greater than 0.5 inch. For surface water depth of 0.0 to 0.5 inch, an exponential decay function (Equation 75) was considered. The decay coefficient, DF, was varied over a broad range to test its effect on interrill erosion. It was concluded that for Gingles Watersheds characterized by steep slopes, the effect of surface water depth was insignificant, and the reduction for interrill detachment need not be considered; DF was assumed to be zero.

Parameters that had to be changed to calibrate the erosion and sediment yield model were C1, C2, C3, and RC. The definition and calibrated values of these parameters are summarized in Table 8.

A comparison of measured and predicted surface runoff volume for the events in 1972 calibration period is shown in Table 9. The comparisons

Table 8. Erosion and sediment yield parameter definitions and calibrated values as used in the model

Parameter name	Parameter definition	Calibrated values
KI	Soil susceptibility to interrill erosion as used in Equation 69, $kg.hr/N.m^2$	0.03
KR	Soil susceptibility to rill erosion as used in Equation 76, $kg.hr/N.m^2$	0.03
ALPHA	An exponential decay constant which determines the decreasing rate at which deposited materials become unavailable for transport used in Equation 88.	0.25
RF1	Initial roughness factor. Represents the effect of surface roughness on transportability of detached particles by rainfall. Fraction of detached particles by rainfall available for transport immediately after tillage, when TRST = 0.0. Used in Equation 74.	0.75
DF	An exponential decay constant as used in Equation 75. Represents the effect of surface water depth on detachment by rainfall.	0.0
C1	A constant coefficient as used in Equation 69.	2.25
C2	A constant coefficient as used in Equation 76.	25.0
C3	A constant exponent as used in Equation 76.	1.65
RC	An exponential decay constant as used in Equation 80. Represents the rate at which rills stabilize and rill erosion reduces with time.	0.090

Table 9. Comparison of measured and predicted surface runoff depth for 1972 calibration period on NE watershed

Date	Measured runoff (centimeters)	Predicted runoff (centimeters)
5/1	0.00	0.50
5/5	1.32	1.62
5/6	0.00	0.05
5/12	0.00	0.02
6/14	0.00	0.00
7/1	1.60	2.18
7/6	0.00	0.00
7/11	1.04	--[a]
7/17	1.50	1.24
7/26	1.29	1.22
8/7	1.14	1.19
8/25	0.20	0.005
9/5	0.30	0.28
10/10-11	1.95	1.91
10/12	1.27	0.91
Total	10.57[b]	11.12

[a] None of the three rain gages was working and rainfall distribution was not known for this day.

[b] Runoff volume on July 11, the day that rainfall data were not available, is excluded.

of surface runoff hydrographs for events with surface runoff of more than 0.25 centimeter are shown in Figures 12 to 17.

Despite considering the effect of tillage on surface runoff, the model predicted a volume of surface runoff of 0.5 centimeter for the rainfall event on May 1, while no measured runoff was recorded.

The cultivation date on Gingles Watershed for the year of 1972 was June 19. The next rainfall after cultivation was on July 1, the date that the model overpredicted surface runoff. It is known that cultivation increases the surface storage and roughness and therefore decreases the surface runoff. It was assumed first that an increase in surface roughness and storage due to cultivation is the same as increase by conventional tillage (plowing). The model was run using this assumption but predicted too little surface runoff. This suggested that cultivation increases surface storage and roughness somewhat less than the increase resulting from conventional tillage (plowing). To reduce the complexity related to overland flow and keep the model simple at this point, the cultivation effect was neglected even though the model overpredicted the runoff immediately after cultivation.

A comparison of measured and predicted sediment yield for the 1972 calibration period is shown in Table 10. The comparison between measured and predicted sedographs (graphs showing the variation of sediment yield with time) for individual storms is shown in Figures 18 through 21.

The difference between measured and predicted sediment yield for the storm on July 17 is large. A part of this deviation between measured and predicted sediment yield could be due to the error in measurement of sediment concentration and the method of sediment yield

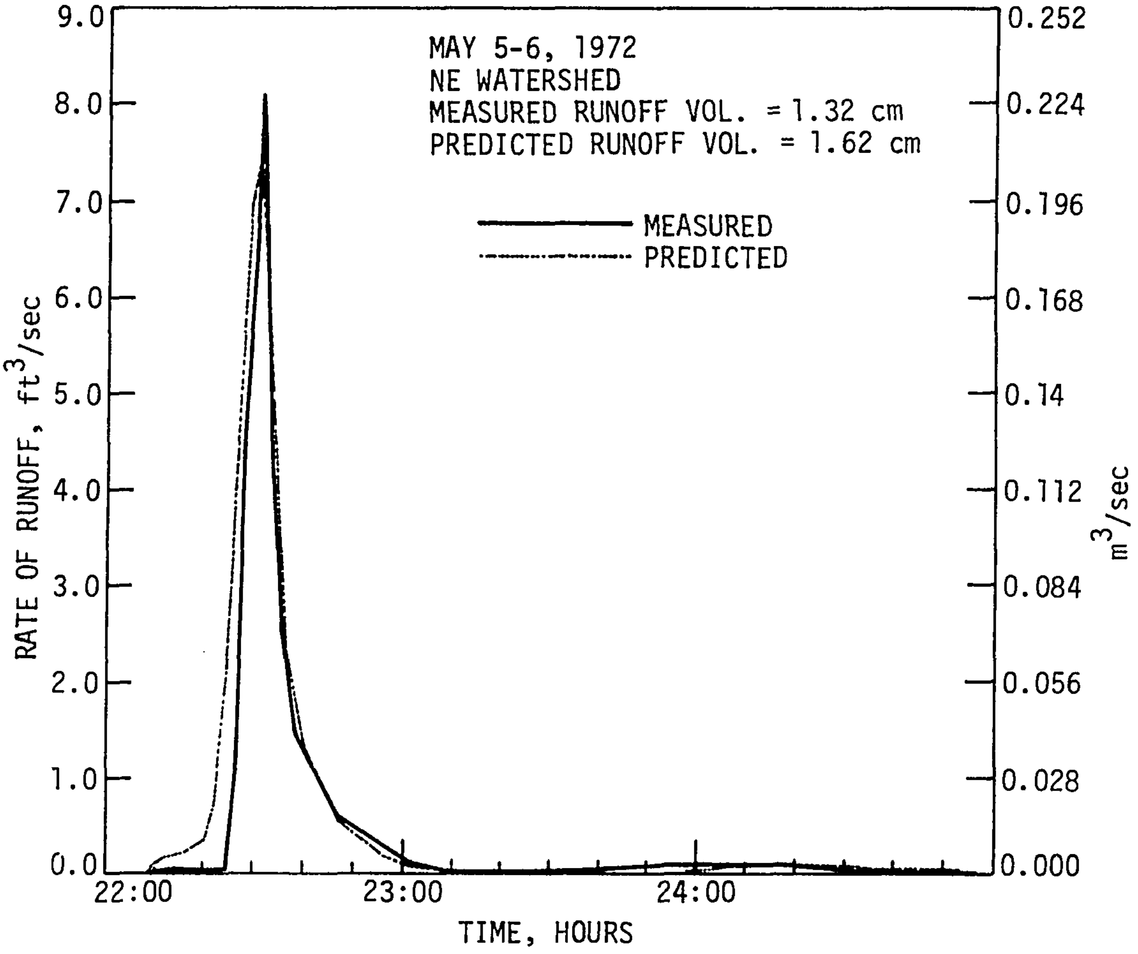

Figure 12. Comparison of measured and predicted surface runoff from NE watershed on May 5-6, 1972

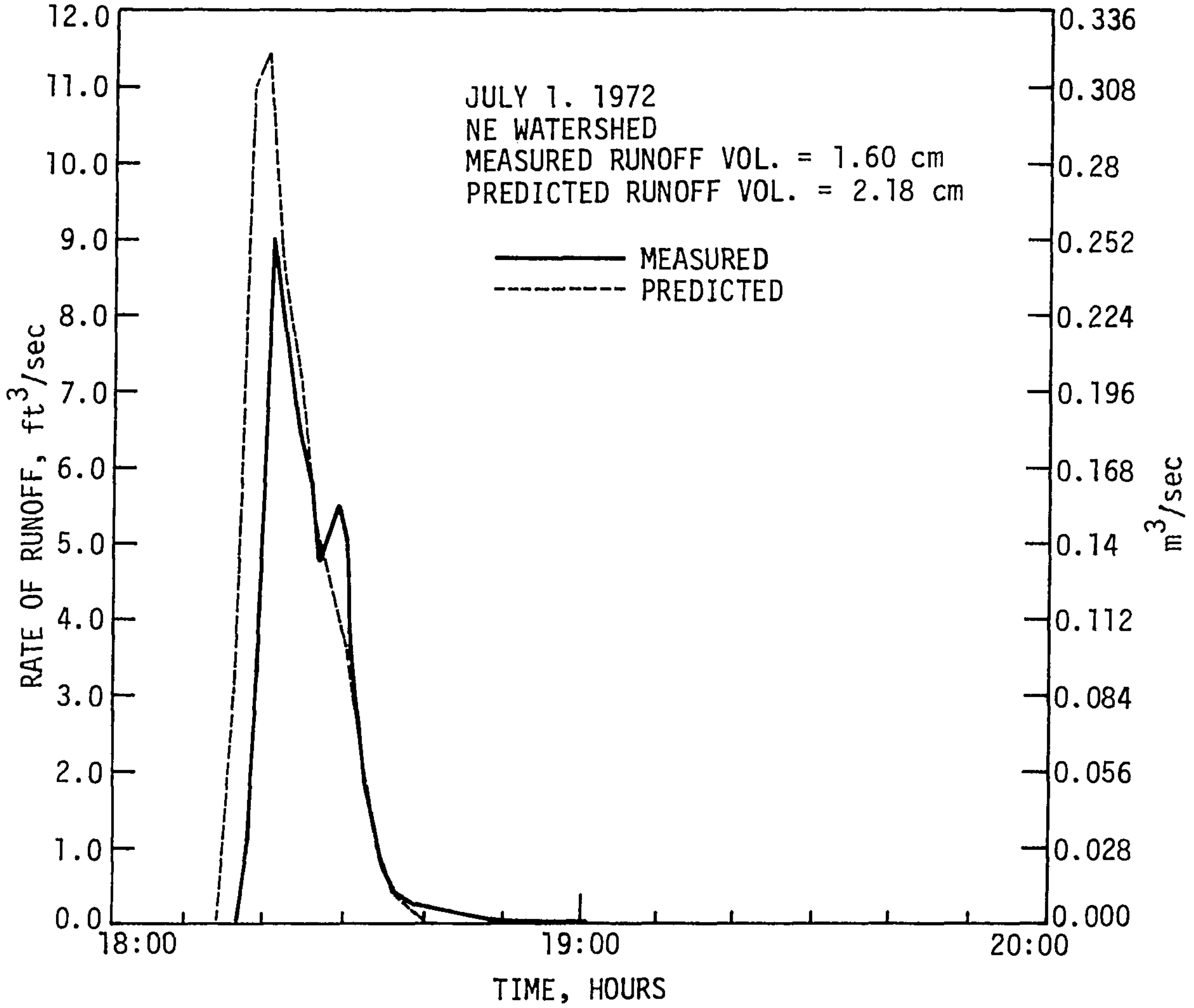

Figure 13. Comparison of measured and predicted surface runoff from NE watershed on July 1, 1972

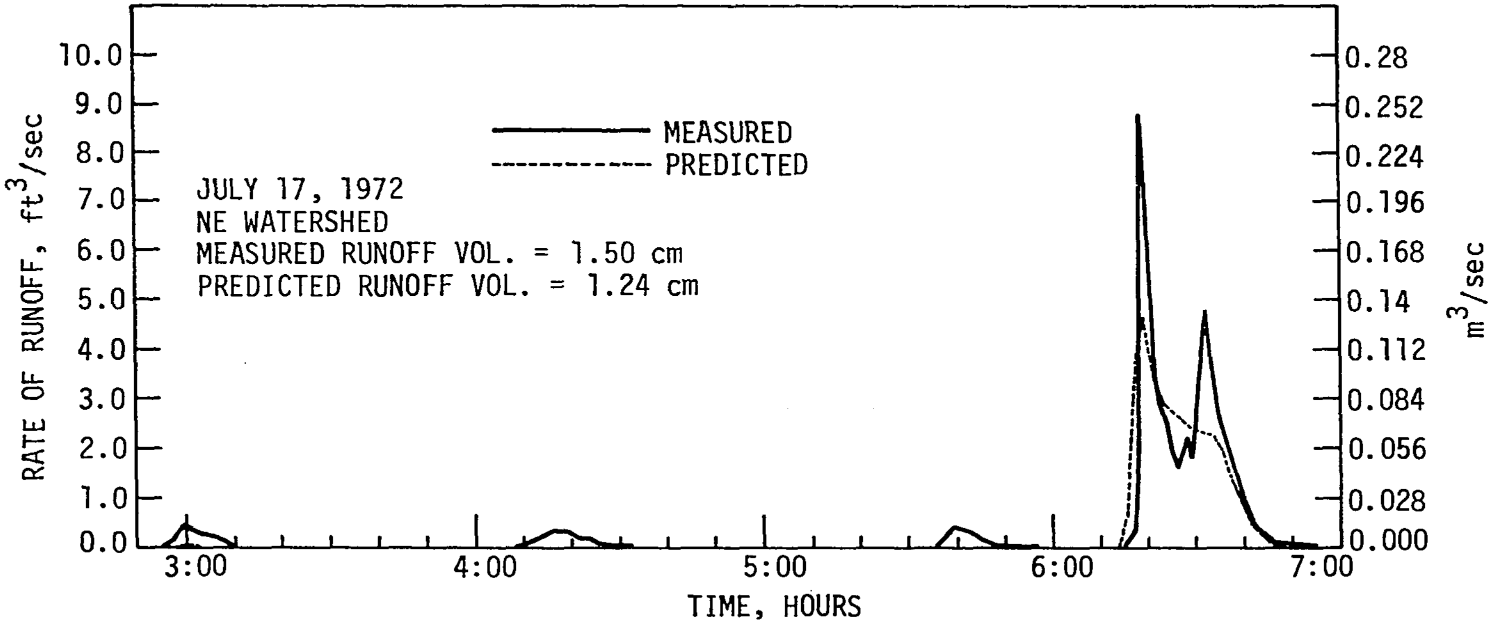

Figure 14. Comparison of measured and predicted surface runoff from NE watershed on July 17, 1972

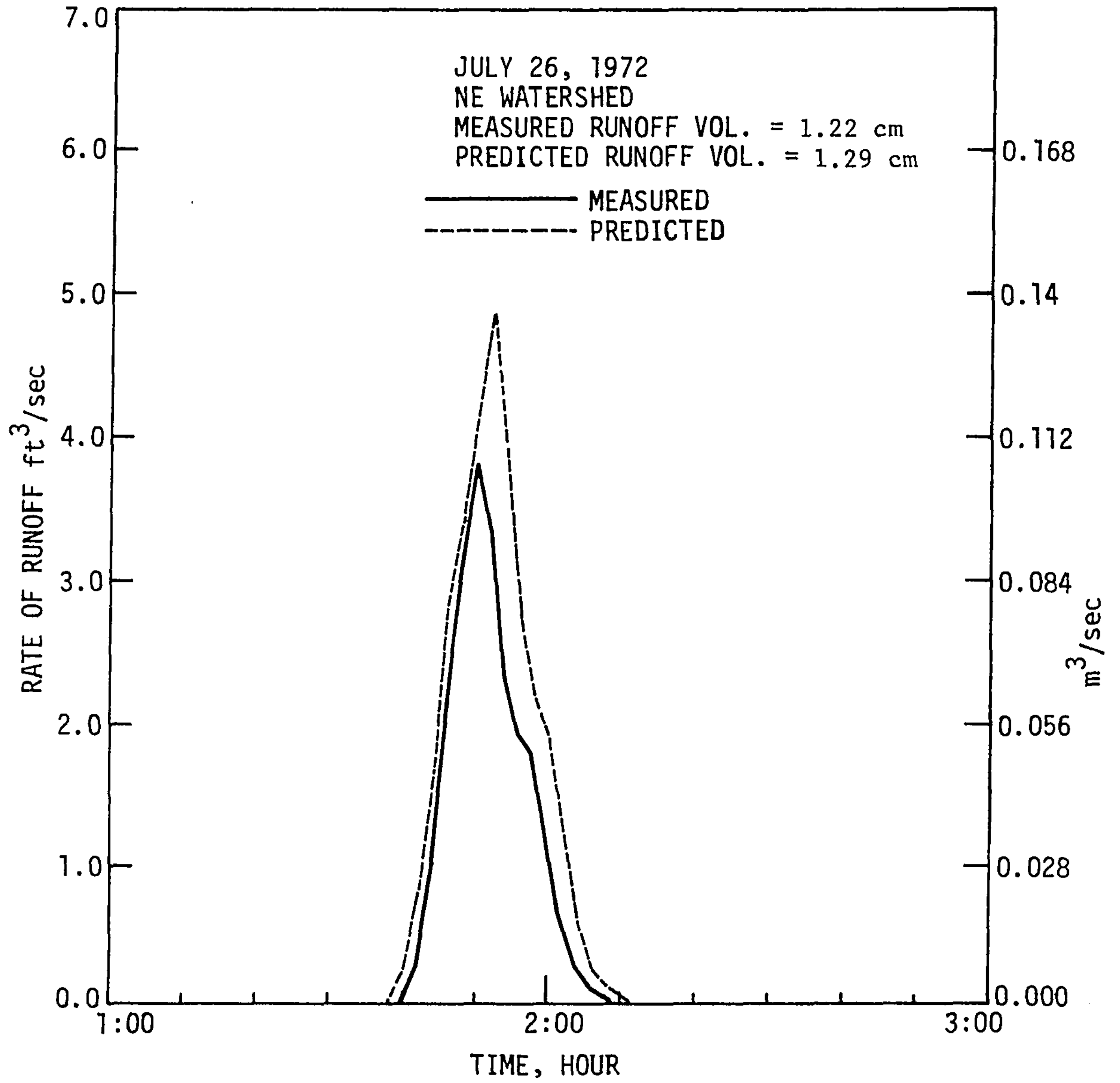

Figure 15. Comparison of measured and predicted surface runoff from NE watershed on July 26, 1972

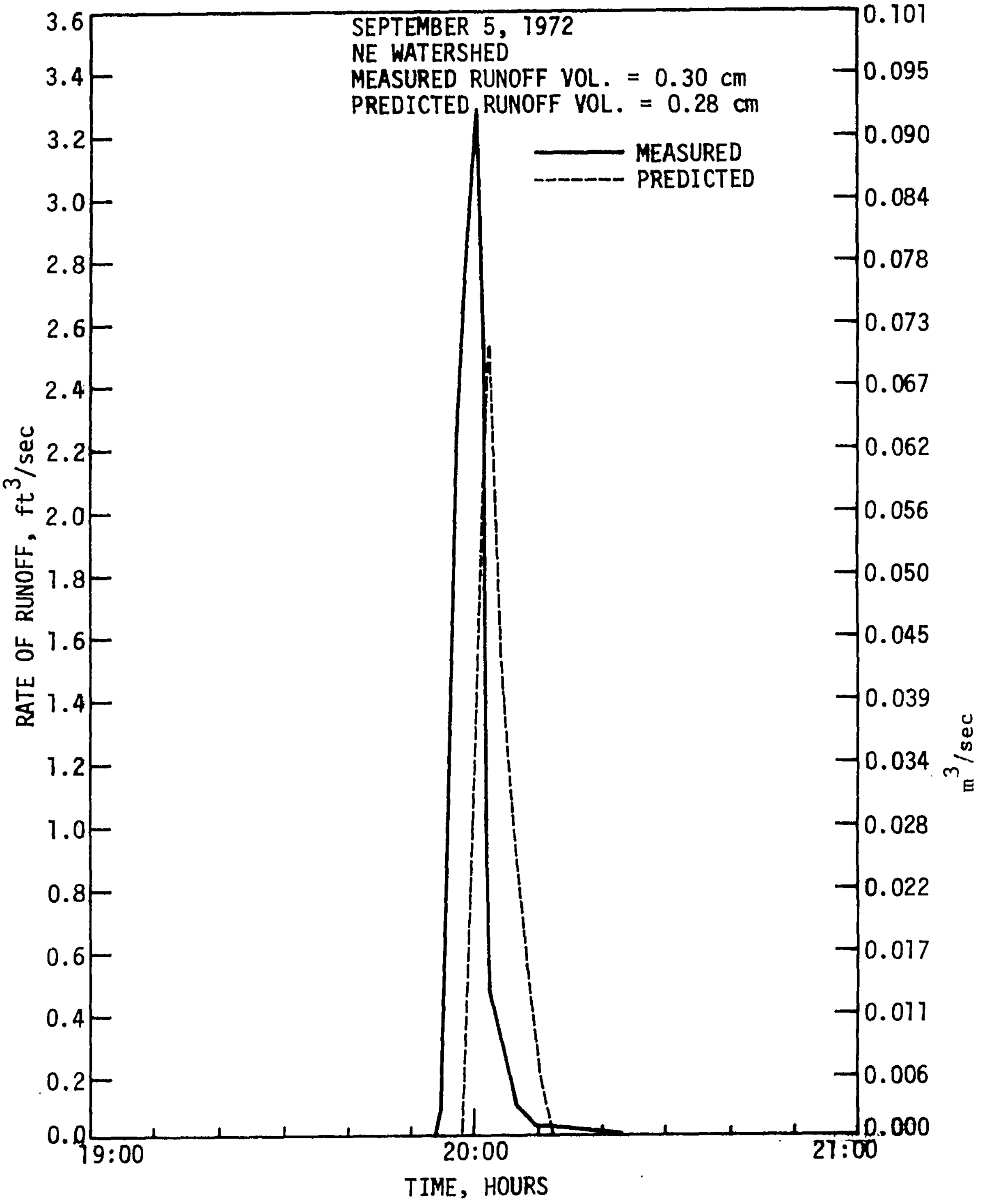

Figure 16. Comparison of measured and predicted surface runoff from NE watershed on September 5, 1972

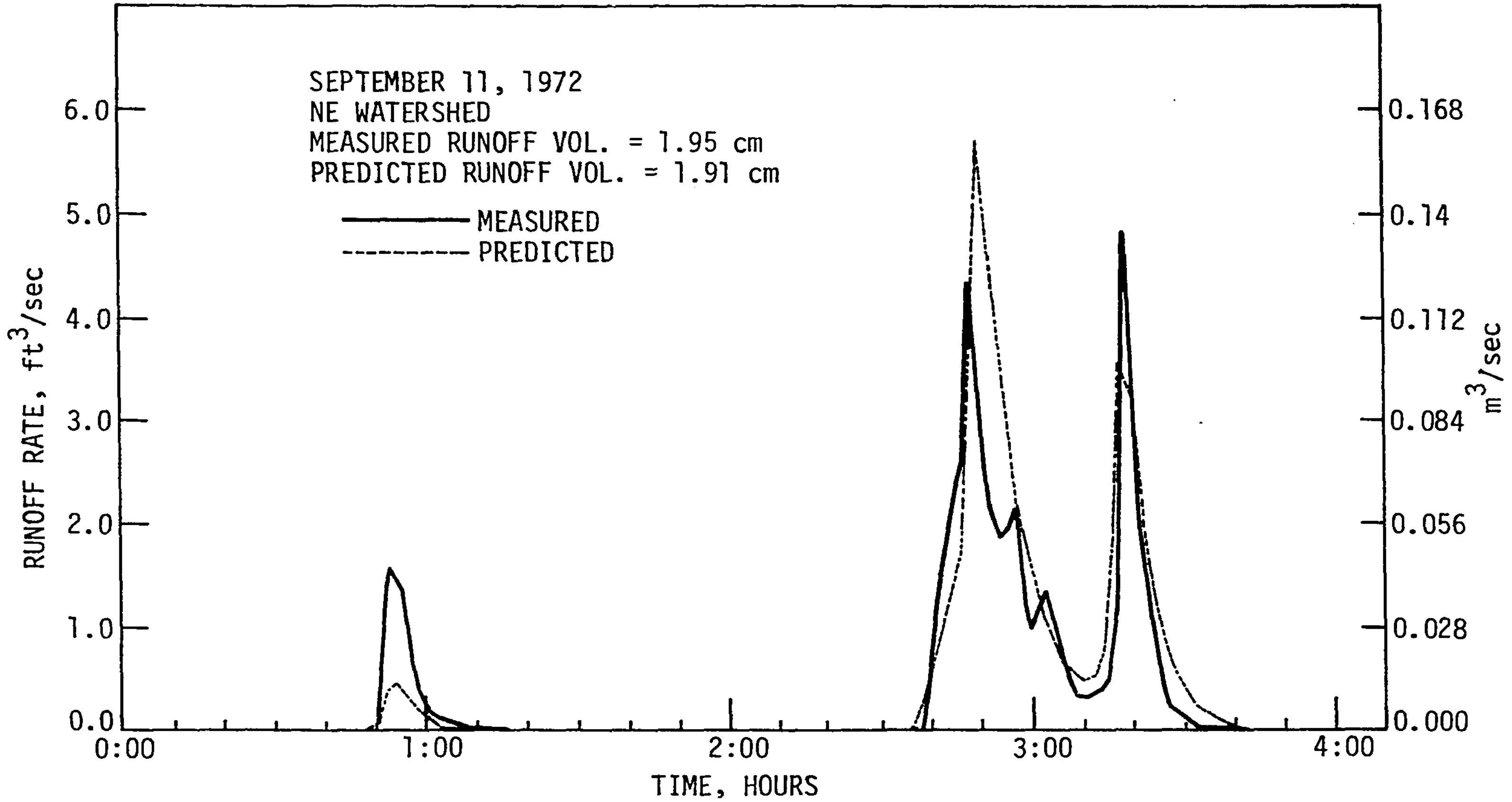

Figure 17. Comparison of measured and predicted surface runoff from NE watershed on September 11, 1972

Table 10. Comparison of measured and predicted sediment yield from individual storms of 1972 for NE watershed

Date	Measured sediment yield (tonnes/hectare)	Predicted sediment yield (tonnes/hectare)
	0.00	0.36
5/5	27.79	26.00
7/1	28.40	32.43
7/11	9.24	--[a]
7/17	11.73[b]	3.26[b]
7/26	2.04	2.62
8/7	2.07	2.28
9/5	0.83	0.80
10/10-11	3.65	2.85
Total	76.51	70.60

[a] None of the three rain gages was working and rainfall distribution was not known for this day.

[b] See following discussion.

calculation using Equation 89. The major reason for this unreasonably large difference seems to be due to the fact that the model was not able to simulate closely the rate of runoff for this specific storm even though the predicted volume of runoff was close to the recorded one (see Figure 14). The recorded peak rate of runoff (first peak) as shown in Figure 14 was 8.8 ft^3/sec (0.25 m^3/sec), while the predicted peak rate of runoff was 4.7 ft^3/sec (0.13 m^3/sec). The second recorded peak of the same storm was 4.8 ft^3/sec (0.13 m^3/sec), while the simulated one was 2.3 ft^3/sec (0.06 m^3/sec). These large differences

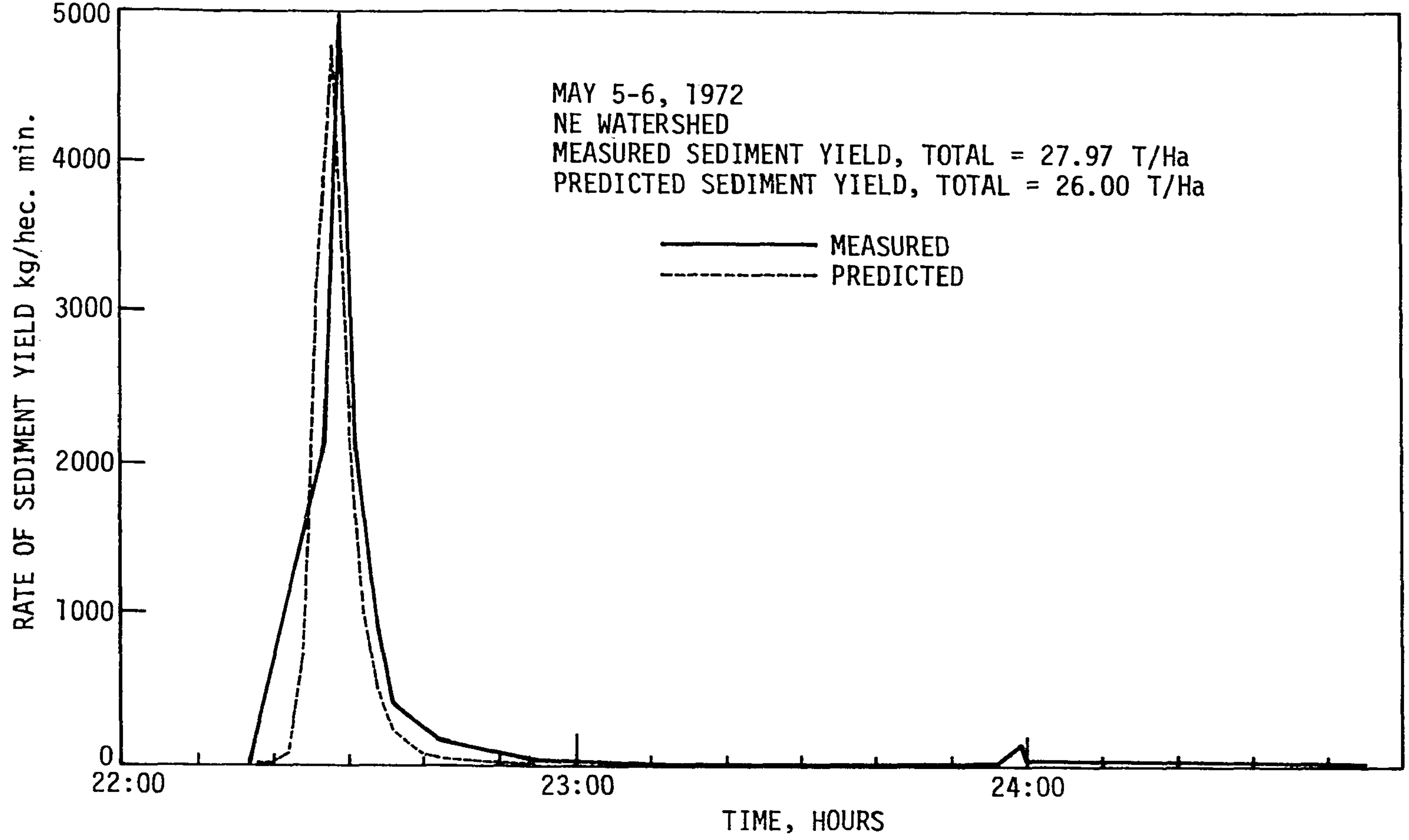

Figure 18. Comparison of measured and predicted sediment yield from NE watershed on May 5-6, 1972

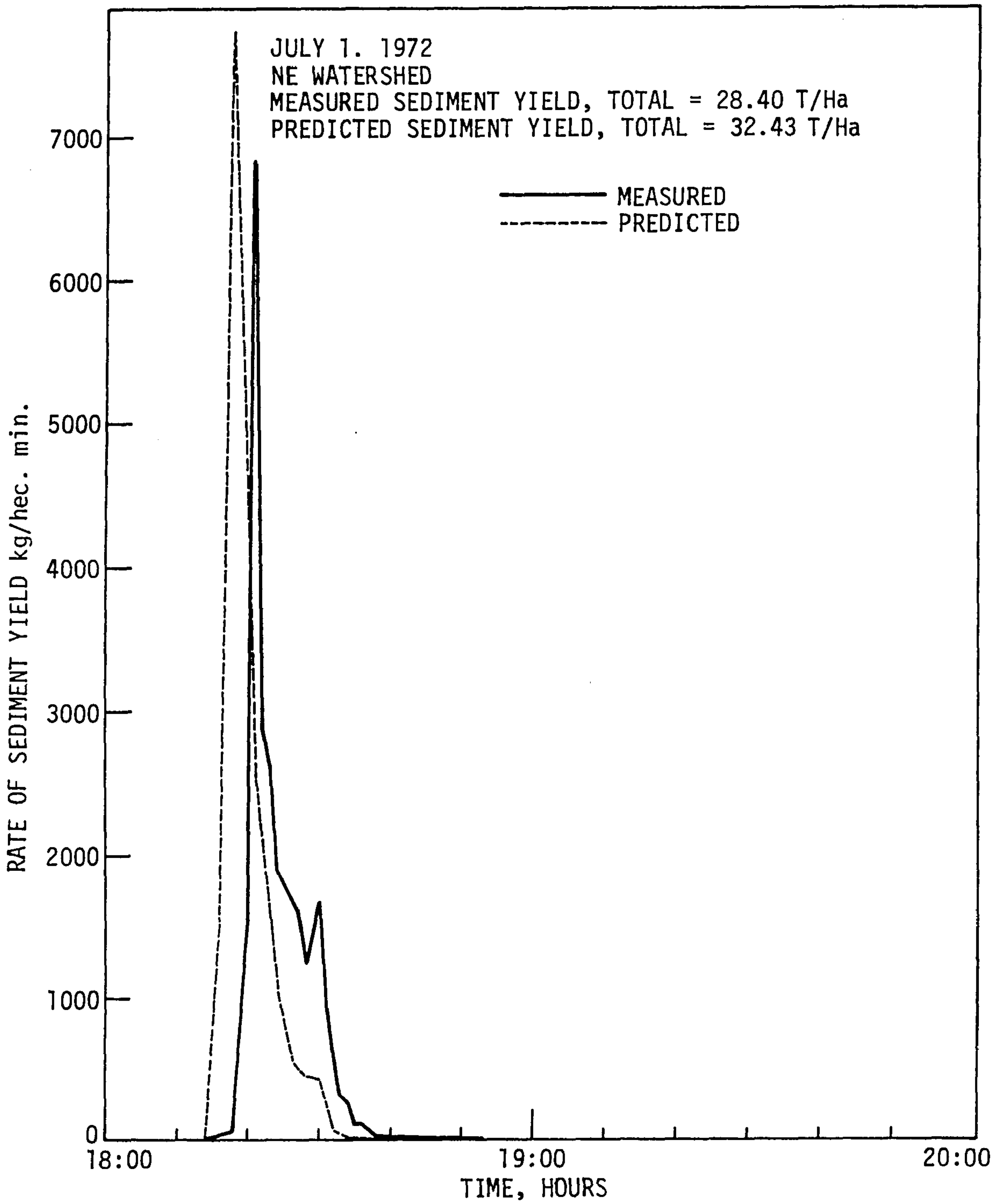

Figure 19. Comparison of measured and predicted sediment yield from NE watershed on July 1, 1972

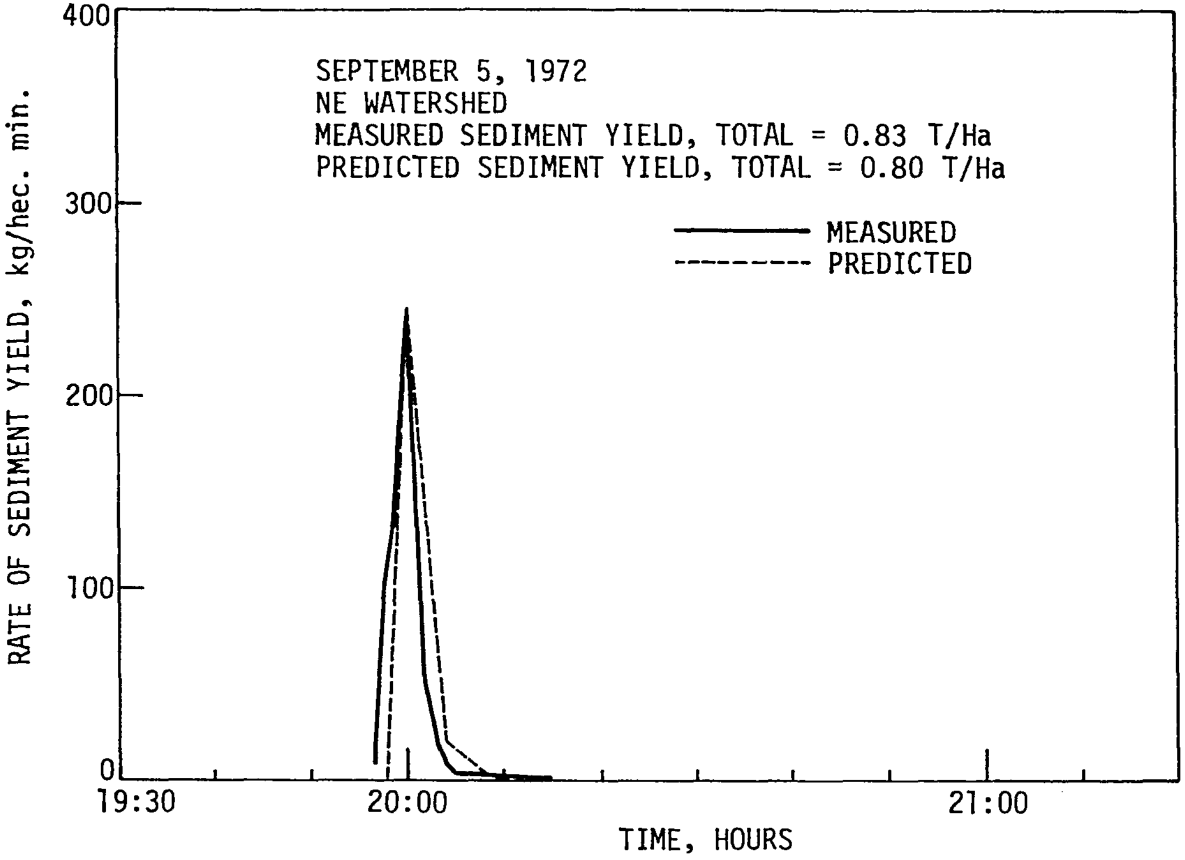

Figure 20. Comparison of measured and predicted sediment yield from NE watershed on September 5, 1972

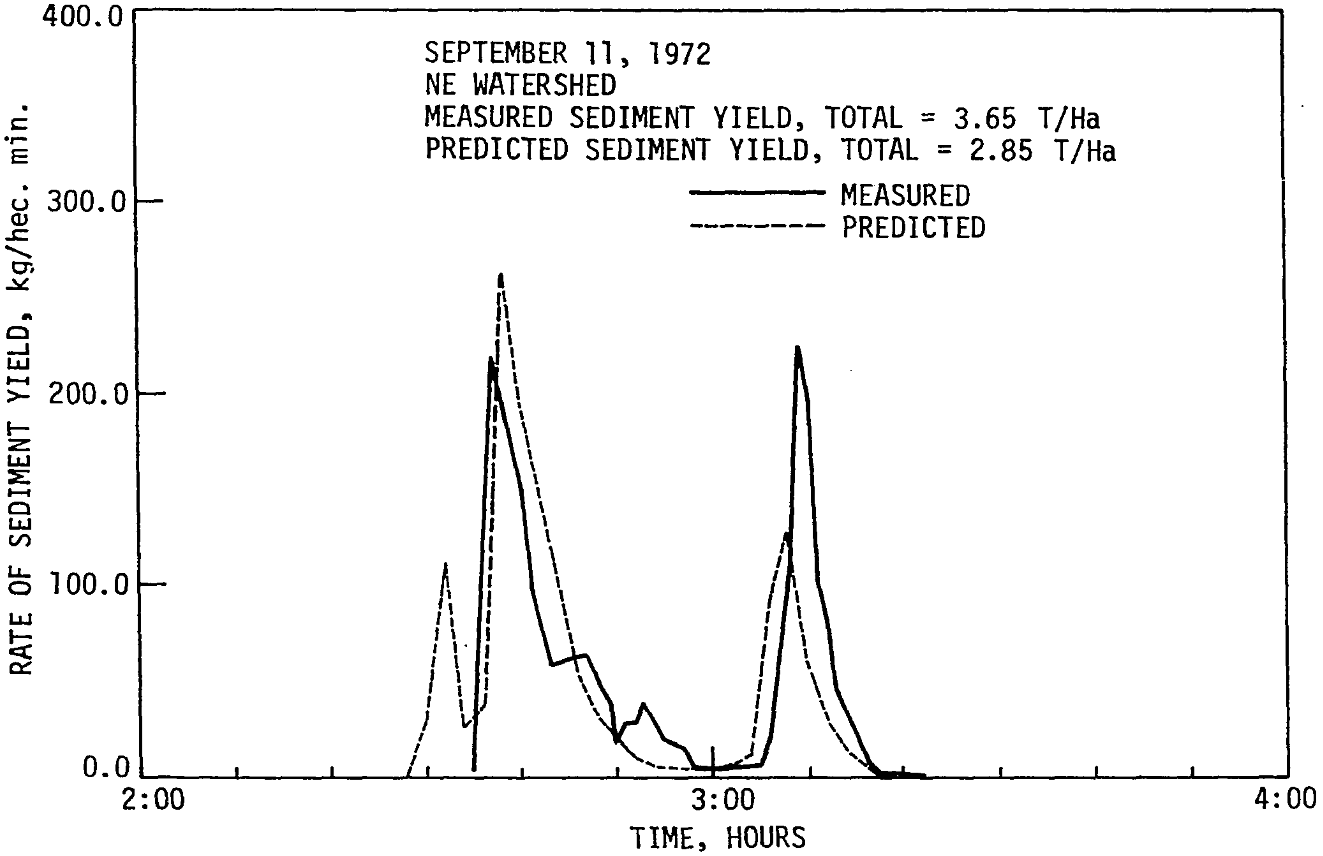

Figure 21. Comparison of measured and predicted sediment yield from NE watershed on September 11, 1972

in peak rate of runoff are the major cause of a large deviation between the measured and predicted sediment yield. It is interesting to note that the same problem, to a lesser extent, appears for the same event on SM watershed (see Table 11).

The reason for large deviations in peak rate of runoff is not clear. Since the watersheds are very small and steep, flow response to any change in rainfall intensity is very fast. Any increase in rainfall intensity, even for a very short time increment, can strongly affect the peak rate of runoff. Comparing Figures 14 and 24, hydrographs of the same storm on two different watersheds, proves the above argument. Watershed NE, having a slope steepness of 15 percent and an overland flow length of about 290 feet, produced a peak rate of runoff of 8.8 ft^3/sec (0.25 m^3/sec). Watershed SM, having a slope steepness of 12 percent and an overland flow length of 400 feet, produced a peak rate of runoff of 4.95 ft^3/sec (0.14 m^3/sec). Considering the above discussion, any error in recording the rainfall intensity, even for a very short time increment, could have a distinct effect on predicted rate of runoff and consequently on sediment yield prediction. Indeed, this was the major reason for use of a 2 minute time interval in this model to simulate the rate of runoff from any individual storm. The argument may not hold in cases of large watersheds with smaller slope steepness and larger overland flow length, and consequently high storage and attenuation capacity, but it is a key point to be considered in simulating the hydrology of small agricultural watersheds.

Model Evaluation

In this section the ability of the model to predict surface runoff and sediment yield outside the time period and/or location used to calibrate the model is evaluated. Data from the years of 1973, 1974, and 1975 on NE watershed, the one used to calibrate the model, and data from 1972 on SM watershed, under conventional tillage, were used for evaluation.

The comparison between measured and predicted surface runoff depth and sediment yield for the year 1972 on SM watershed is shown in Table 11. Hydrograph and sedograph comparisons are shown in Figures 22 through 32. Soil moisture data to be used in the model at the beginning of the growing season were not available for the years of 1973 and 1974. Soil moisture was estimated from data by Shaw (1978) from the Experimental Farm for these years. Comparisons of measured and predicted surface runoff depth and sediment yield for individual storms of 1973, 1974, and 1975 are shown in Tables 12, 13, and 14, respectively.

As shown in Table 12, even though predictions of total surface runoff were reasonably good for the year 1973, sediment yield prediction was poor, especially on an individual storm basis.

One of the factors contributing to these discrepancies is that sediment yield is not sampled throughout a runoff event. Equation 89 is used to estimate sediment yield for the recession part of the hydrograph using concentration of sediment at peak flow. This means any error in measurement of sediment concentration at peak flow causes a proportional error in sediment yield from recession side of the hydrograph. Considering the fact that Equation 89 has a coefficient of determination (R^2) of 0.68, one may relate part of the deviations to this factor. The other factor which seems to be the controlling one is that the hydrologic model has not predicted any surface runoff for the event on May 26, a smaller amount of surface runoff for storms on May 27 and on June 18. Rill erosion, erosion due to surface runoff,

Table 11. Comparison of measured and predicted surface runoff depth and sediment yield from individual storms of 1972 on SM watershed

Date	Measured runoff (centimeters)	Predicted runoff (centimeters)	Measured sediment yield (tonnes/hectare)	Predicted sediment yield (tonnes/hectare)
5/5	1.78	1.90	28.85	21.8
7/1	1.58	1.82	22.57	22.73
7/11	0.99	--[a]	6.15	--[a]
7/17	1.62	1.12	9.24	4.0
7/26	0.61	1.17	1.51	3.16
8/7	0.99	1.14	1.22	2.45
8/25	0.10	0.01	0.03	0.0
9/5	0.33	0.33	0.55	0.76
9/10-11	1.90	1.95	2.70	3.14
9/12	1.19	0.94	0.81	0.74
Total	10.10[b]	10.38	67.48[b]	58.78

[a] The three recording rain gages were not running; rainfall distribution data were not known for this day.

[b] Surface runoff depth and sediment yield on July 11, the day that rainfall data were missed, are excluded from the totals.

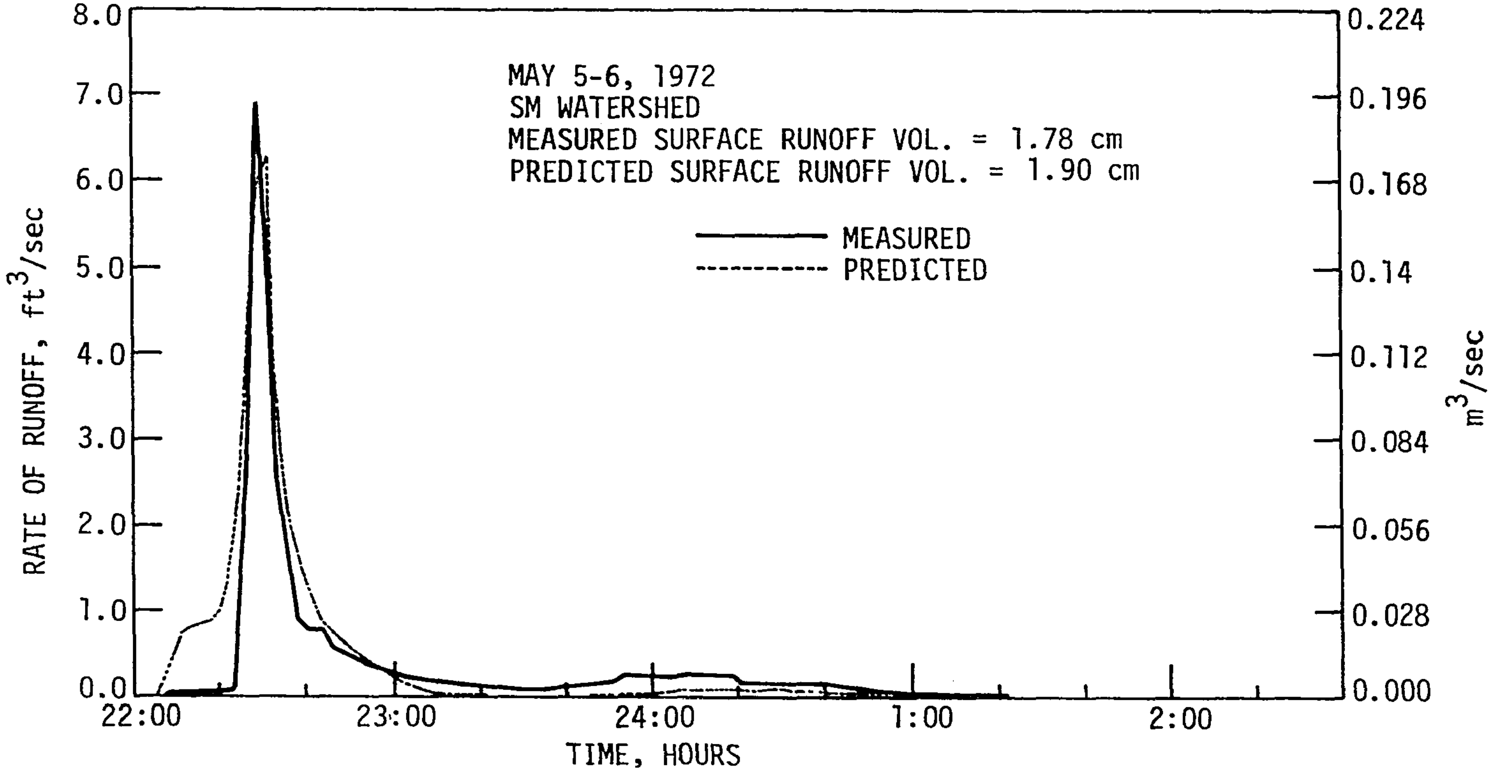

Figure 22. Comparison of measured and predicted surface runoff from SM watershed on May 5-6, 1972

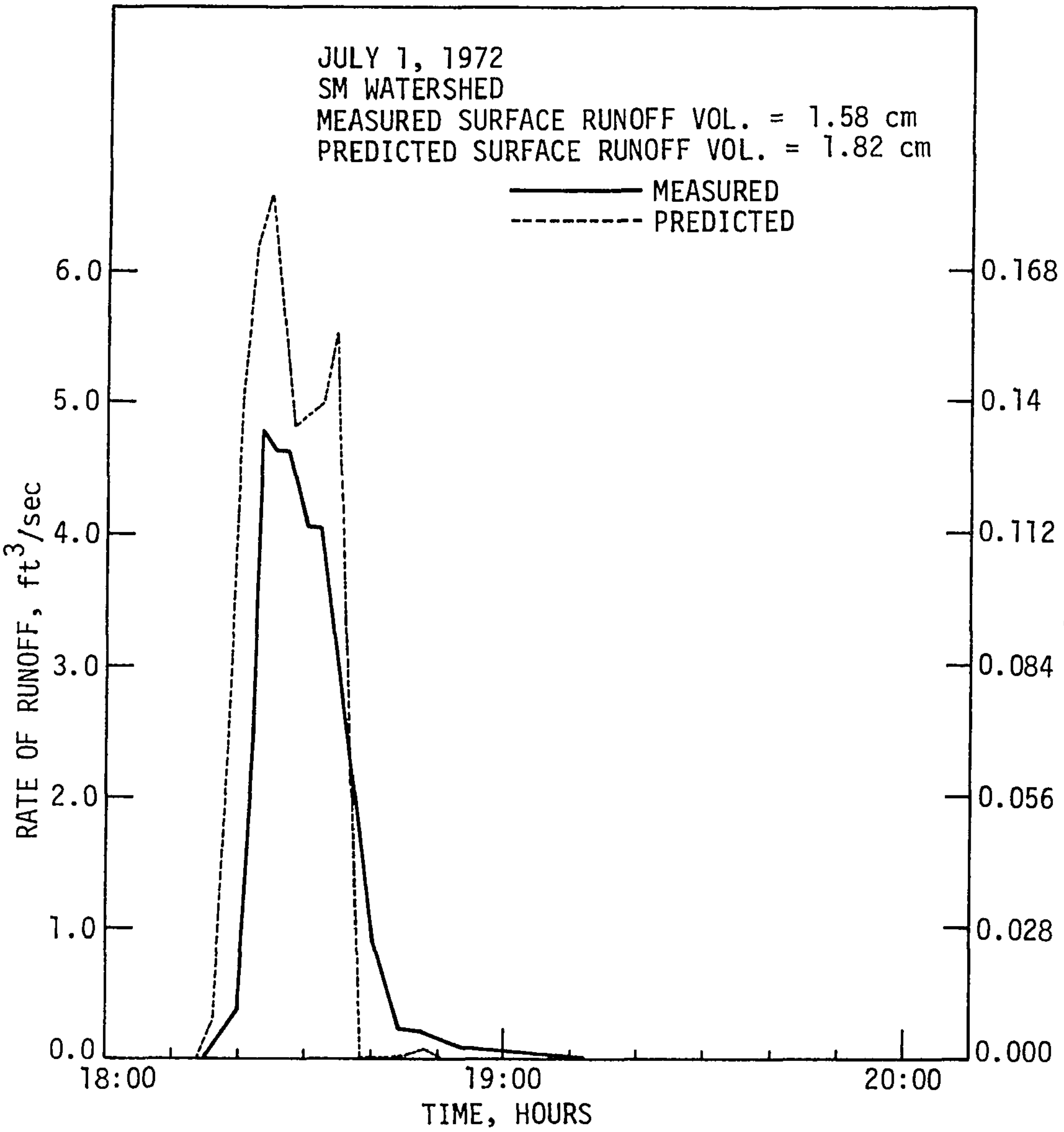

Figure 23. Comparison of measured and predicted surface runoff from SM watershed on July 1, 1972

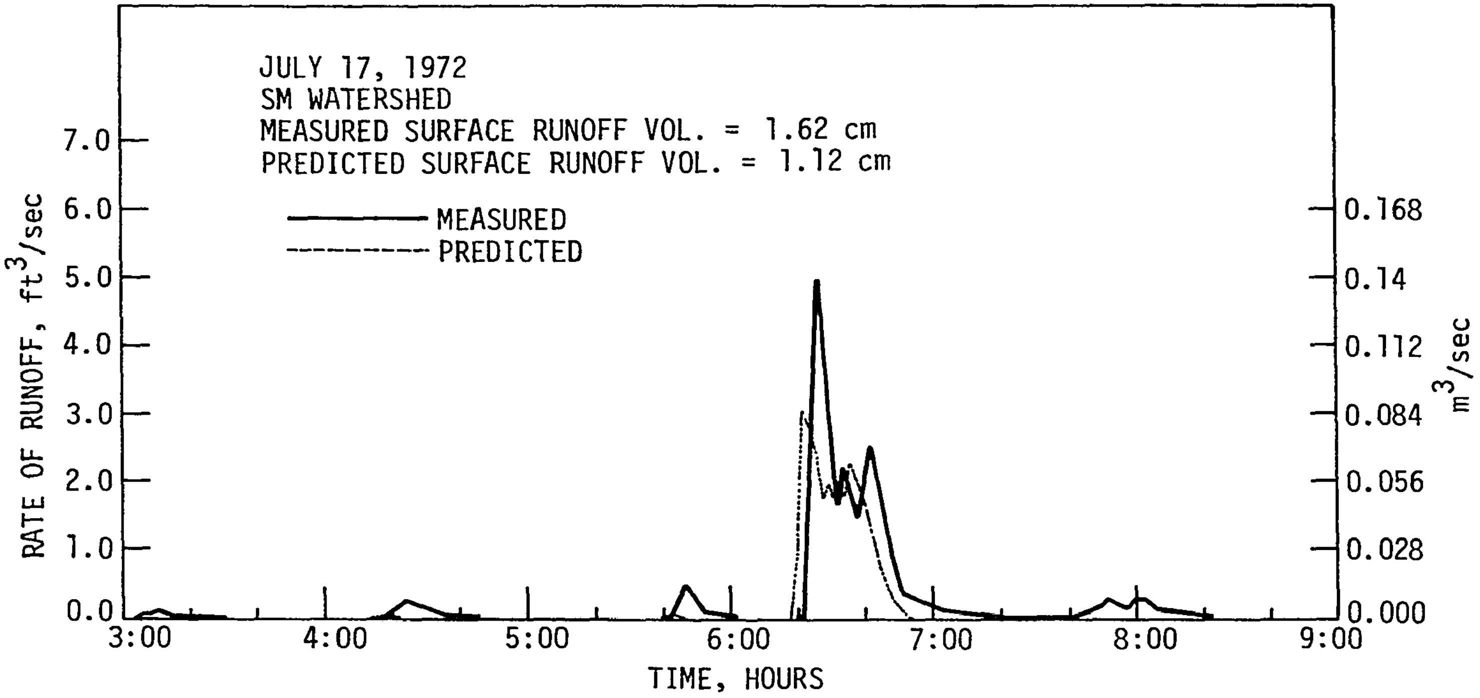

Figure 24. Comparison of measured and predicted surface runoff from SM watershed on July 17, 1972

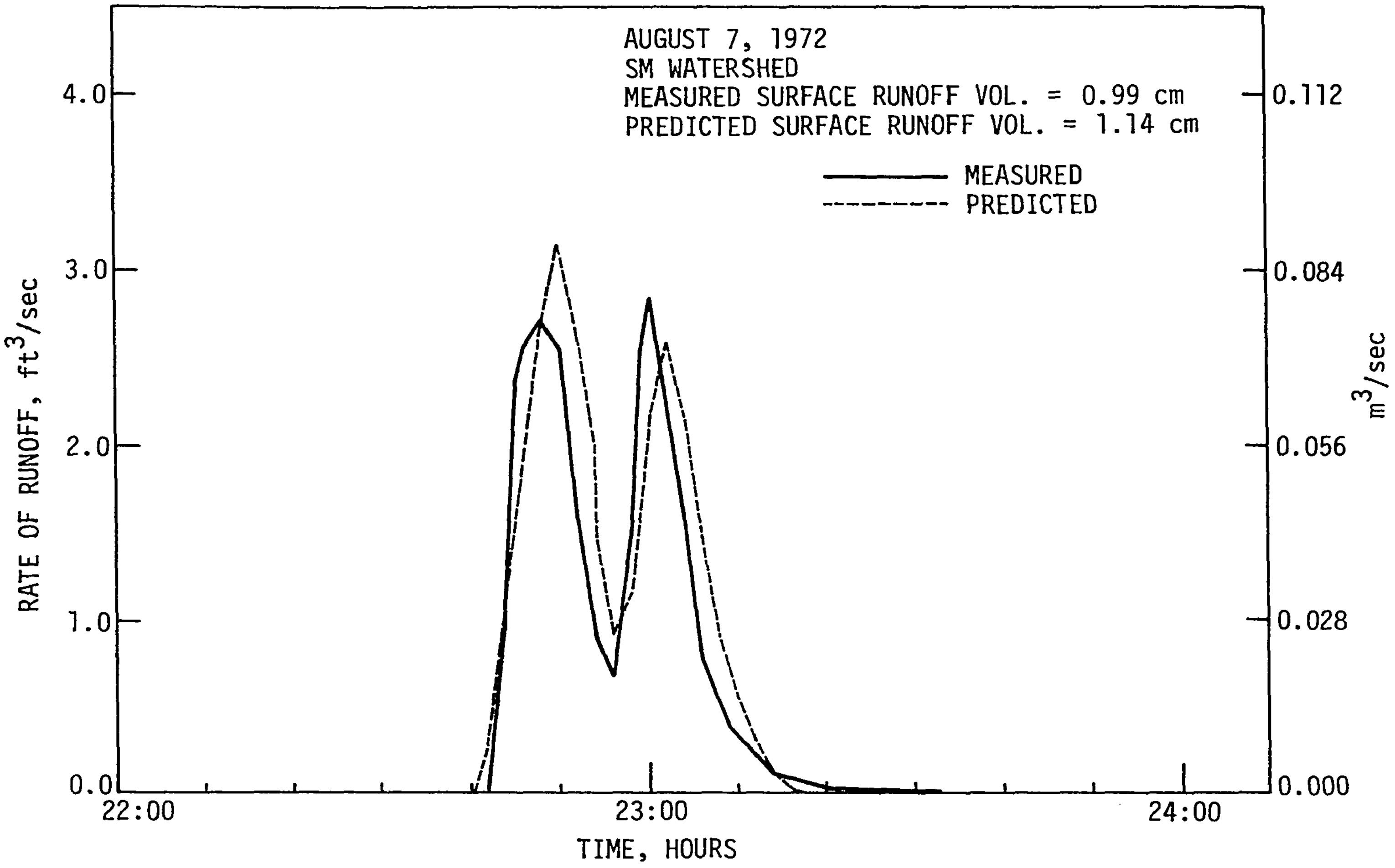

Figure 25. Comparison of measured and predicted surface runoff from SM watershed on August 7, 1972

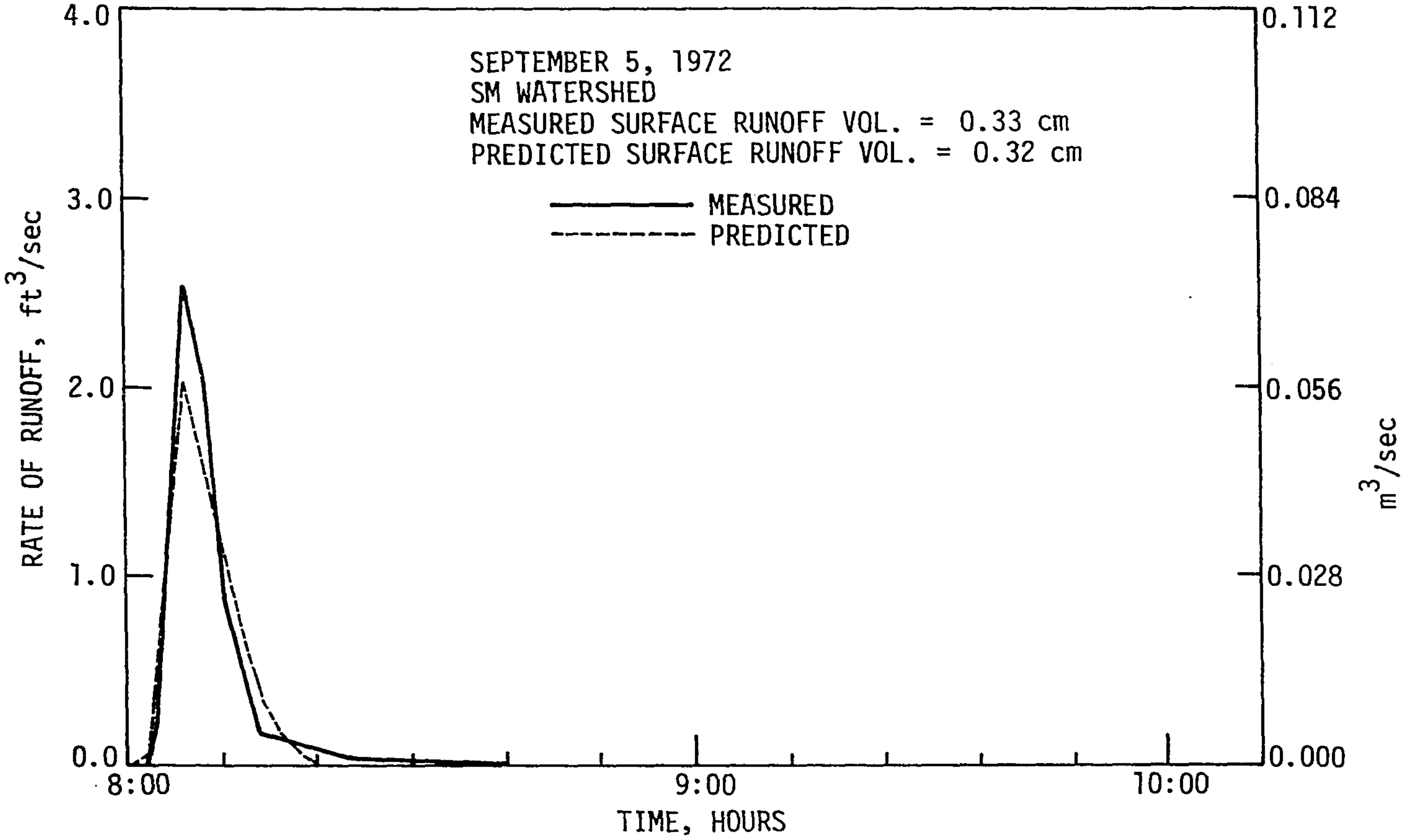

Figure 26. Comparison of measured and predicted surface runoff from SM watershed on September 5, 1972

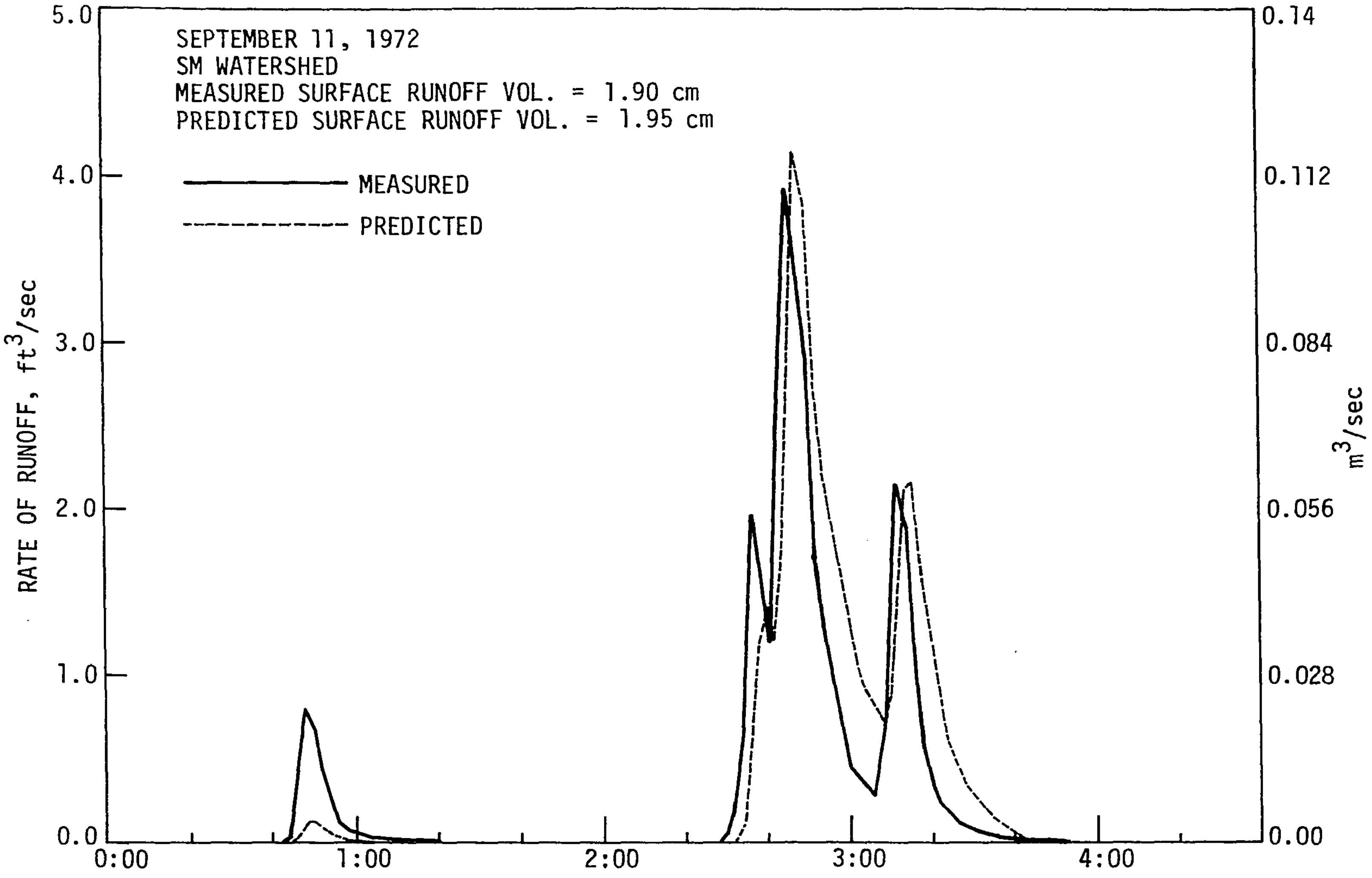

Figure 27. Comparison of measured and predicted surface runoff from SM watershed on September 11, 1972

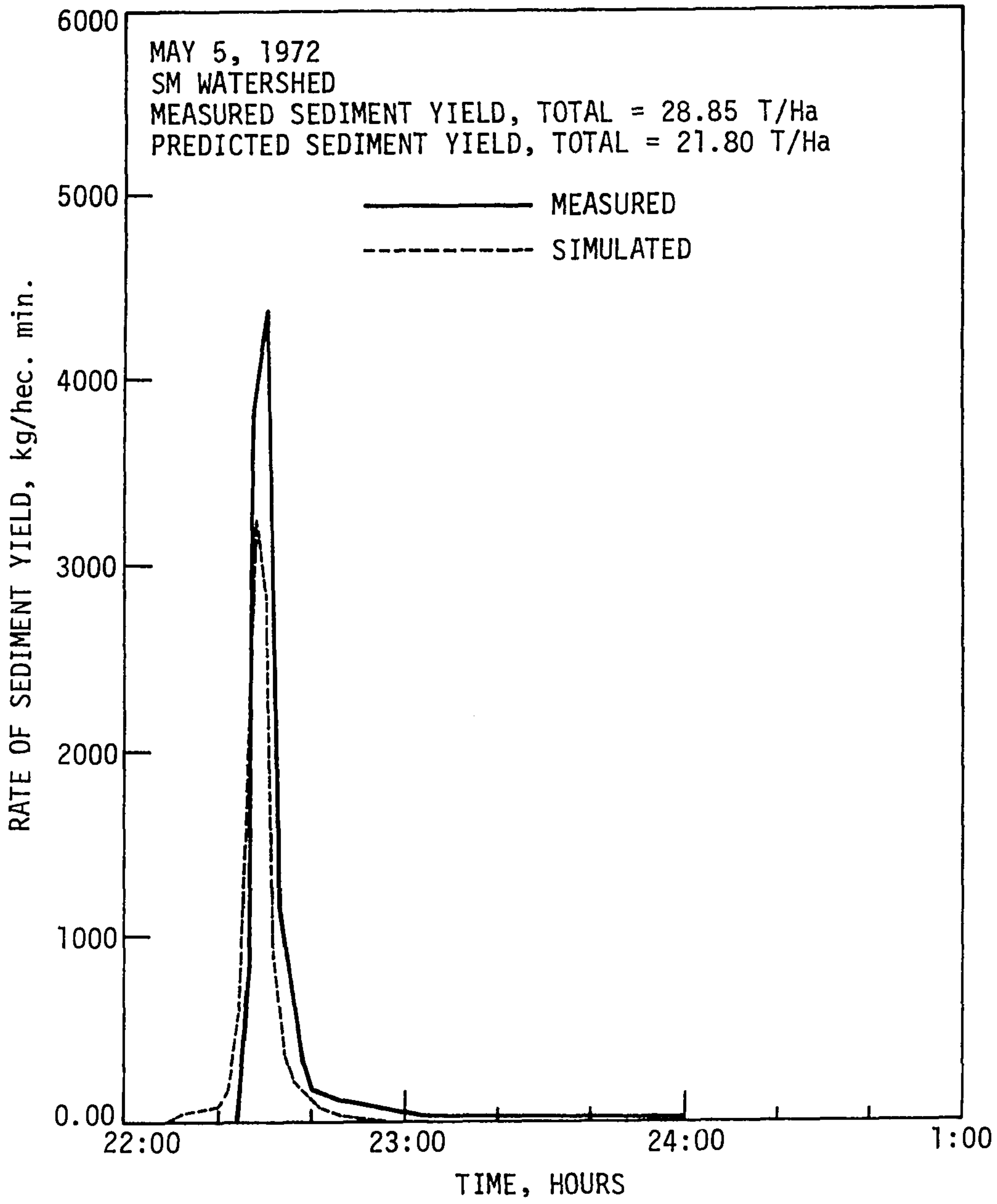

Figure 28. Comparison of measured and predicted sediment yield from SM watershed on May 5, 1972

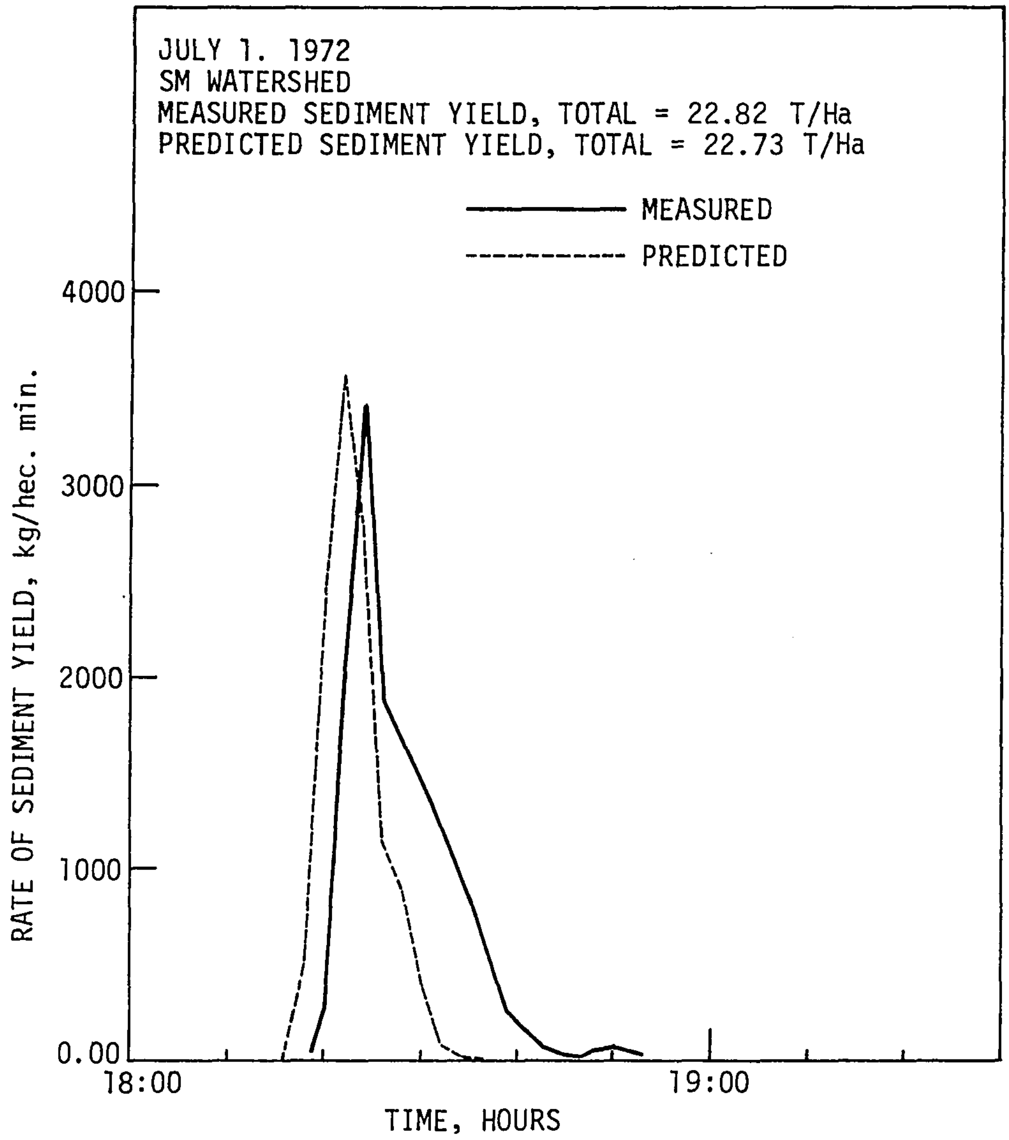

Figure 29. Comparison of measured and predicted sediment yield from SM watershed on July 1, 1972

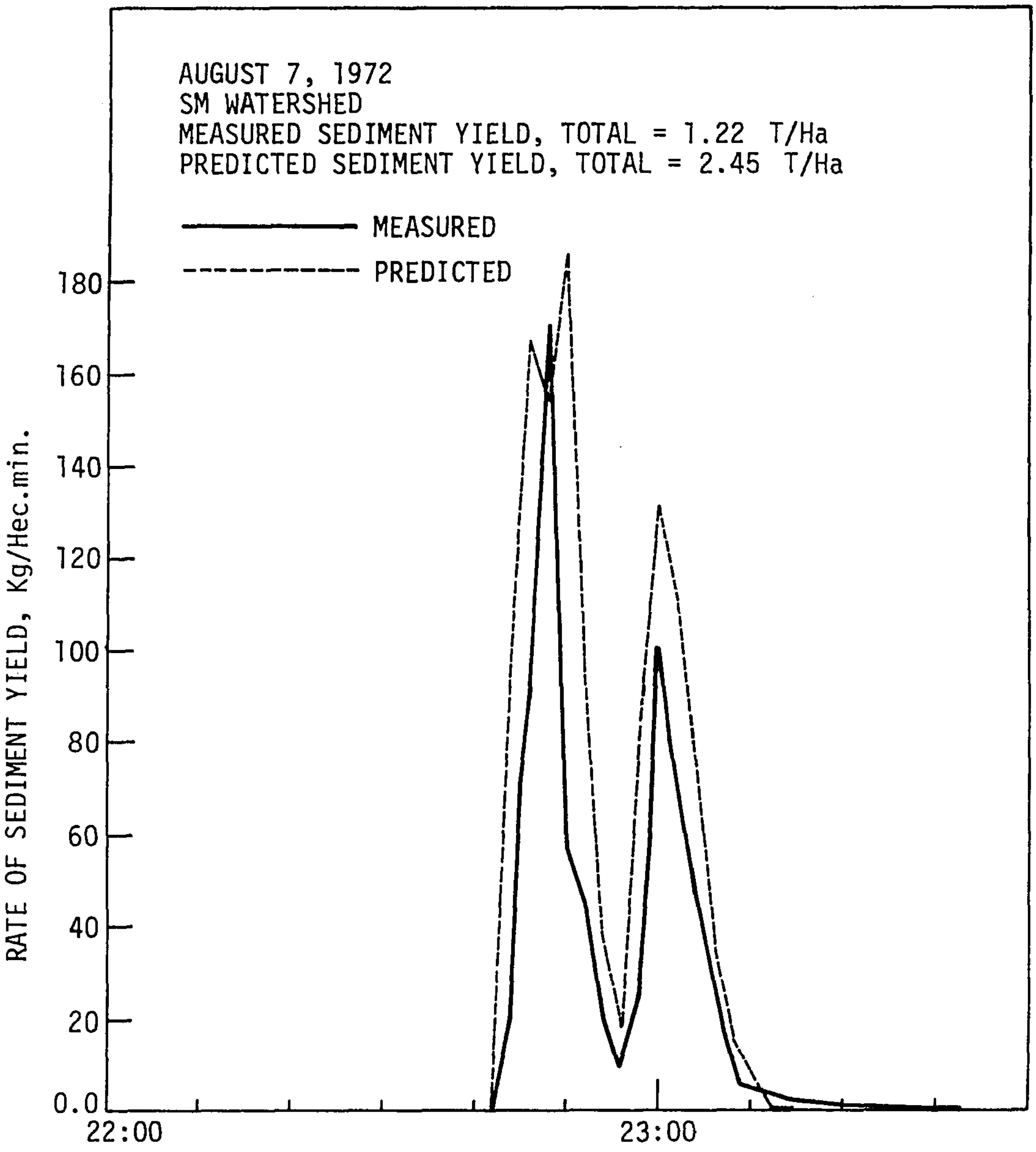

Figure 30. Comparison of measured and predicted sediment yield from SM watershed on August 7, 1972

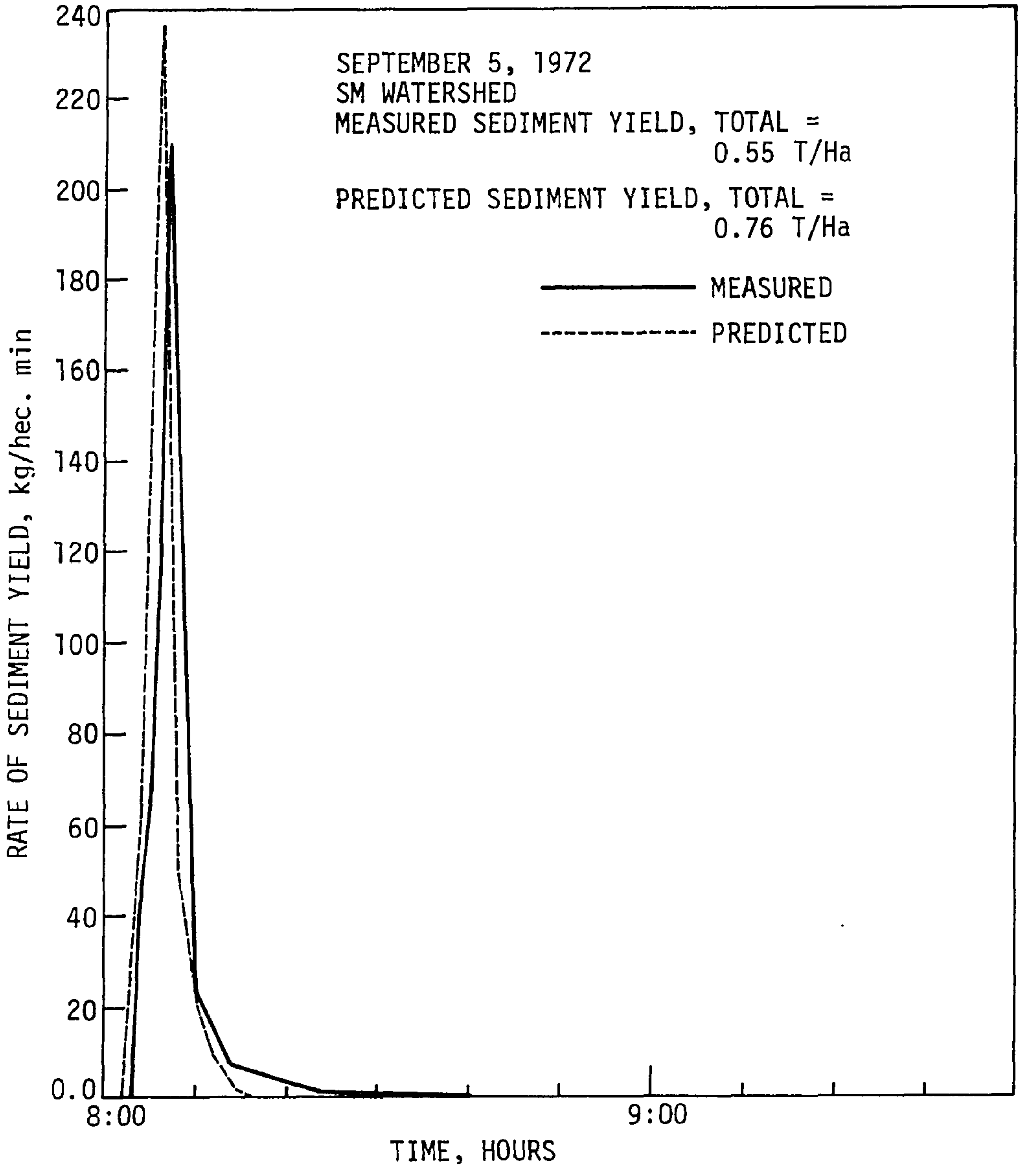

Figure 31. Comparison of measured and predicted sediment yield from SM watershed on September 5, 1972

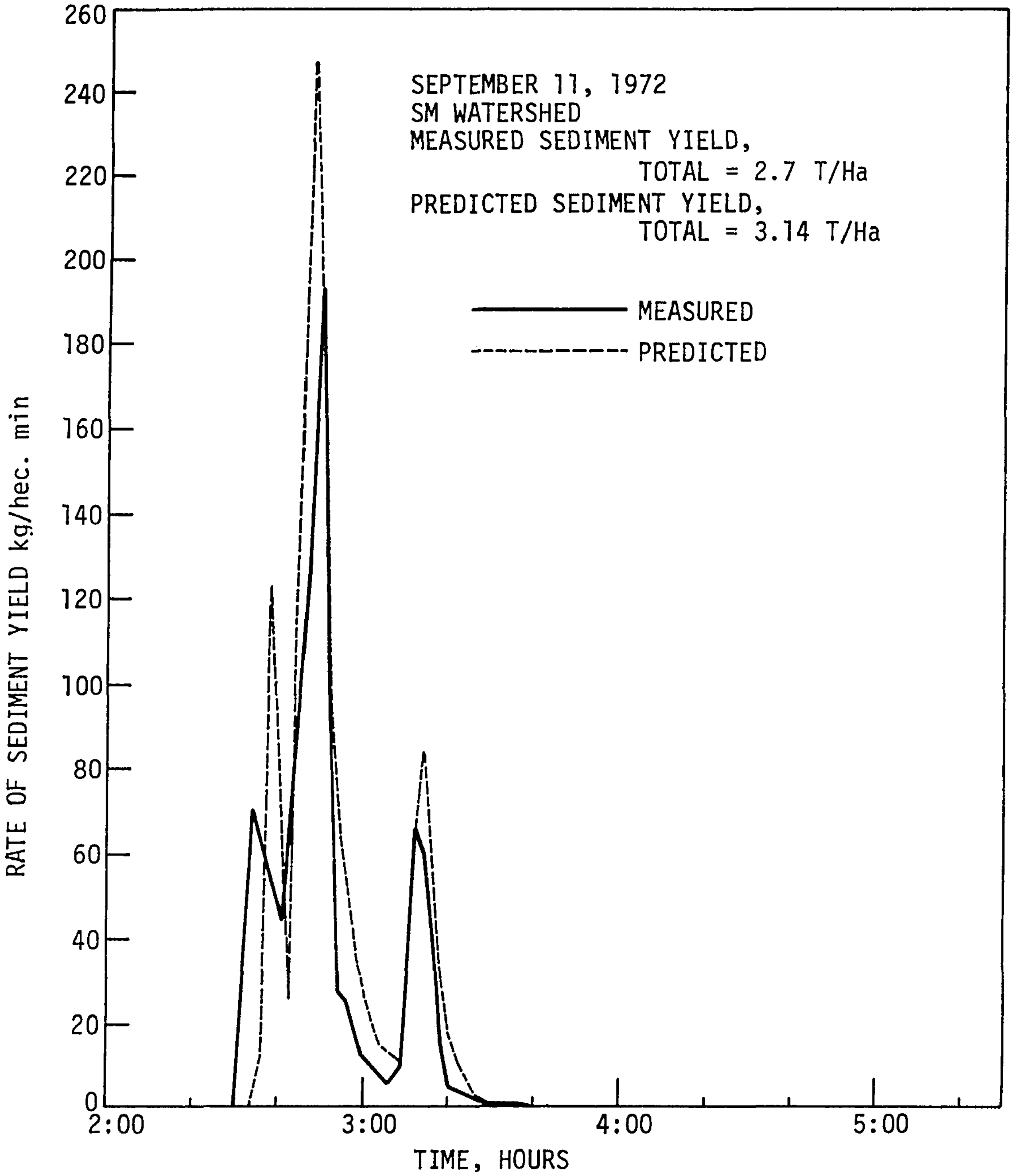

Figure 32. Comparison of measured and predicted sediment yield from SM watershed on September 11, 1972

Table 12. Comparison of measured and predicted surface runoff depth and sediment yield from individual storms of 1973 on NE watershed

Date	Measured runoff (centimeters)	Predicted runoff (centimeters)	Measured sediment yield (tonnes/ hectare)	Predicted sediment yield (tonnes/ hectare)
5/26	0.23	0.00	4.59	0.00
5/27	0.51	0.44	3.26	1.17
6/14	0.02	0.00	0.03	0.00
6/18	0.86	0.38	4.64	1.18
7/19	0.05	0.41	0.24	6.18
7/24	0.20	0.21	0.53	0.98
7/29	0.53	0.54	0.96	4.70
8/8	0.38	0.86	1.69	6.64
8/30	0.99	1.22	5.73	8.85
Total	3.77	4.06	21.67	29.7

is the major source of erosion immediately after tillage as discussed later. Underpredicting the rill erosion at the beginning of the growing season would produce this result. Overpredicting of sediment yield at the end of the growing season is largely due to overpredicting of surface runoff. The model has not simulated enough sediment yield at the beginning of the growing season for the rills to be stabilized, and consequently rills have provided more detached particles at the end of the growing season. Since sediment prediction on an individual basis was poor for the year 1973, no sedograph comparisons were made for this year.

Table 13. Comparison of measured and predicted surface runoff depth and sediment yield from individual storms of 1974 on NE watershed

Date	Measured runoff (centimeters)	Predicted runoff (centimeters)	Measured sediment yield (tonnes/hectare)	Predicted sediment yield (tonnes/hectare)
5/13	0.07	0.0	1.58	0.00
5/16	0.10	0.0	0.71	0.0
5/17-18	2.92	2.16	33.52	31.45
5/21	0.91	1.37	7.95	11.68
5/29	1.14	0.99	12.24	7.72
6/6	0.08	0.08	0.71	0.10
6/7	0.28	0.13	0.78	0.34
6/8	0.78	0.08	2.48	0.00
8/9	1.29	1.14	4.40	3.81
8/13	1.47	1.75	5.57	3.17
8/14	0.08	0.008	0.20	0.00
Total	9.12	7.71	70.14	58.28

Hydrograph and sedograph comparisons for storms of 1974 are shown in Figures 33 through 41. Hydrograph comparisons for two major storms of 1975 are shown in Figures 42 and 43.

On May 17 and 18, 1974, a surface runoff of 2.92 centimeters was recorded, while the model has predicted 2.16 centimeters of surface runoff. This large difference between measured and predicted surface runoff for the first major event after plowing may be due to the

Table 14. Comparison of measured and predicted surface runoff depth and sediment yield from individual storms of 1975 on NE watershed

Date	Measured runoff (centimeters)	Predicted runoff (centimeters)	Measured sediment yield (tonnes/ hectare)	Predicted sediment yield (tonnes/ hectare)
4/27	3.33	3.68	13.99	37.32
6/18	0.02	0.00	0.00	0.00
6/20	0.33	0.10	1.35	0.24
6/21	0.56	0.94	5.74	14.88
Total	4.24	4.72	21.08	52.44

increased storage in the top layer resulting from plowing. This suggests that expressions PUDLE1, OFMNI, and TRSTM in overland flow component may vary from one year to another depending on the soil condition at the time of plowing.

For the year 1975, the event on April 27 occurred before plowing. This means that the starting TRST (total runoff since last tillage) value is the accumulated value of surface runoff depth after tillage of the previous year. Since the value of TRST is greater than or equal to the input value of TRSTM (surface runoff required to remove the puddles created by tillage), variables PUDLE and OFMN will be at their minimum values no matter what the value of TRST is. Therefore, in cases when the runoff producing event occurs prior to the tillage (as in this case) and the depth of surface runoff from previous year

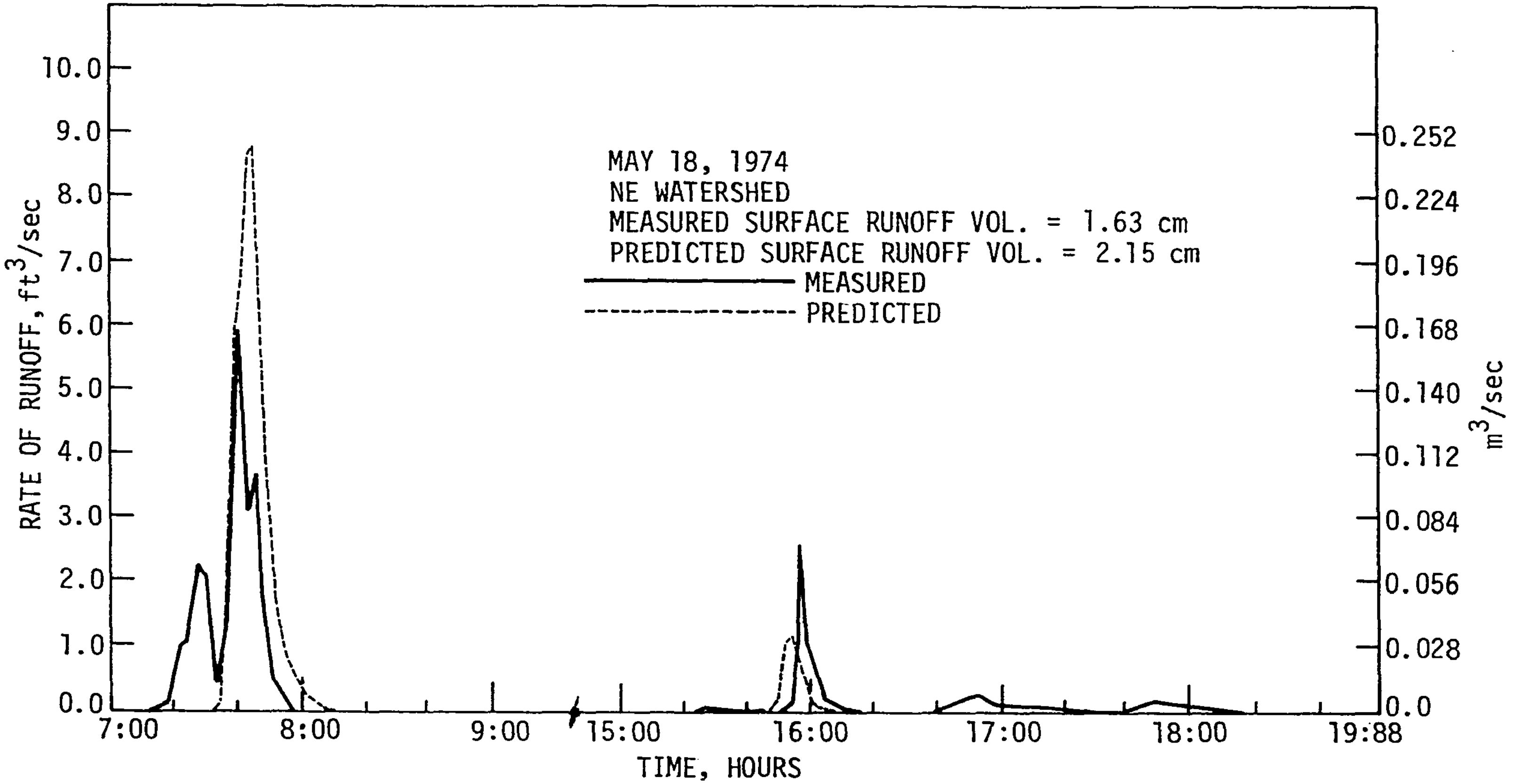

Figure 33. Comparison of measured and predicted surface runoff from NE watershed on May 18, 1974

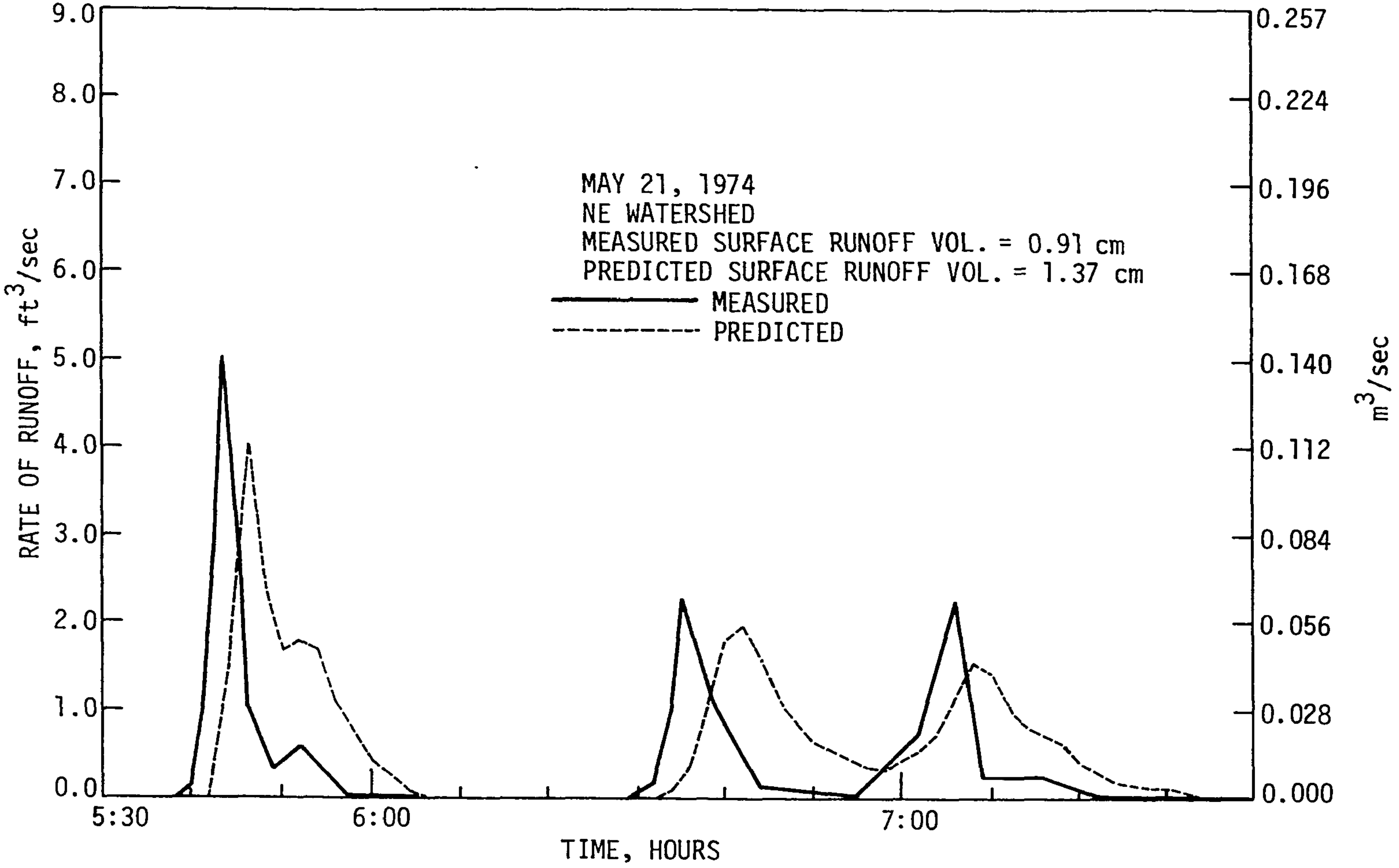

Figure 34. Comparison of measured and predicted surface runoff from NE watershed on May 21, 1974

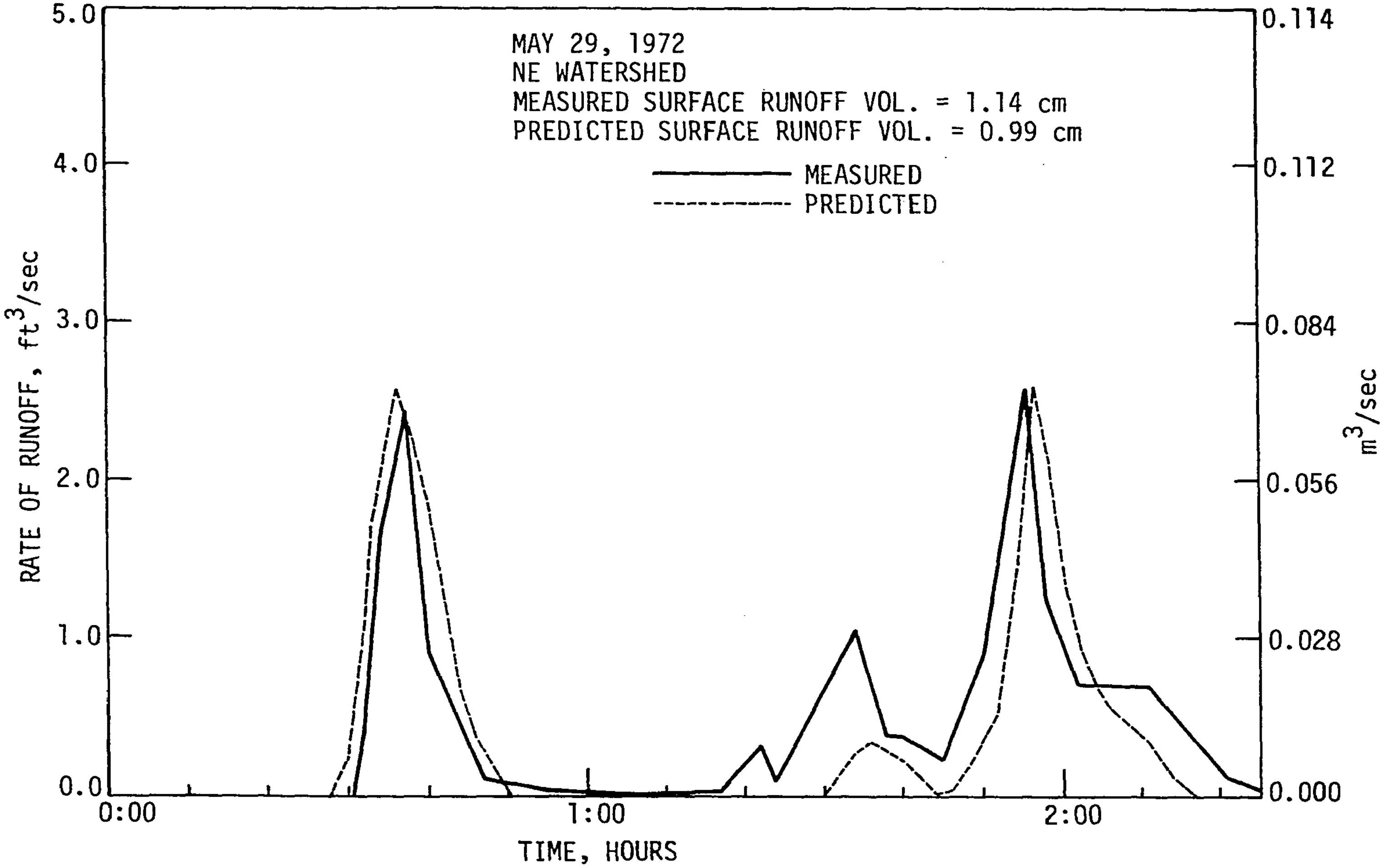

Figure 35. Comparison of measured and predicted surface runoff from NE watershed on May 29, 1974

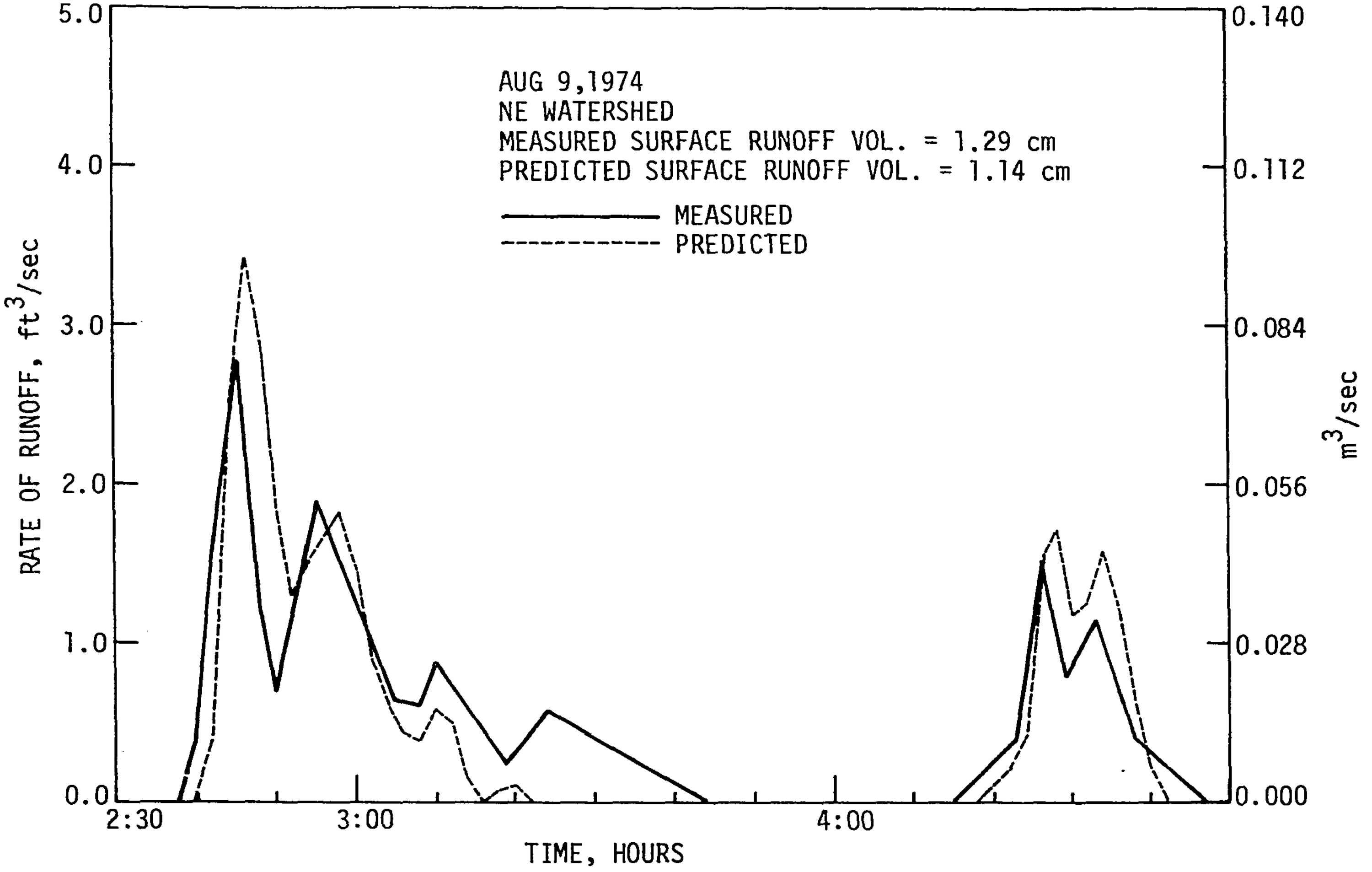

Figure 36. Comparison of measured and predicted surface runoff from NE watershed on August 9, 1974

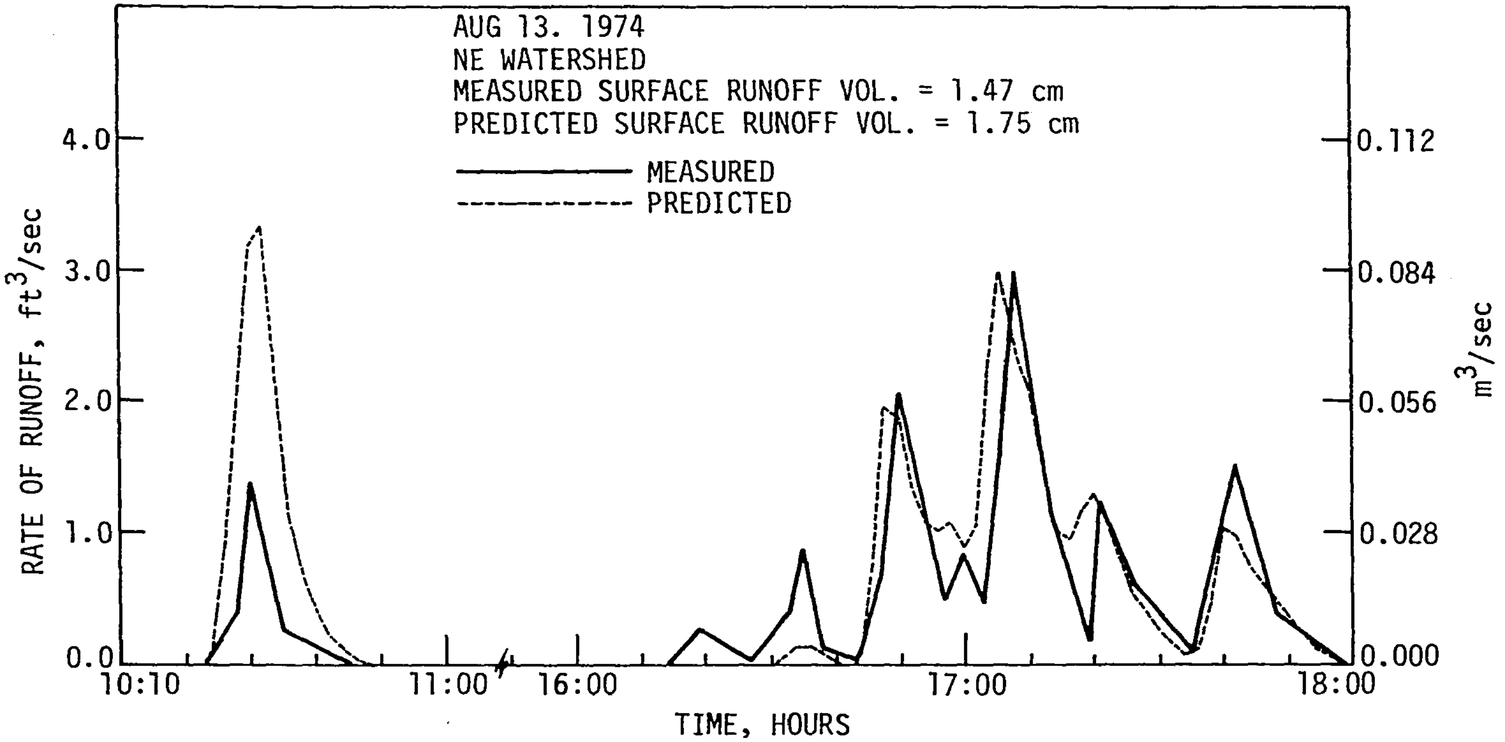

Figure 37. Comparison of measured and predicted surface runoff from NE watershed on August 13, 1974

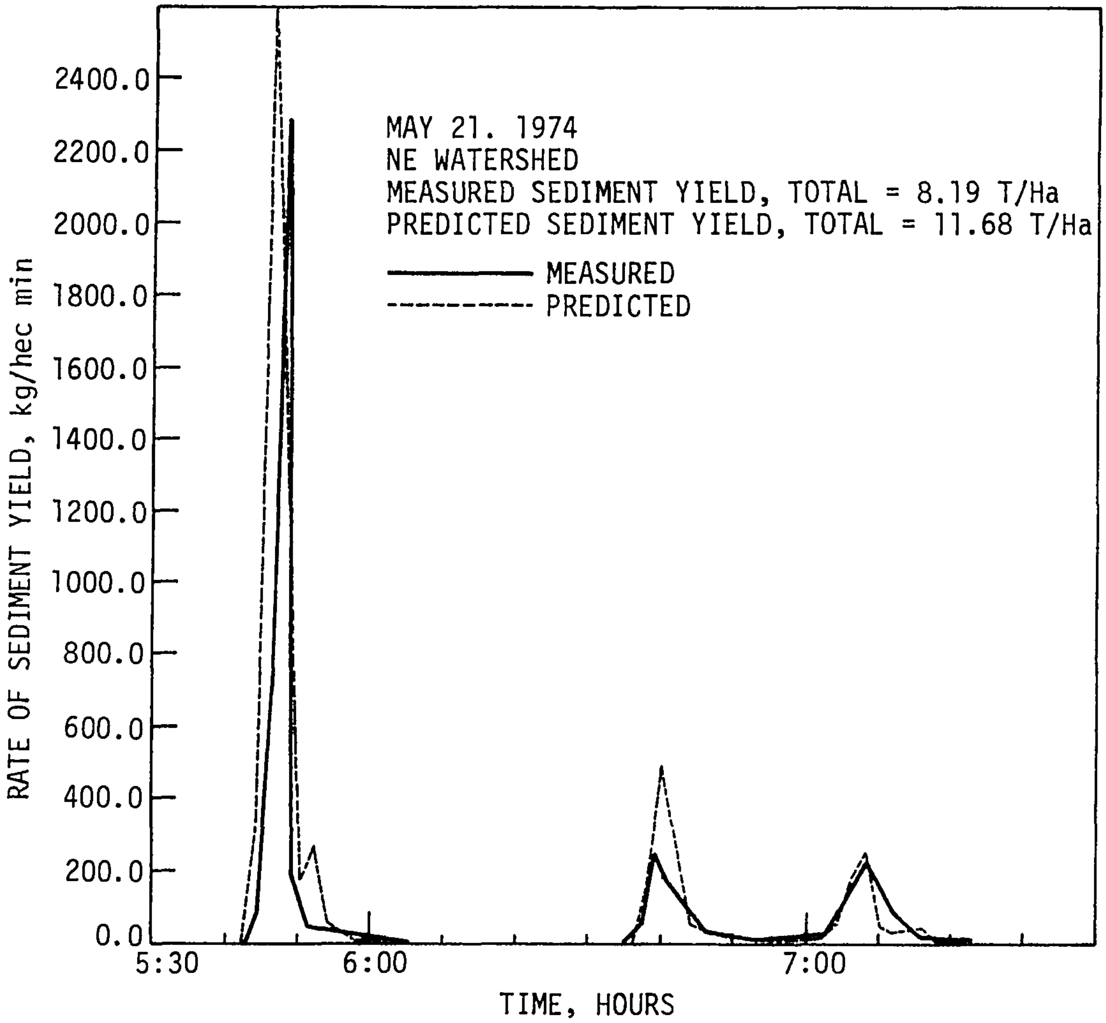

Figure 38. Comparison of measured and predicted sediment yield from NE watershed on May 21, 1974

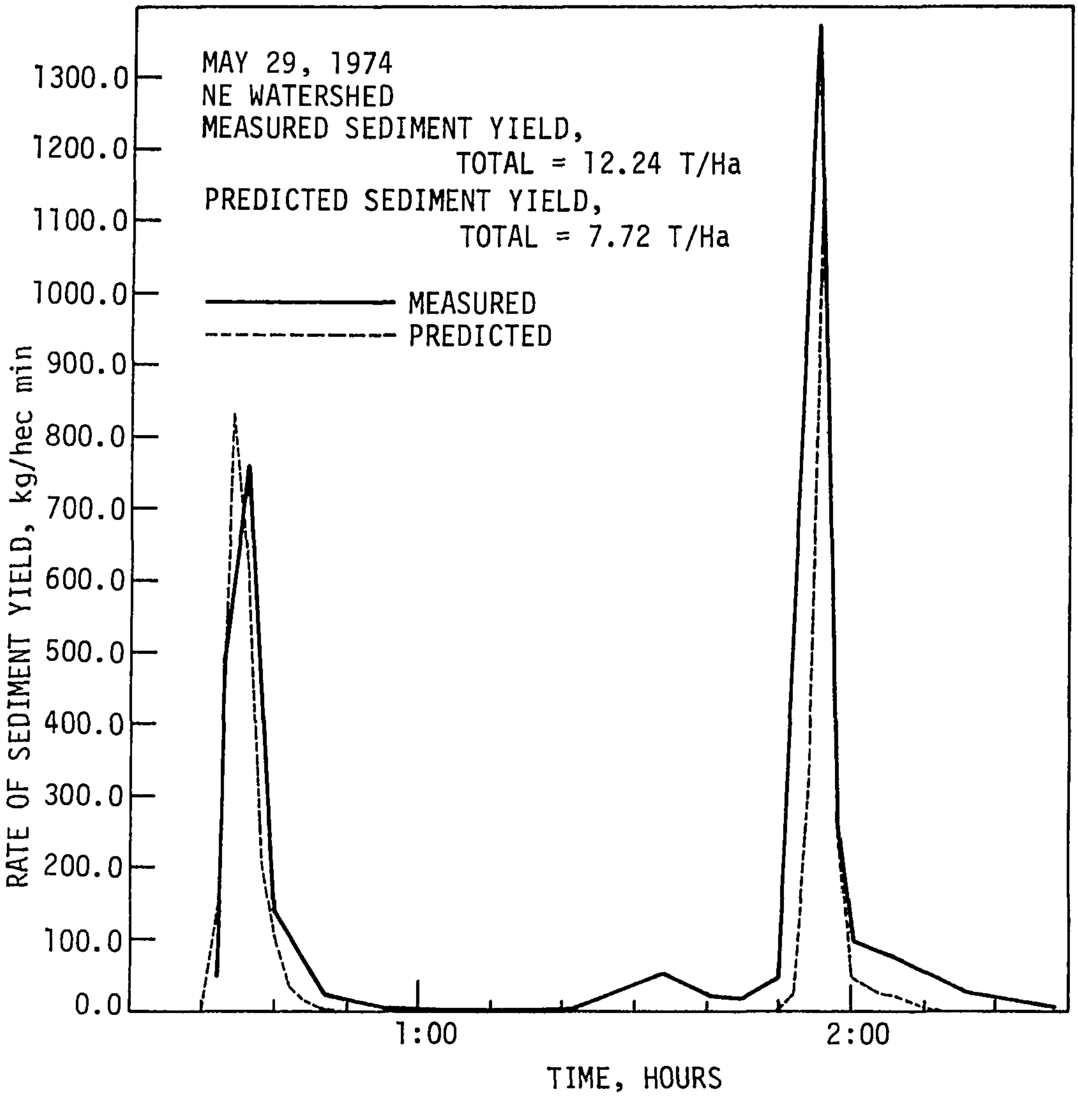

Figure 39. Comparison of measured and predicted sediment yield from NE watershed on May 29, 1974

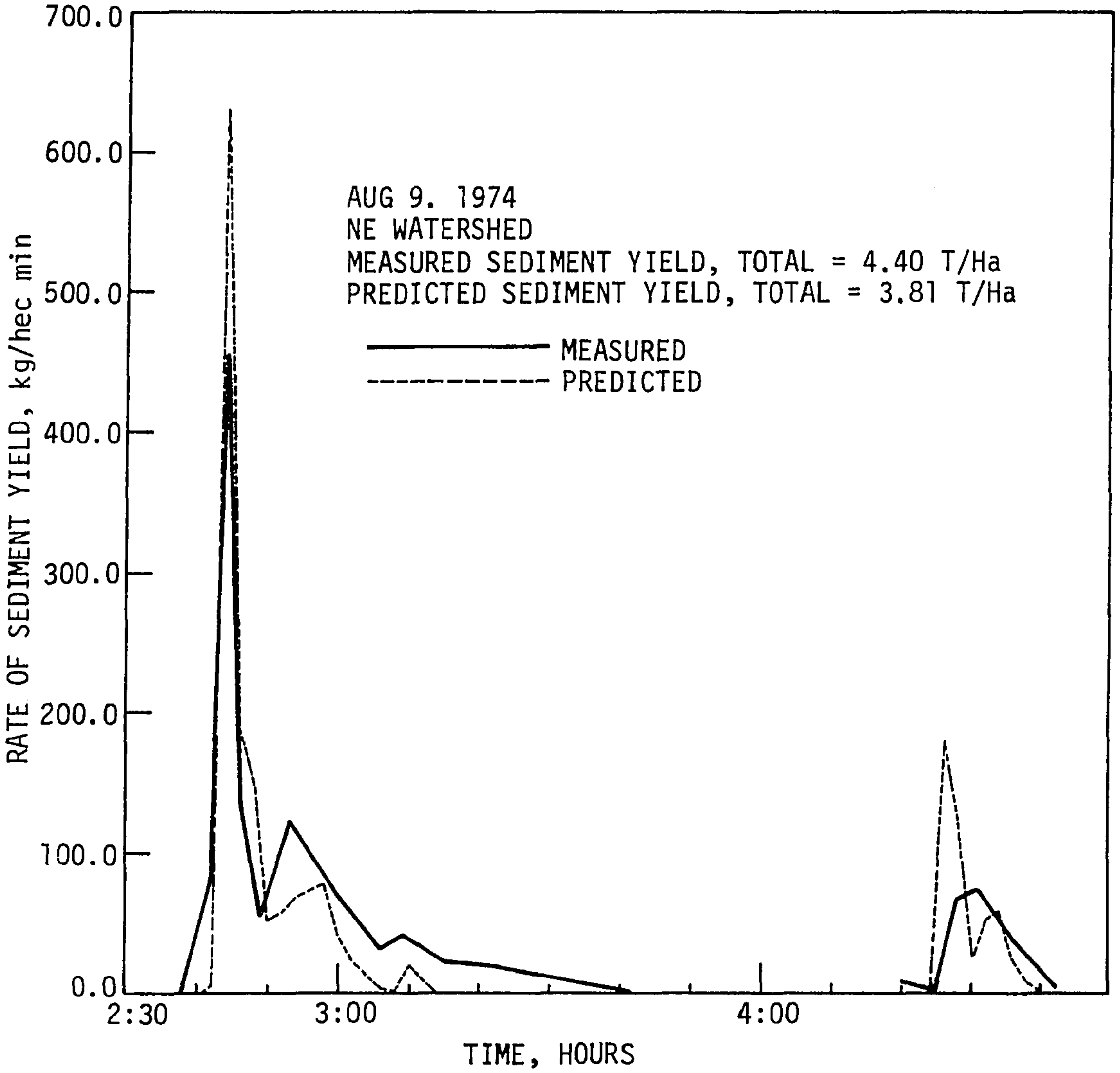

Figure 40. Comparison of measured and predicted sediment yield from NE watershed on August 9, 1974

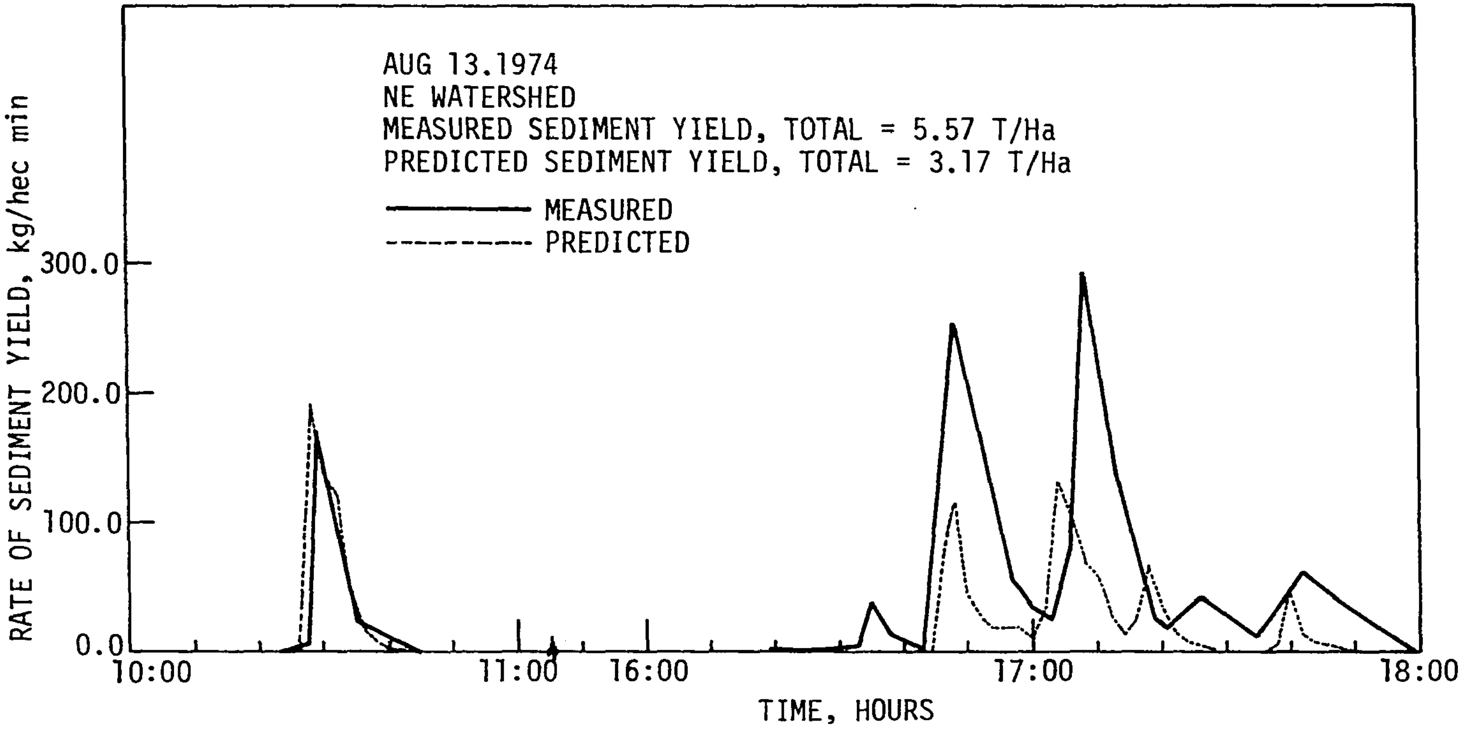

Figure 41. Comparison of measured and predicted sediment yield from NE watershed on August 13, 1974

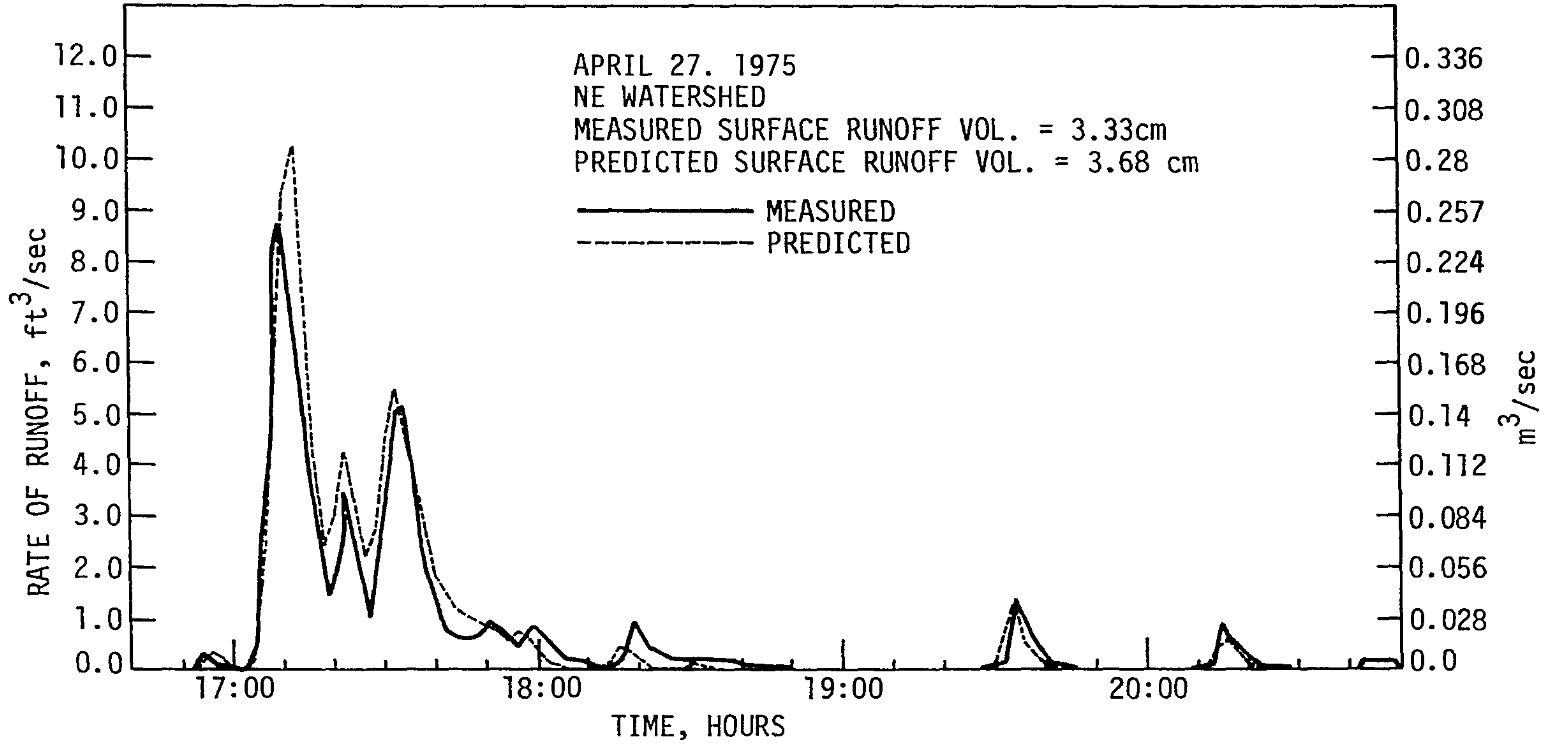

Figure 42. Comparison of measured and predicted surface runoff from NE watershed on April 27, 1975

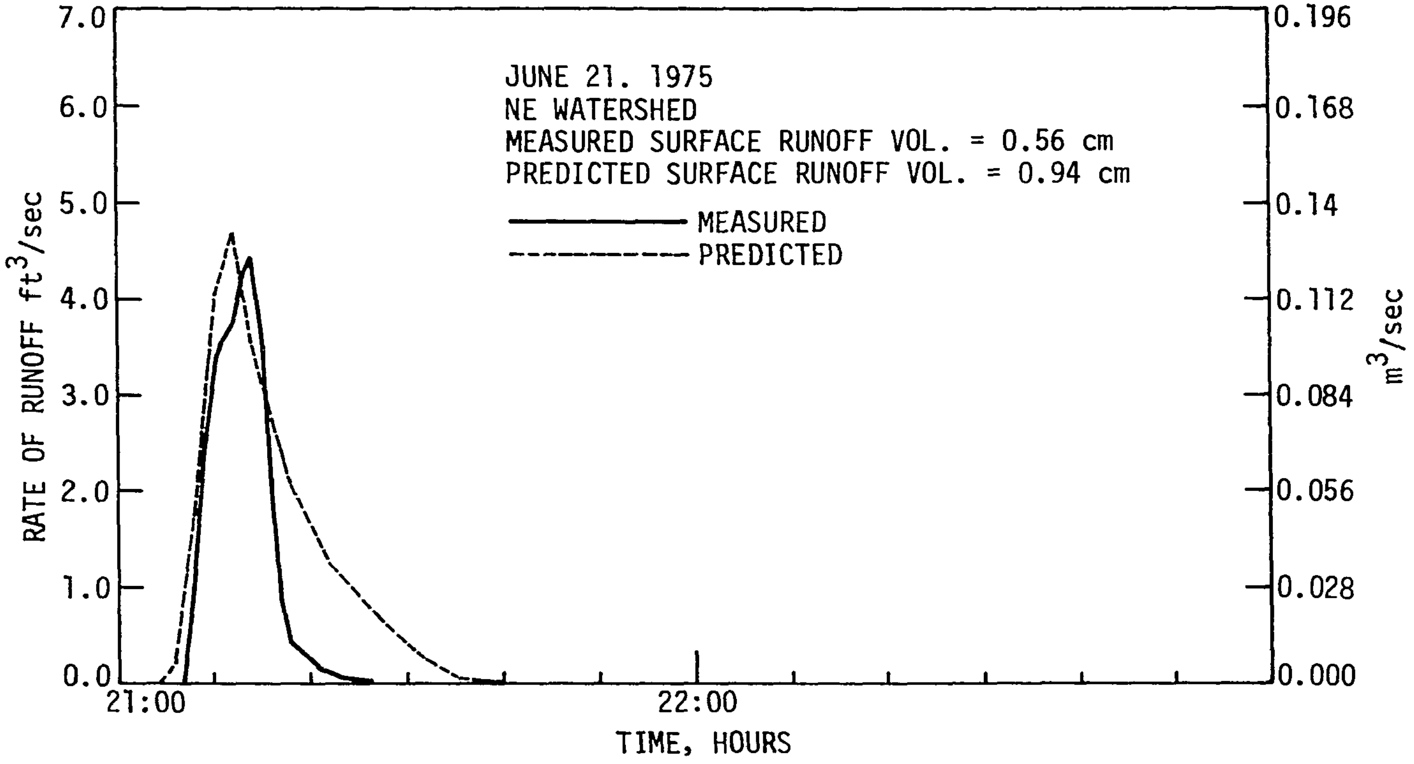

Figure 43. Comparison of measured and predicted surface runoff from NE watershed on June 21, 1975

is not known, an approximate value greater than or equal to input value of TRSTM should be used.

The large difference in predicted and recorded sediment yield on April 27, 1975, shows the dramatic effect of the residue cover on erosion and sediment yield. The event on April 27 occurred before plowing, when the cornstalks from the previous year were on the soil surface. Even though the model is designed to take into account the effect of crop residue left on the surface, the model was not calibrated for this effect. The assumption of "no residue" was made to show its effect on sediment yield prediction.

MODEL SENSITIVITY ANALYSIS

The shortest time increment used in the model to calculate surface runoff and sediment yield was 2 minutes. The reason for use of the 2-minute period is discussed here. The objective of this section is to evaluate the sensitivity of hydrology and erosion models to parameters used.

Sensitivity of Model to Time Interval Used

The model was designed to use any time increment desired during the rainfall to calculate surface runoff and sediment yield. The watersheds under study are very small with low storage and attenuation capacity. These characteristics of the watersheds dictated use of very short time increments for a better simulation of the surface runoff and sediment yield.

The effect of duration of the time increment on response of the model was tested. To do this, all of the other variables were held constant. The only variable changed was NH, which determines the length of the shortest time increment to be used. Data from 1972 on NE watershed were used. Time intervals of 2, 5, 10, and 15 minutes were used. Predicted surface runoff and sediment yield for these time periods are compared with the measured surface runoff and sediment yield in Tables 15 and 16.

The comparison in Table 15 shows that prediction of volume of runoff for large rainfall events is not very sensitive to the length of time interval used in the model; however, the ability of the model

Table 15. Comparison of measured and predicted surface runoff depth for 1972 data on NE watershed using different time intervals

Date	Measured runoff (centimeters)	Predicted runoff (centimeters) for indicated time interval (minutes) 2	5	10	15
5/1	0.00	0.50	0.52	0.44	0.29
5/5	1.32	1.62	1.64	1.64	1.58
7/1	1.60	2.18	2.30	1.89	1.99
7/17	1.50	1.23	1.23	1.12	1.15
7/26	1.29	1.22	1.19	1.17	0.94
8/7	1.14	1.20	1.25	1.22	0.87
8/25	0.20	0.005	0.00	0.00	0.00
9/5	0.30	0.27	0.20	0.10	0.05
9/10-11	1.96	1.92	1.94	1.88	1.79
Total	9.31	9.64	10.27	9.46	8.66

to predict the volume of runoff from small rainfall events decreases as the time interval increases.

In small watersheds like those under study where time of concentration is only a few minutes, any change in rainfall intensity affects both the shape of hydrograph and rate of runoff. Subroutine precipitation (PRECIP) is designed to calculate rainfall intensity from rain gage charts by use of the break points in rainfall intensity. During the periods of rainfall, each hour is divided into NH number of equal time increments, the length of time increments defined as 60/NH minutes (Δt hereafter). The rainfall intensity for each time increment is calculated by dividing the total precipitation during that time

Table 16. Comparison of measured and predicted sediment yield for 1972 data on NE watershed using different time intervals

Date	Measured sediment yield (tonnes/hectare)	Predicted sediment yield (tonnes/hectare) for indicated time intervals (minutes) 2	5	10	15
5/1	0.00	0.36	7.41	17.43	17.18
5/5	27.79	26.00	49.54	72.36	116.10
7/1	28.40	32.43	28.91	15.16	19.28
7/17	11.73	3.26	2.44	1.15	1.10
7/26	2.04	2.26	2.00	1.08	0.79
8/7	2.07	2.28	1.74	1.01	0.68
9/5	0.83	0.80	0.49	0.26	0.18
9/10-11	3.65	2.85	2.21	1.11	0.78
Total	76.51	70.60	94.74	109.56	156.09

increment by Δt. In case the Δt chosen is 15 minutes (NH = 4), the hour is divided into 4 periods of 15 minutes. For each 15 minutes, the precipitation subroutine (PRECIP) is called to calculate the total precipitation and consequently the rainfall intensity for that period. This means that the model assumes a uniform rainfall intensity during the entire 15-minute period. For example, on May 5, 1972, using 15-minute time interval, the calculated rainfall intensity during the time from 22:15 through 22:30 was 4.488 cm/hr and from 22:30 through 22:45 it was 1.583 cm/hr (see Figure 46). For the same storm and during the same period of time, calculated rainfall intensities using 2-minute time interval are shown. As Figure 46 shows, the calculated rainfall intensity is the average of rainfall intensities during that time period. Comparisons between calculated rainfall intensities for 5- and 10-minute increments with 2-minute increments are shown in Figures 44 and 45. Usually rainfall does not start or end at the same time that Δt starts or ends. Assume that rainfall is actually started at 22:07 and total precipitation occurred uniformly between 22:07 to 22:15 is 0.45 centimeter. Actual rainfall intensity for this period would be 3.375 cm/hr. Precipitation subroutine, which is called at 22:00, takes the 0.45 centimeter of rainfall occurring within 15 minutes (with Δt = 15 minutes) and assumes that precipitation is uniform over the entire 15 minutes and calculates the rainfall intensity to be of 1.8 cm/hr. This causes a deviation from the measured intensity and dictates use of a short time increment to overcome the problem.

By use of short time periods, rainfall intensity is better defined at any time. With better defined rainfall intensity, the predicted runoff rate at any time is closer to the measured runoff rate. Figures 47 through 52 show the sensitivity of the rate of runoff to time increment used in the model for a single and double peak storm.

Figures 47 through 52 show that increasing Δt decreases the peak rate of runoff. The reason for a lag in hydrograph when using larger time increments (see Figure 52 as an example) is partly due to precipitation subroutine (PRECIP) and the way that the model works. At the beginning of each time increment, the precipitation subroutine calculates the total precipitation for the period of Δt, which ends at the beginning of the next time increment. By use of the calculated

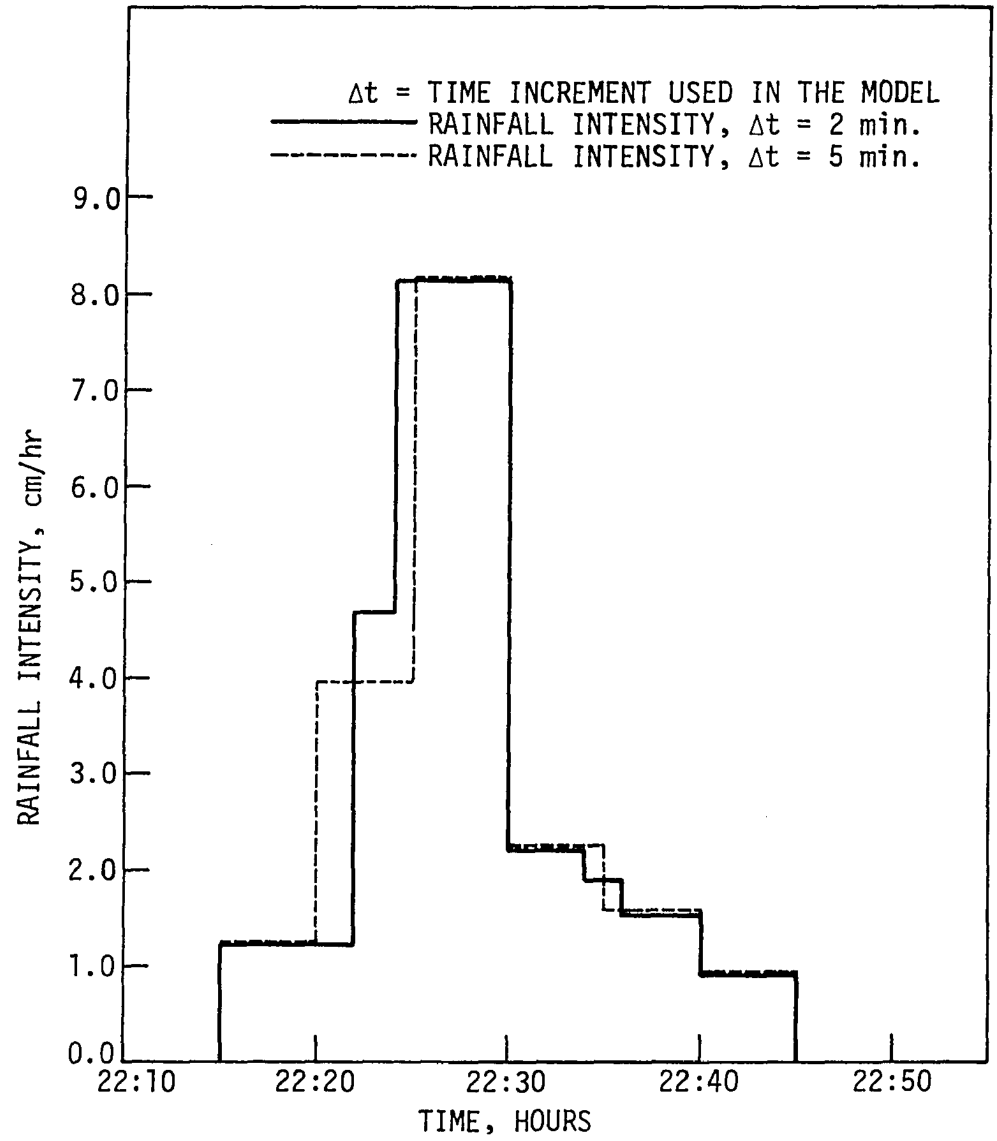

Figure 44. Rainfall intensity calculated on May 5, 1972, using 2 and 5 minute time increments

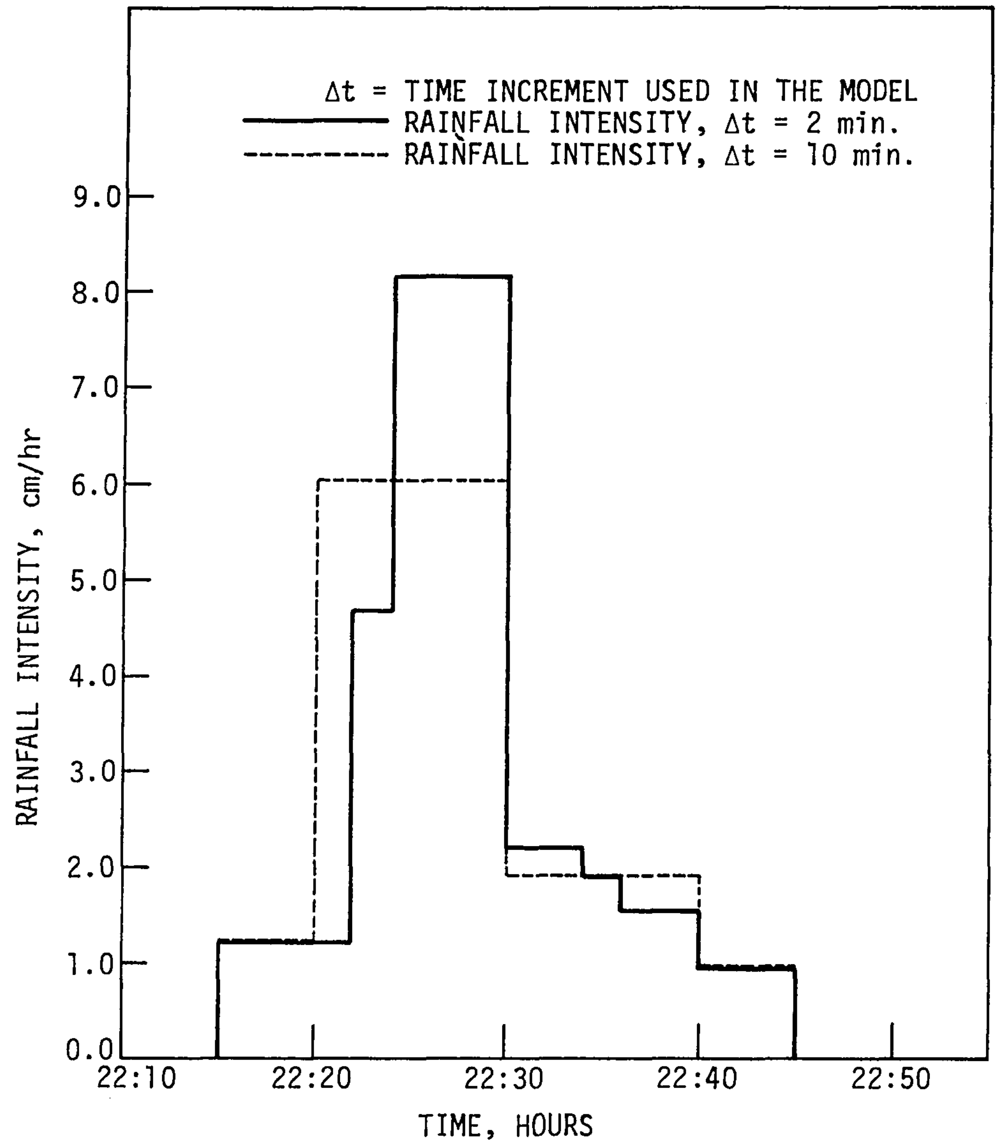

Figure 45. Rainfall intensity calculated on May 5, 1972, using 2 and 10 minute time increments

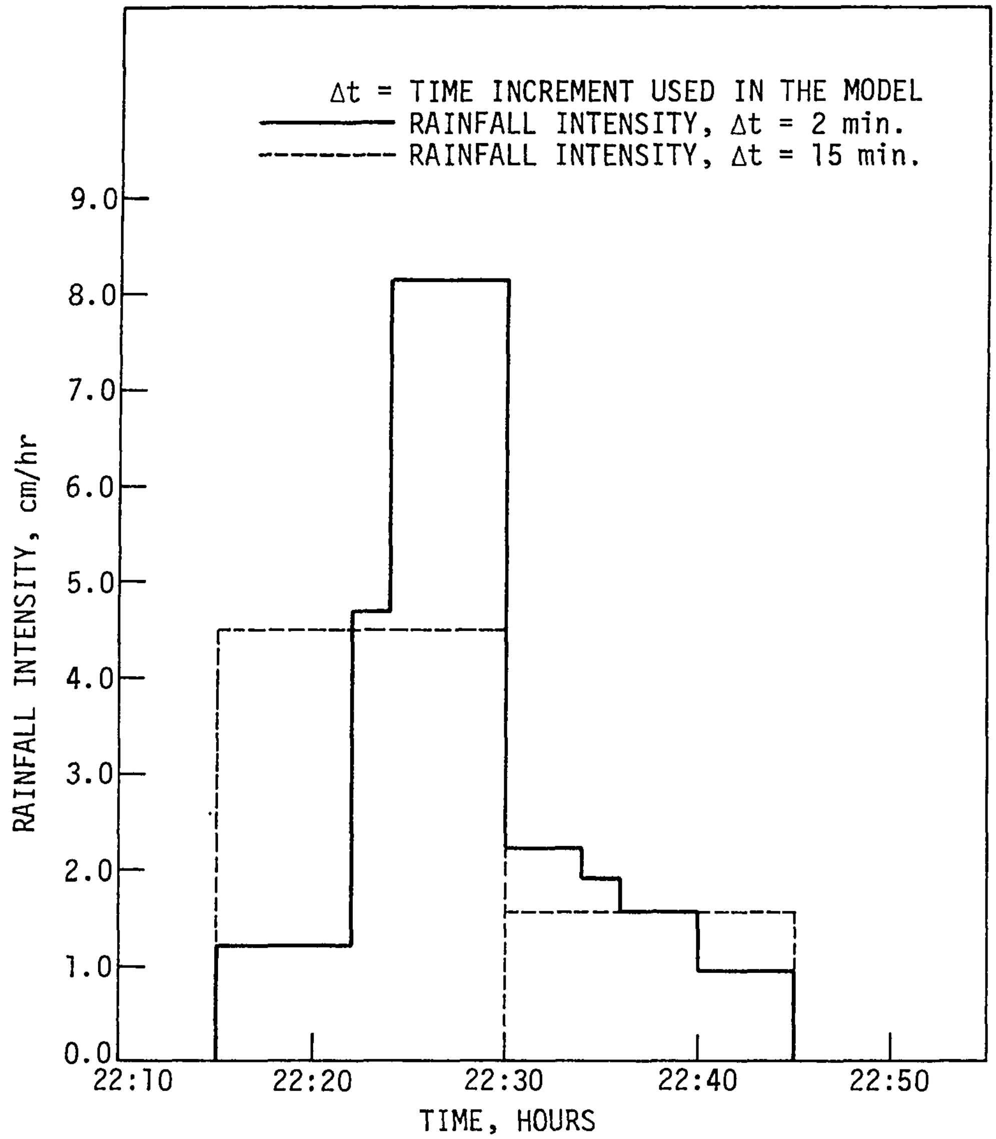

Figure 46. Rainfall intensity calculated on May 5, 1972, using 2 and 15 minute time increments

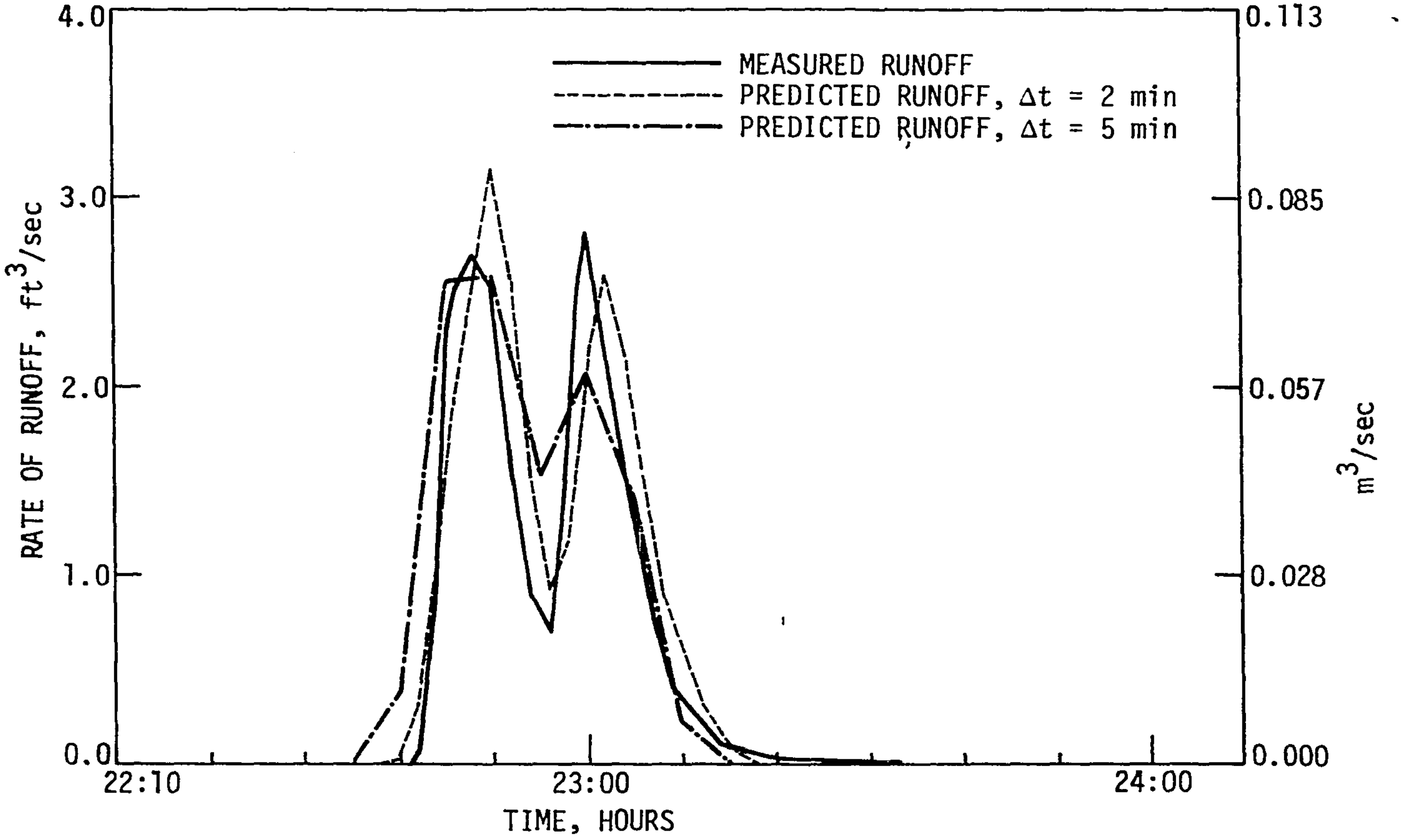

Figure 47. Comparison of measured and predicted surface runoff from SM watershed on August 7, 1972, using time increments of 2 and 5 minutes

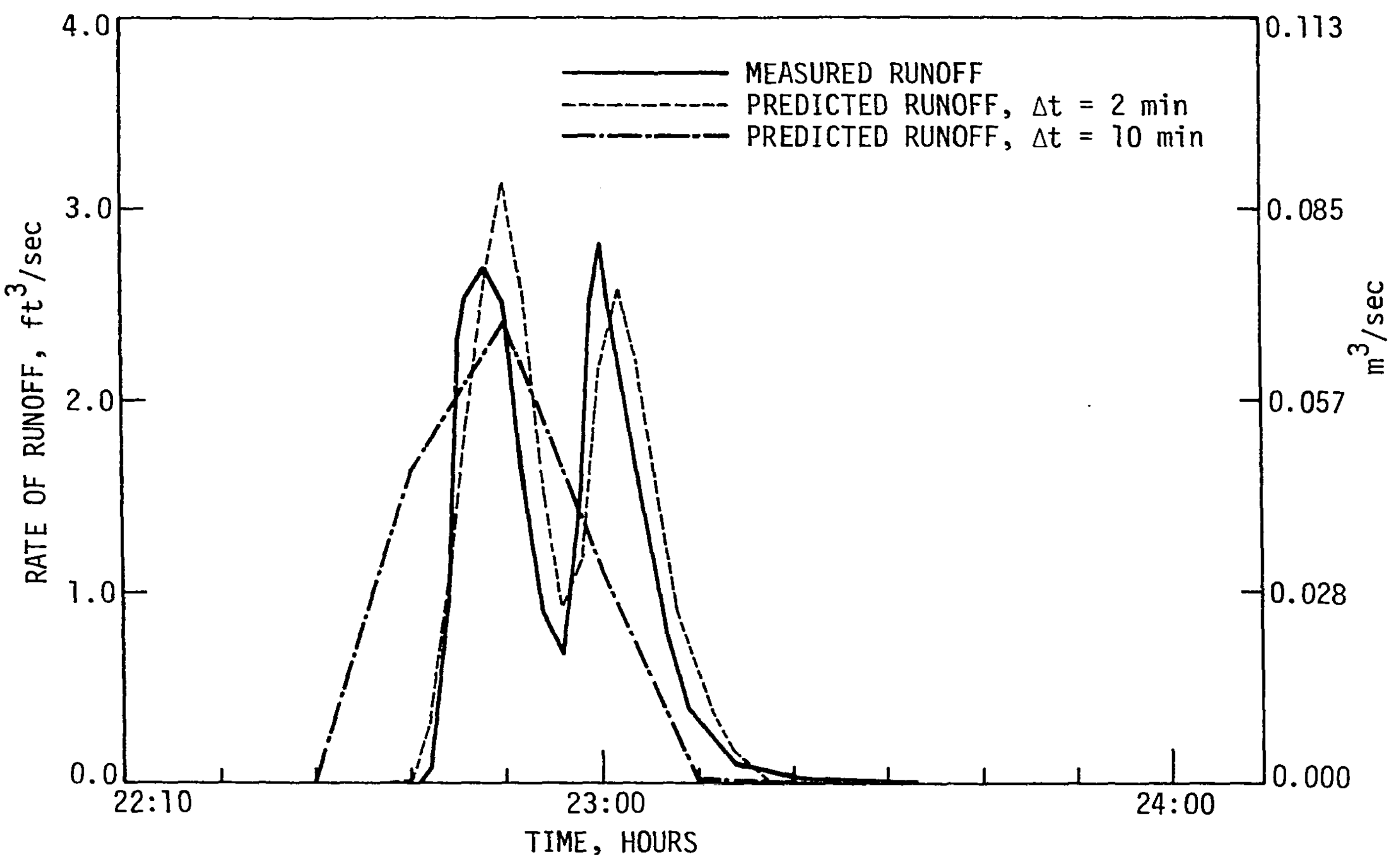

Figure 48. Comparison of measured and predicted surface runoff from SM watershed on August 7, 1972 using time increments of 2 and 10 minutes

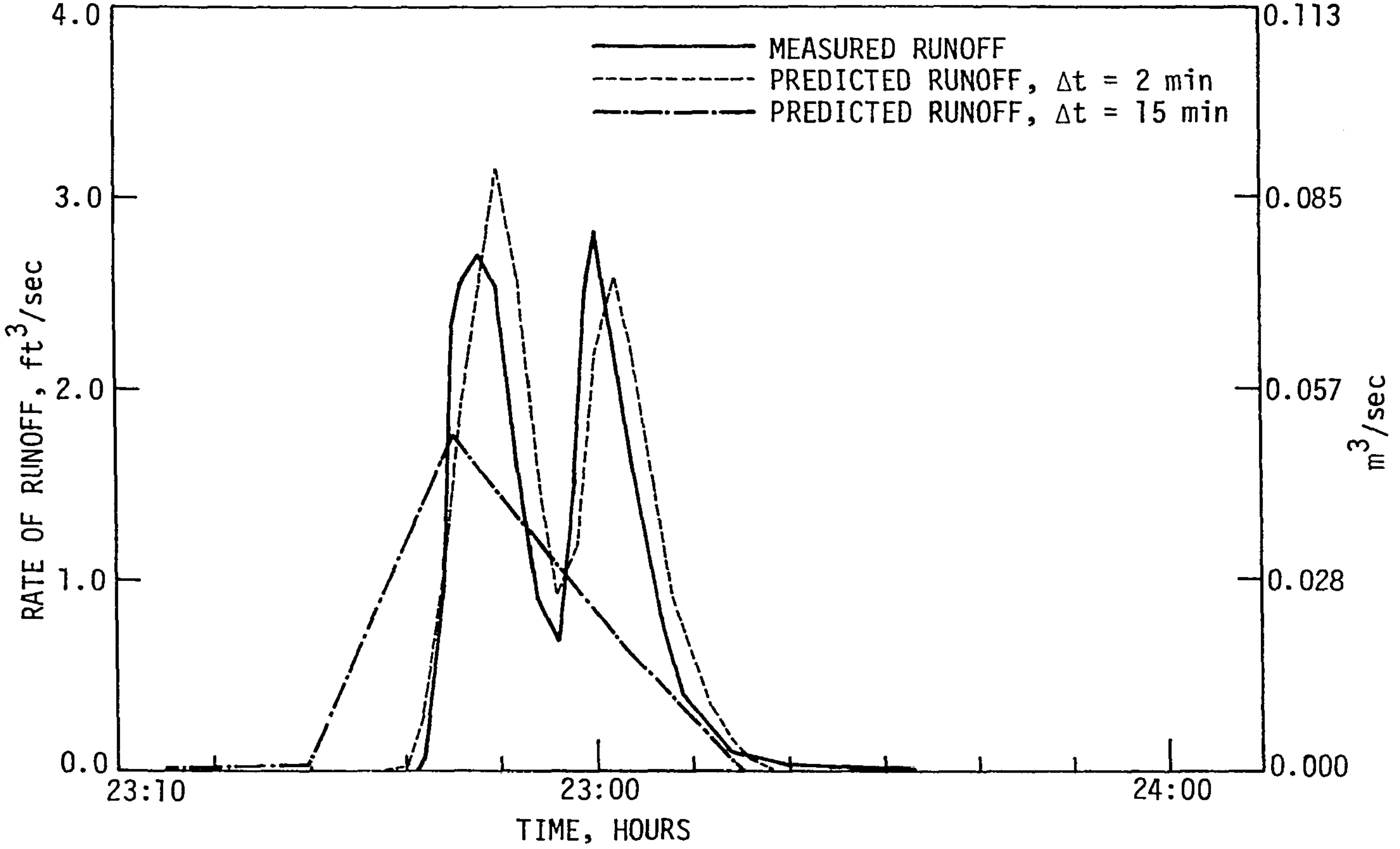

Figure 49. Comparison of measured and predicted surface runoff from SM watershed on August 7, 1972 using time increments of 2 and 15 minutes

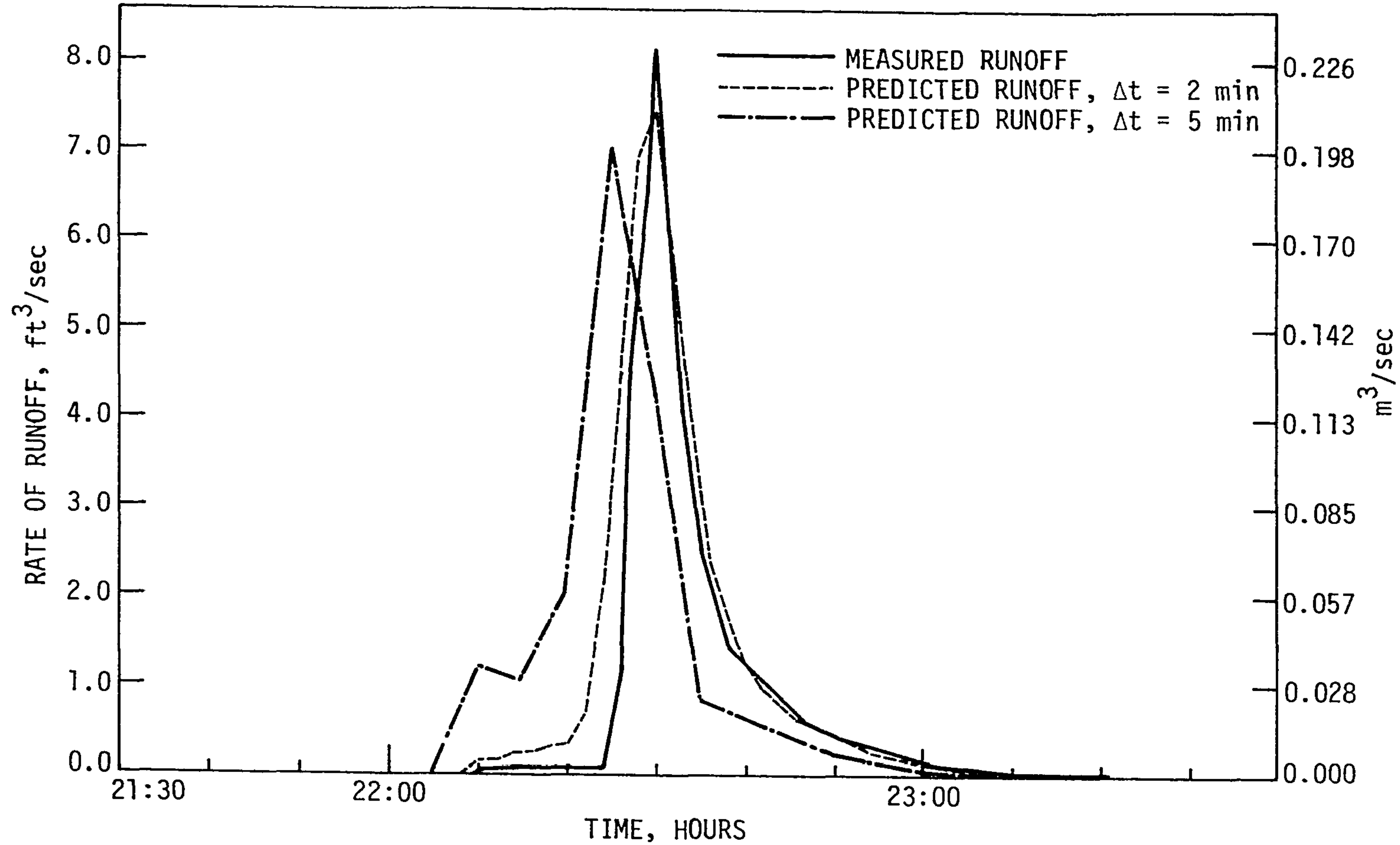

Figure 50. Comparison of measured and predicted surface runoff from NE watershed on May 5, 1972 using time increments of 2 and 5 minutes

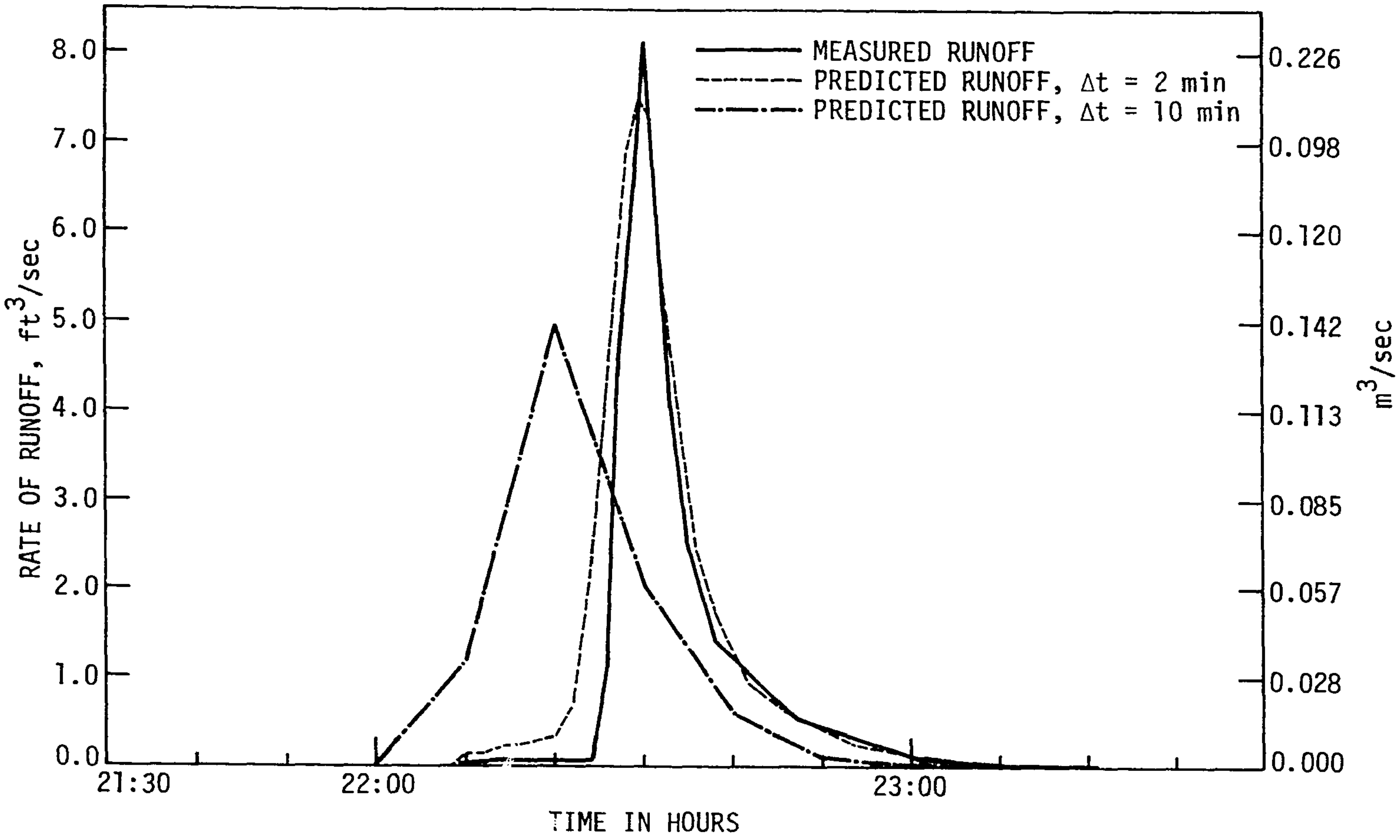

Figure 51. Comparison of measured and predicted surface runoff from NE watershed on May 5, 1972 using time increments of 2 and 10 minutes

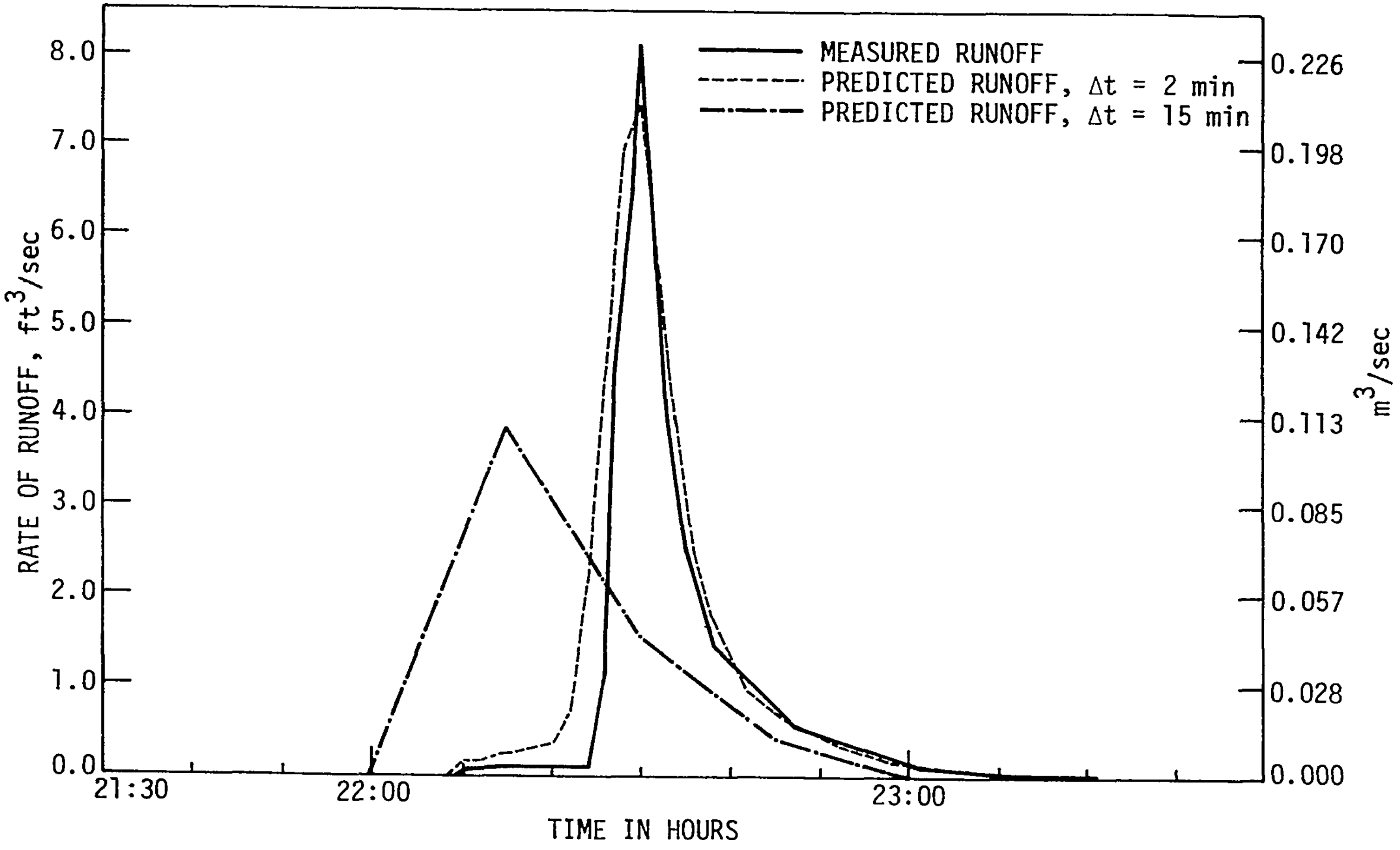

Figure 52. Comparison of measured and predicted surface runoff from NE watershed on May 5, 1972 using time increments of 2 and 15 minutes

precipitation, overland flow runoff is calculated and is assumed to correspond to the time at the beginning of Δt. This advances the hydrograph timing half of Δt. The predicted peak rates and discharges are the same (the hydrograph has the same shape), but the programming technique advances the runoff in time. This causes the apparently large discrepancy in Figure 52.

The comparisons shown in Table 16 indicate that prediction of sediment yield is very sensitive to time interval. Since erosion and sediment yield are functions of both rainfall intensity and runoff rate at any time, the importance of the length of time increment used in the model and its effect on rainfall intensity and runoff rate is obvious. With larger time intervals (even though the rainfall intensity decreases, amount of precipitation stays the same) the model overpredicts sediment yield at the beginning and underpredicts at the end of the growing season. As discussed later in this section, rill detachment is the major source of predicted erosion immediately after tillage, the time that soil is very susceptible to rill erosion. The major cause of the deviation reflects the way that the model works. For example, in Figure 52, the value used in the model to calculate rill erosion and transport capacity over a 15-minute time interval from 22:00 through 22:15 is 2.8 ft^3/sec (0.11 m^3/sec), which causes considerable rill erosion and consequently sediment yield. A better representative value of overland flow runoff during this period would be the average of surface runoffs at 22:00 and at 22:15. This factor and the large susceptibility of soil to rill erosion immediately after tillage near the beginning of the growing season is the cause of overprediction at this time of the year. The reason for underprediction, apart from the smaller contribution by interrill erosion due to decrease in rainfall intensity using a larger time increment, is stabilization of rills at the end of the growing season which results from the severe rill erosion at the beginning of the growing season.

Sensitivity of Model to Hydrologic Parameters

In this section sensitivity of the hydrologic model to some of the major model parameters is analyzed. In a run made to test the effect of a specified parameter, all other parameters were held constant at their calibrated values. The value of the parameter under study was increased and decreased by 25 and 50 percent of its calibrated value.

The main objective was to evaluate the effect of changes in a parameter value on corresponding changes in volume of runoff, peak rate of runoff, amount and peak rate of sediment yield. Since some of the parameter values change with time, their effect on response of the model is not the same throughout the growing season. This means some of the parameters which significantly affect the model response at the beginning of the growing season may not have the same effect at the end of the growing season. For example, those parameters which have been incorporated into the overland flow component to sense the effect of tillage on overland flow are important at the beginning of the growing season immediately after tillage. It is shown that the model has predicted a depth of runoff of 0.50 centimeter for the event on May 1, 1972, while no measured runoff has been reported. The effects of parameters PUDLE1, OFMN1, and TRSTM on predicted depth of runoff from NE watershed for this storm are shown in Figure 53. Model response, especially for the first event right after plowing, is very sensitive to parameters TRSTM and PUDLE1. A run was made assuming PUDLE1 and TRSTM to be zero and OFMN1 to be the same as OFMN2. Predicted depth of runoff for the event on May 1, 1972, increased by 90 percent. OFMN1, the initial value of Manning's coefficient, n, does not have a large effect on predicted depth of runoff. One reason is probably that the initial value of OFMN1 (0.15) is assumed to be close to its final, OFMN2 (0.10).

The overland flow parameters of PUDLE1, OFMN1, and TRSTM, despite their significant effect at the beginning of the growing season, are not significant whenever a certain amount of surface runoff has occurred (TRST becomes equal or greater than TRSTM). Figure 54 shows that changing the value of the parameters by 50 percent of their calibrated value changes the predicted volume of surface runoff over the growing season not more than plus or minus 3 percent.

The main parameters controlling the predicted volume of runoff over the growing season are those related to the infiltration processes. The most sensitive parameters are CE1, CE2, ASOILM, and PSFC. The sensitivity of the model to prediction of volume of runoff over the period of the growing season as related to these parameters is shown in Figure 54.

The effects of the hydrologic parameters on predicted volume of runoff for the storm on July 1, 1972, are shown in Figure 55. The same

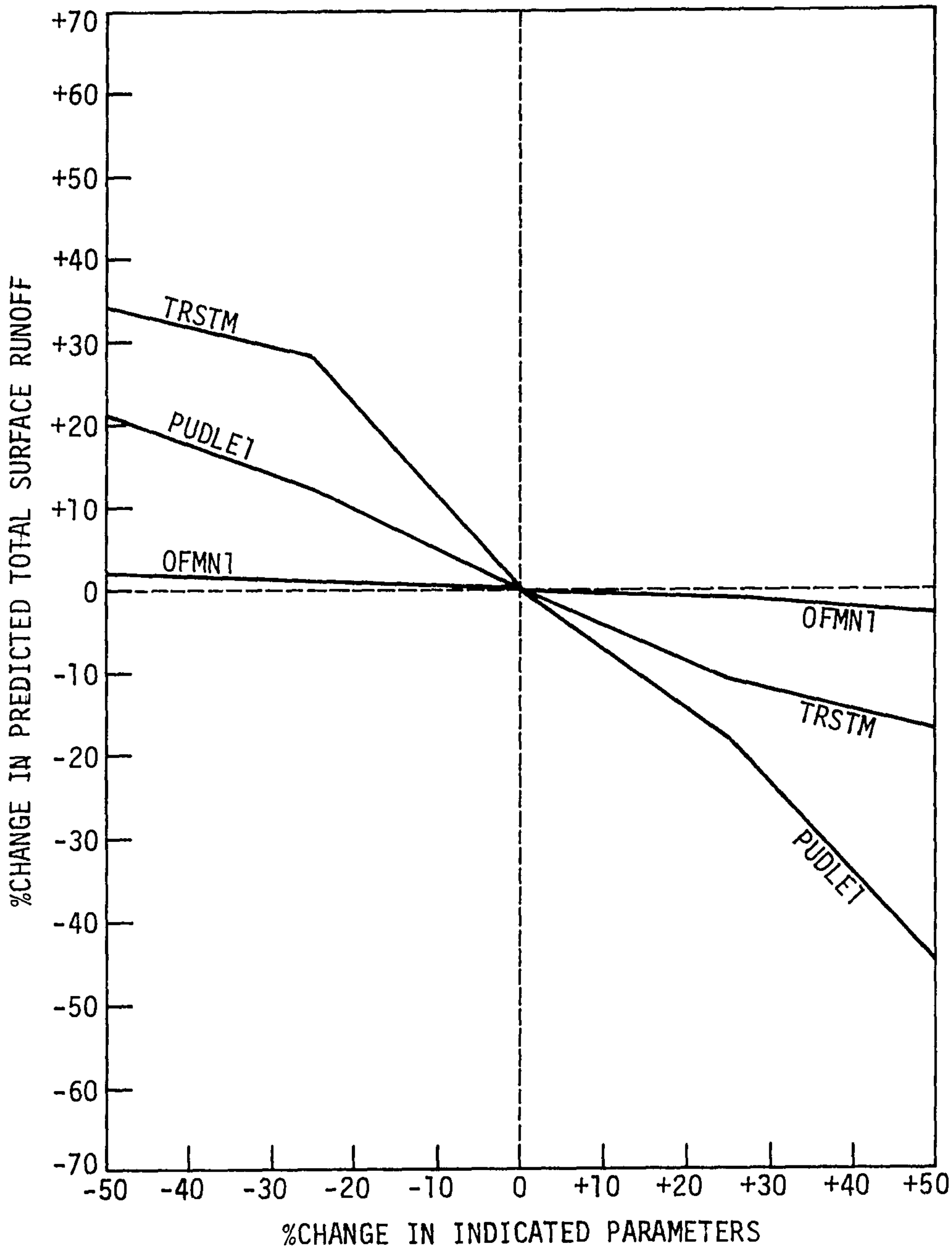

Figure 53. Hydrologic parameter sensitivity - total surface runoff from NE watershed for the storm of May 1, 1972

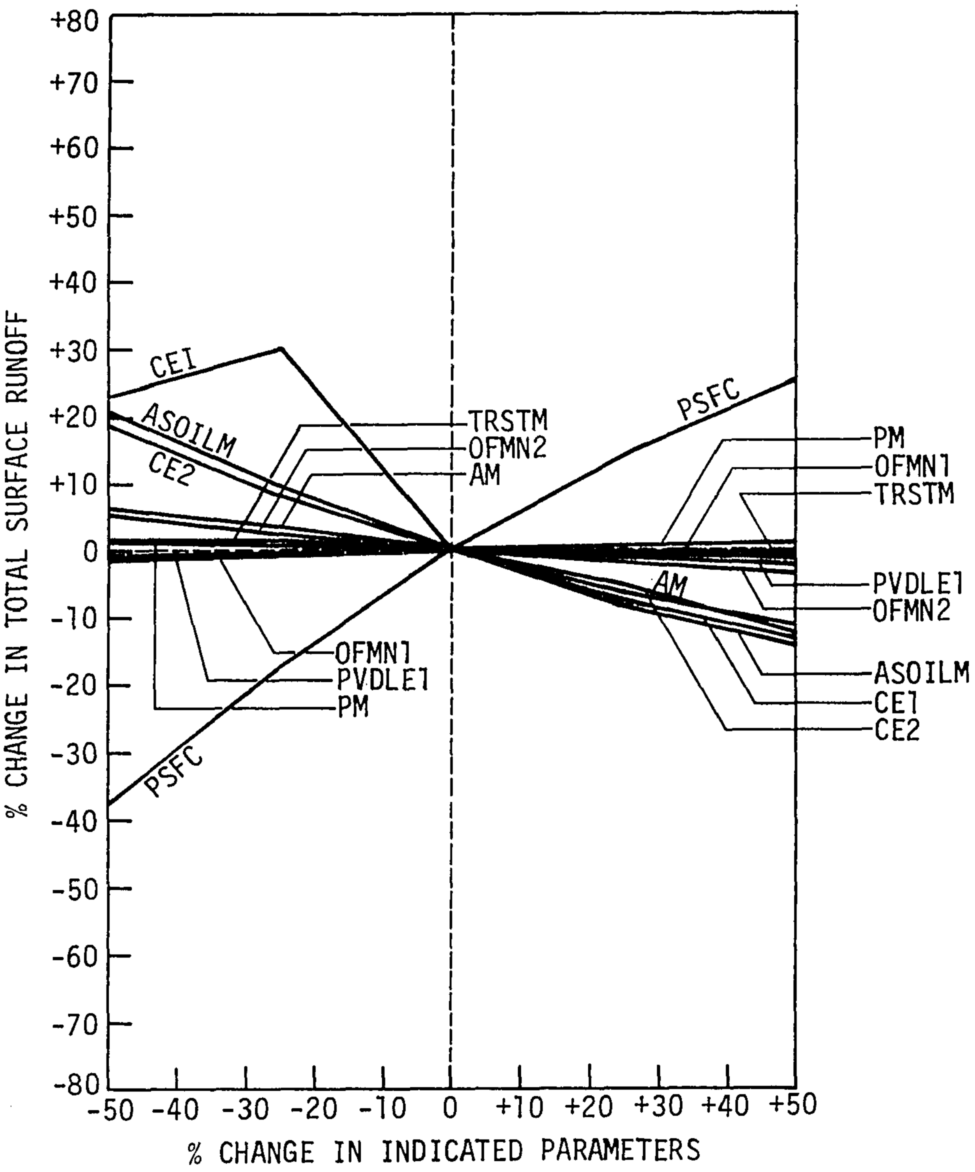

Figure 54. Hydrology parameter sensitivity - total surface runoff from NE watershed for the growing season of 1972

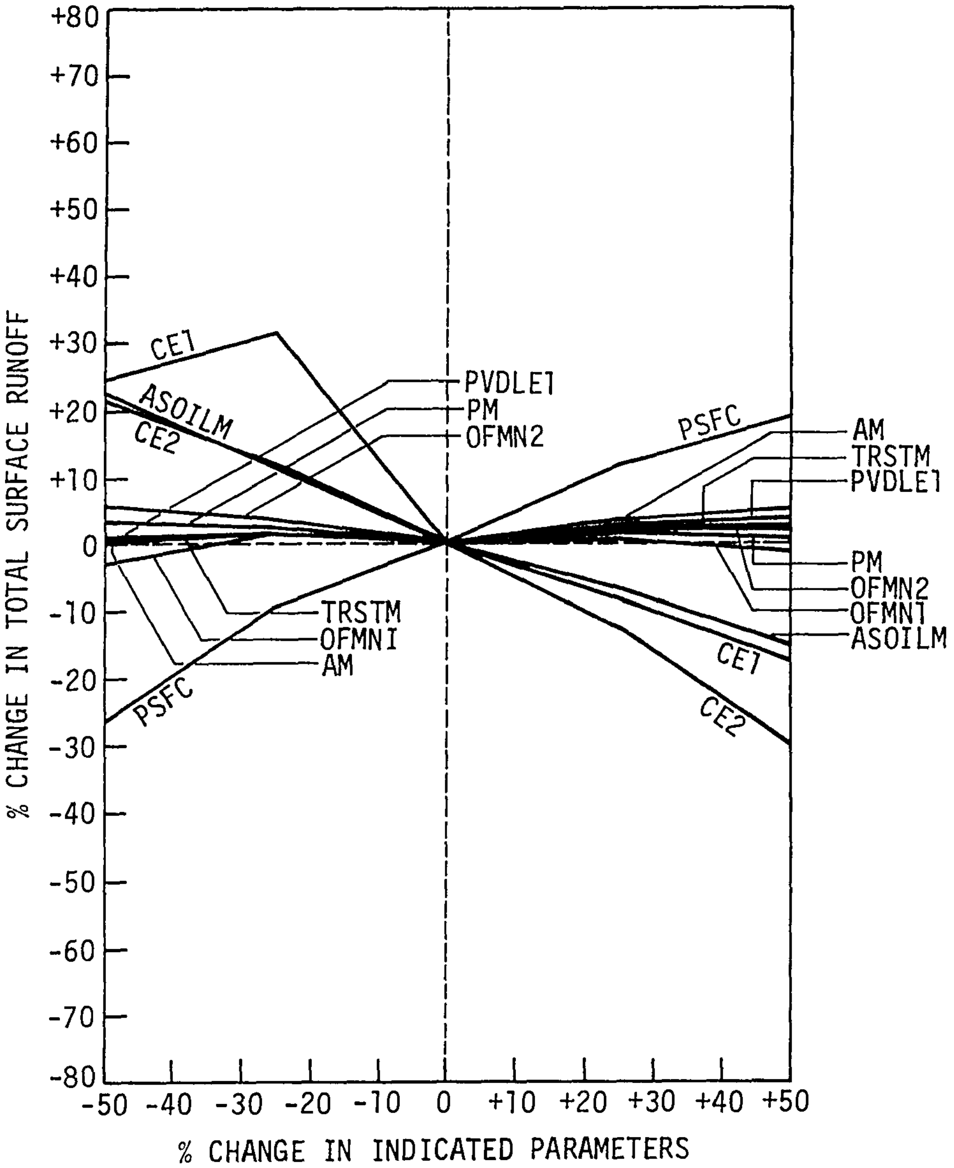

Figure 55. Hydrology parameter sensitivity - total surface runoff from NE watershed for the storm of July 1, 1972

trend can be seen in prediction of volume of runoff for the storm as for the growing season.

The effects of different parameters on peak rate of runoff for the storm on July 1, 1972, are shown in Figure 56. Even though infiltration parameters of CE1, CE2, ASOILM, and PSFC are important, the hydraulic roughness coefficient has the greatest effect on predicted peak rate of runoff when the coefficient is reduced to a value below its calibrated one. The calibrated value of OFMN2 (same as OFMN for this storm) was 0.10 in this model. Decreasing this value by 50 percent increases the peak rate of runoff by 51 percent, as shown in Figure 55.

Sensitivity of Model to Erosion and Sediment Yield Parameters

The parameters most important in prediction of the sediment yield were C1, C2, C3, and RC. The parameter C1 controls predicted interrill erosion, while parameters C2, C3, and RC control predicted rill erosion. Parameter RC is used to account for the effect of rill stabilization over the growing season. As for the hydrologic model, the value of the parameter under study was increased and decreased by 25 and 50 percent of its calibrated value.

The effect of these parameters also changes with time. At the beginning of the growing season (Figures 57 and 58) on May 5, 1972, the day that first major runoff occurred after tillage when the soil was very susceptible to rill erosion, both peak and total predicted sediment yield were more sensitive to rill parameters, C2 and C3, than the interrill parameter, C1. Later in the growing season, as

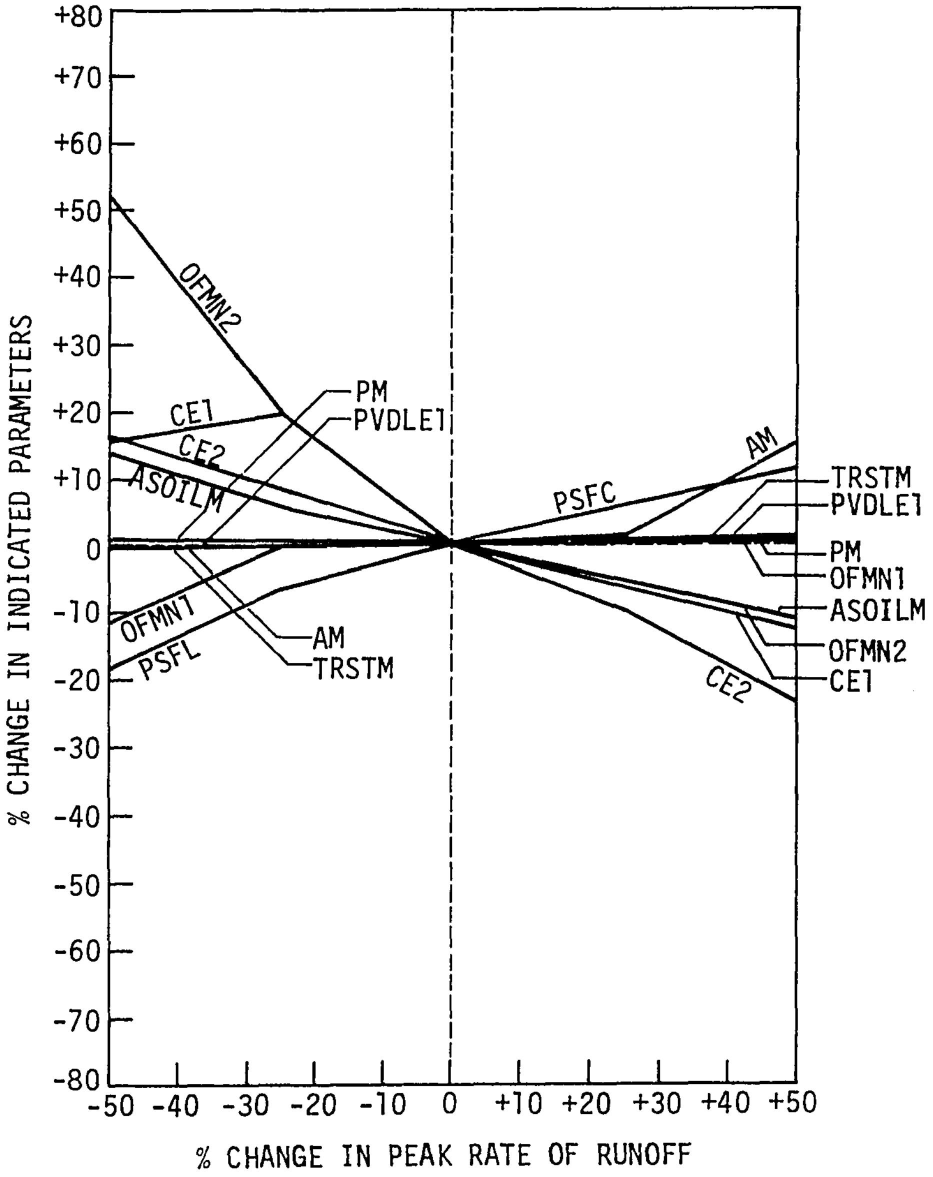

Figure 56. Hydrology parameter sensitivity - peak rate of runoff from NE watershed for the storm of July 1, 1972

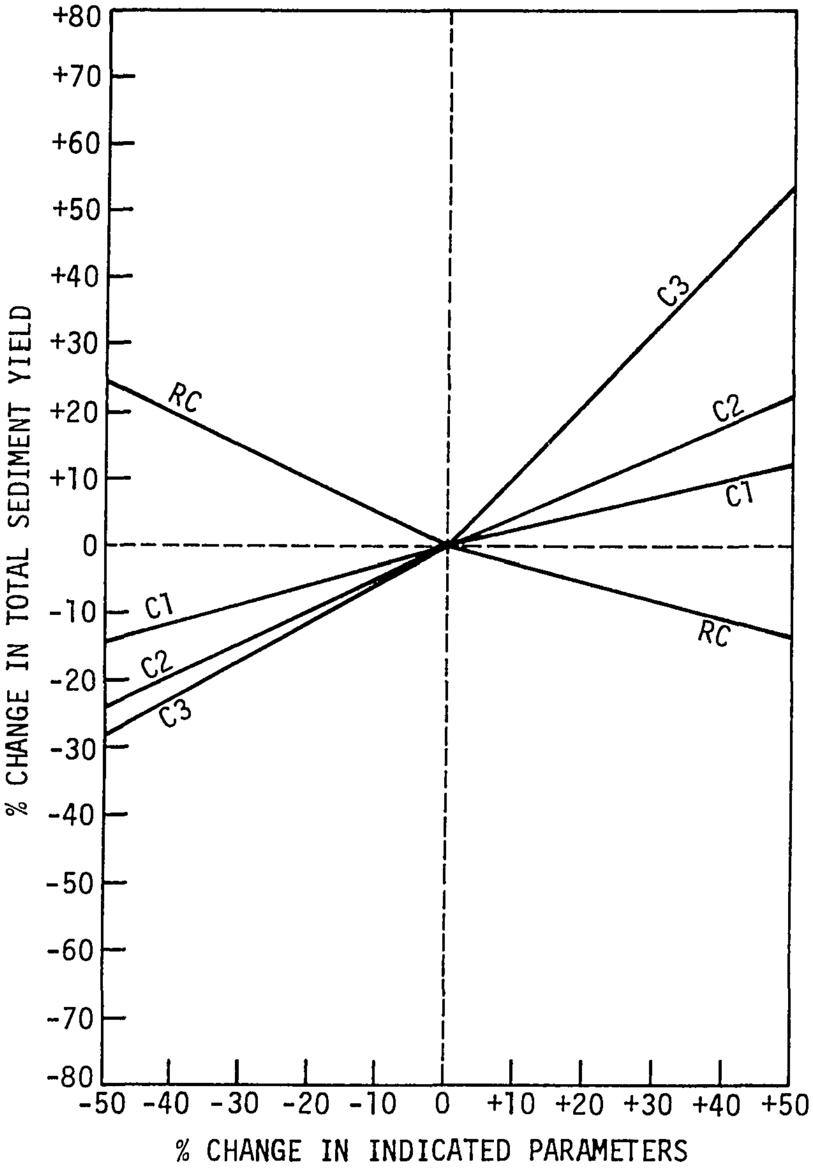

Figure 57. Sediment parameter sensitivity - total sediment yield from NE watershed for the storm of May 5, 1972

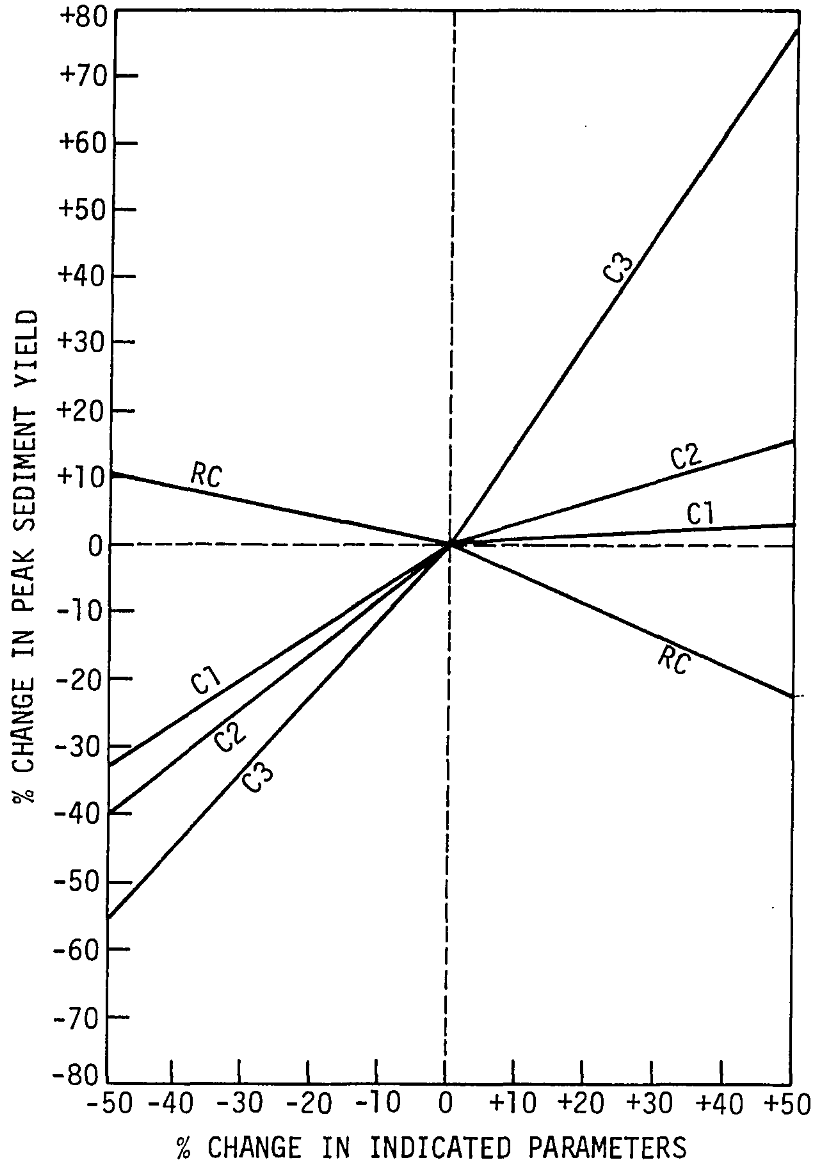

Figure 58. Sediment parameter sensitivity - peak sediment yield from NE watershed for the storm of May 5, 1972

Figures 59 and 60 show, the model was less sensitive to parameters C2 and C3 and more sensitive to parameter C1. Over a longer period of time, the growing season for example, as shown in Figure 61, the model prediction is less sensitive to reduction of values of C2 and C3, while it becomes more sensitive to increase of these parameters. This is in agreement with the reported values of these parameters in the available literature. For example, the value of C2, which is reported by Foster (1978), was 83.7, and he believes that it can vary over a 50-percent range. The calibrated value obtained for C2 in this study was 125.0. On a yearly basis, reducing the value of C2 by 25 percent of 125.0 (93.75), reduces the total sediment yield by only 1 percent (see Figure 61). The reported values for C3 are somewhere between 1.0 to 1.5 (Foster *et al.*, 1977a; Meyer and Wischmeier, 1969; David and Beer, 1975; Ross and Contractor, 1978). The calibrated value obtained in this study by use of the predicted sediment yield and predicted peak rate of sediment discharge on an individual storm basis was 1.65. Reducing this value by 25 percent (1.24) reduces the total sediment yield by only 25 percent on a yearly basis (see Figure 61). The reported value for C1, the parameter which controls interrill erosion, was 1.83 (Foster, 1978), and the value obtained in this study is 2.25.

The effect of these parameters on peak sediment discharge also changes during the growing season. At the beginning, when soil is very susceptible, rill erosion is the major contributor to the total predicted erosion, and the model is more sensitive to parameter C2 and C3. On May 5, 1972, as Figure 58 shows, reducing the value of C3 by

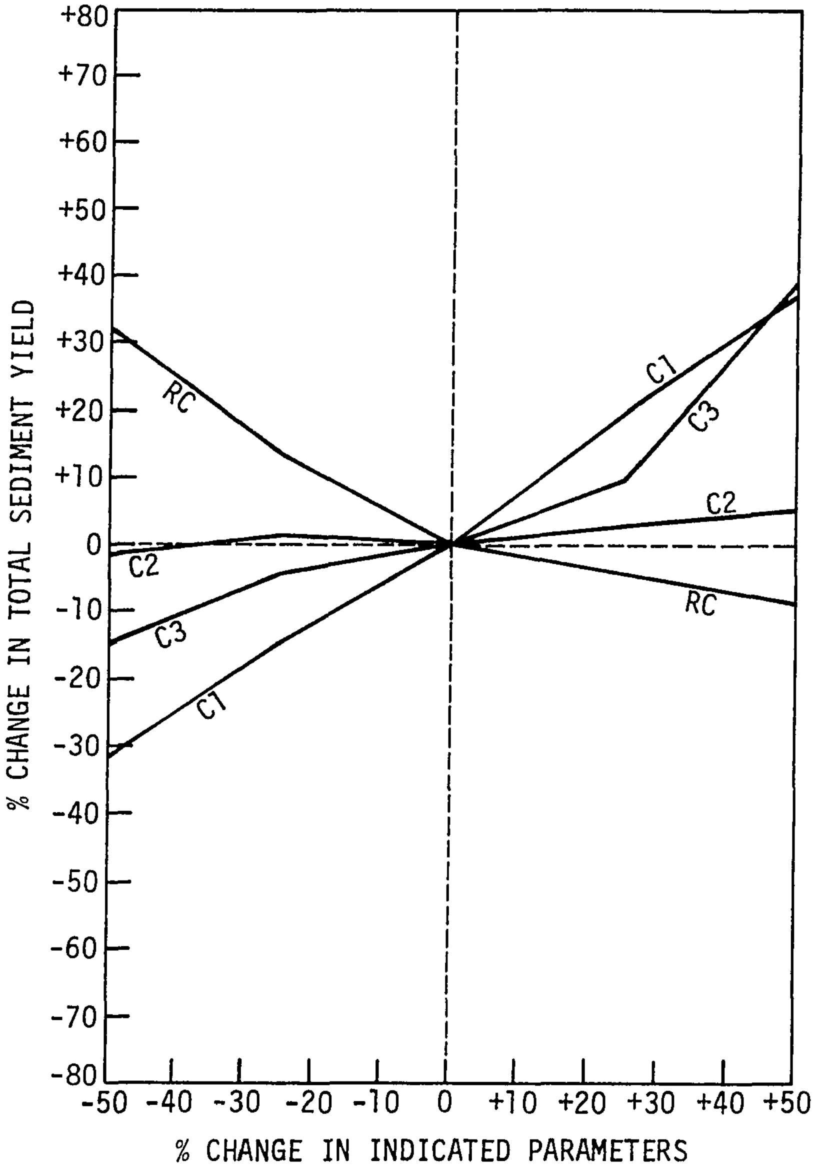

Figure 59. Sediment parameter sensitivity - total sediment yield from NE watershed for the storm on July 1, 1972

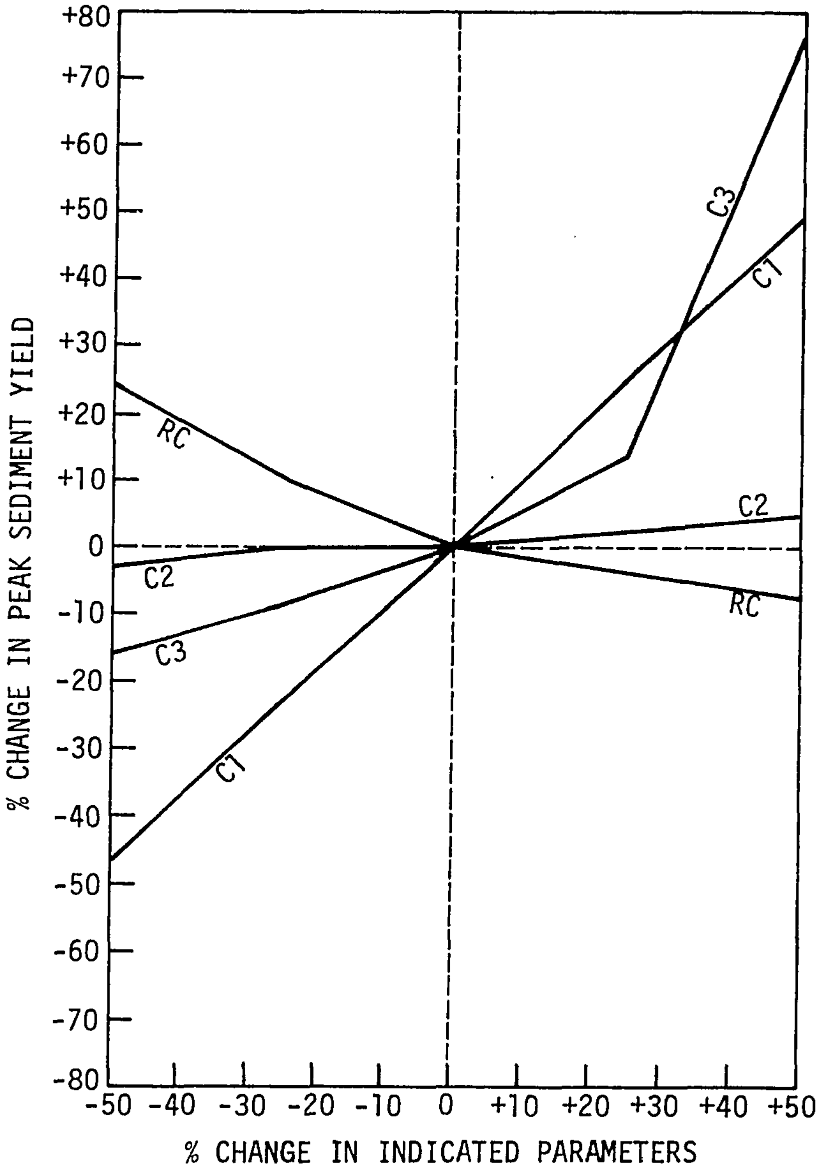

Figure 60. Sediment parameter sensitivity - peak sediment yield from NE watershed for storm on July 1, 1972

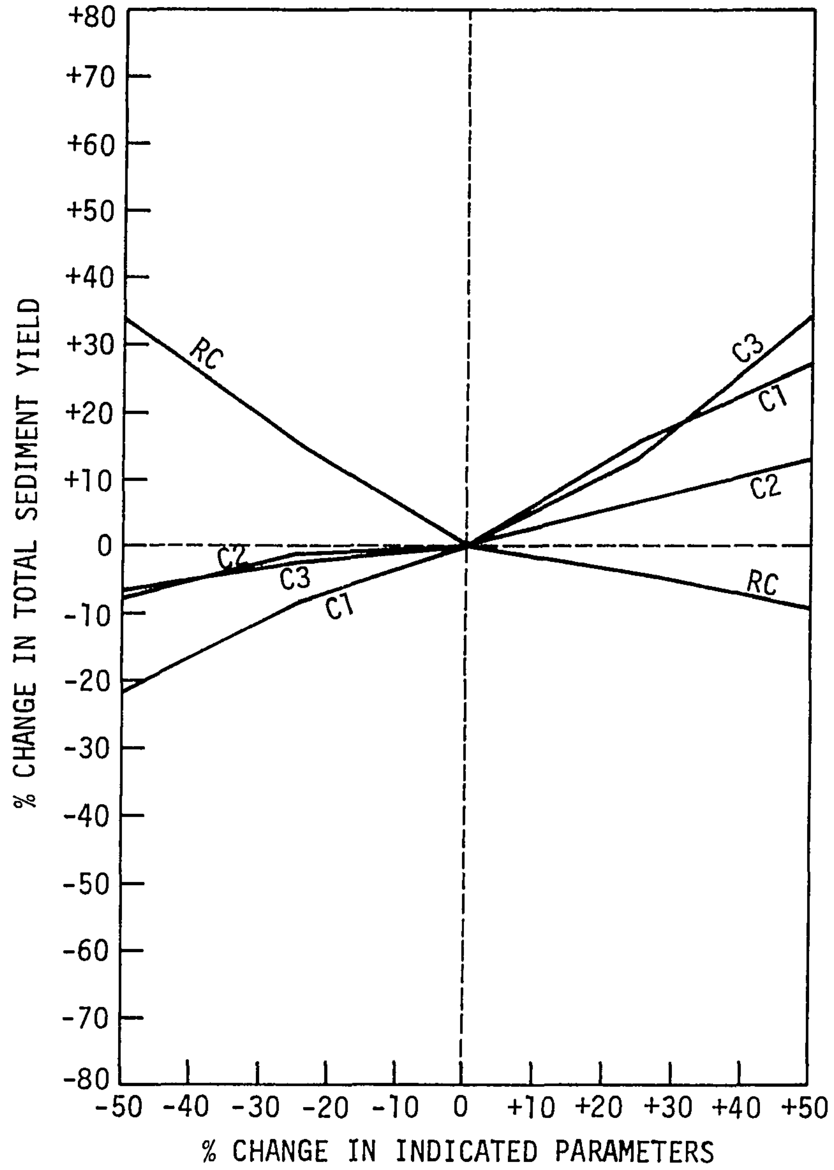

Figure 61. Sediment parameter sensitivity - total sediment yield from NE watershed for the growing season of 1972

25 percent (from its calibrated value) reduces the peak sediment discharge by about 28 percent. This was the reason for using a value larger than the one reported in the literature for parameter C3. The same argument is used to support the change of the value of the parameter C2, which is related to rill erosion.

As the time passes, the parameter C1, which is related to interrill erosion, becomes a sensitive prediction parameter. The reason for this is that at the beginning of an event, when rainfall has started but runoff has not yet started, interrill erosion resulting from kinetic energy or rainfall occurs, while none of the detached particles is transported. This causes a reservoir of sediment to accumulate prior to runoff. This provides a reason to believe that peak sediment discharge usually occurs a short time ahead of the peak rate of runoff. Considering this and knowing that rills are almost stabilized at the end of the growing season, one can understand the reason that the model is very sensitive to parameter C1 (especially peak sediment discharge) this time of the year.

SUMMARY AND CONCLUSIONS

The general objective of this study was to simulate the surface runoff and sediment yield from small agricultural watersheds in deep loess hills of western Iowa. A water balance model (Anderson, 1975) was modified to simulate the rate of surface runoff. Modifications included:

1) Adding a subroutine to calculate potential evaporation as a function of pan evaporation data for cases where data for Penman's equation are not available.

2) Adding an overland flow routing component to route the excess precipitation to the outlet of the watershed. The overland flow routing concept from the Stanford Watershed Model (Crawford and Linsley, 1966) was used. Modifications were made to consider the effect of tillage on surface runoff. Overland flow runoff was assumed to be a function of surface storage created by tillage and a variable hydraulic roughness coefficient used in Manning's equation. Values expressing storage created by tillage and the hydraulic roughness coefficient were assumed to decrease with time as a function of accumulated amount of runoff from the time of plowing.

3) Modification of the infiltration subroutine to consider the effect of tillage and rainfall kinetic energy on infiltration capacity. Parameter A in infiltration equation, which represents the maximum increase in infiltration capacity above the wet soil infiltration rate, was assumed to be at its maximum value immediately after plowing and

decreased exponentially as a function of accumulated rainfall kinetic energy through the growing season.

Parameters related to infiltration and overland flow routing components were calibrated by use of data from NE Gingles Watershed for the year 1972. The calibrated model was then verified on NE Gingles Watershed by use of data for the years 1973, 1974, and 1975, and on the SM Gingles Watershed for the year 1972.

The concept of rill and interrill erosion was utilized as the basis for the erosion simulation model in conjunction with the Yalin's equation to simulate sediment yield. Interrill erosion was expressed as a function of rainfall intensity and independent of rill erosion. In cases when transport capacity was limiting, rill erosion was assumed to be dependent on interrill erosion. The effects of crop canopy, roughness created by tillage, and surface water depth on interrill erosion were considered. A rill stabilization factor was included in rill erosion process and assumed to be an exponential function of total rill erosion after the time of plowing.

Parameters related to rill and interrill erosion were calibrated by use of data from the NE Gingles Watershed for the year 1972. The calibrated model was verified on the NE Gingles Watershed by use of data from the years of 1973, 1974, and 1975, and the SM Watershed data from 1972.

A sensitivity analysis of the hydrologic model parameters related to infiltration and overland flow was completed. Predicted volume of runoff was very sensitive to infiltration parameters. The important parameters are CE1 and CE2, which represent the effect of tillage and rainfall kinetic energy on infiltration rate throughout the growing season, ASOILM, which represents the maximum value of parameter A in infiltration equation, and PSFC, which represents exponent P in infiltration equation at field capacity of the surface layer of the soil. The most sensitive parameter is PSFC. On a growing season basis, predicted volume of runoff is not sensitive to the overland parameters incorporated into the model to consider the effects of the plowing. These parameters are PUDLE1, which represents the surface storage created by plowing immediately after the tillage, OFMN1, which represents the maximum value of roughness coefficient immediately after the tillage, and TRSTM, which represents the maximum amount of overland flow water required to smooth the soil surface. Despite the insignificant effects of these parameters on a growing season basis, they are significantly important immediately after plowing.

On an individual storm basis, infiltration parameters are important; however, the hydraulic roughness coefficient has the greatest effect on predicted peak rate of runoff if the coefficient is less than the calibrated value.

Selected parameters from the erosion and sediment yield model sensitivity were analyzed. Immediately after plowing, when the soil is loose, sediment yield prediction is more sensitive to rill parameters of C2, a constant coefficient, and C3, an exponent in rill erosion equation. Throughout the growing season, as the rills are stabilized, sediment yield prediction is more sensitive to parameter C1, a constant coefficient in interrill erosion equation.

The shortest time increment used in the model to simulate surface runoff and sediment yield was 2 minutes. Time increments of 5, 10, and 15 minutes were tested. Predicted volume of runoff was not sensitive to length of time increment used; predicted rate of runoff and sediment yield were very sensitive to time increment.

The model is able to simulate soil moisture movement through the soil profile, and consequently deep percolation or possibly flow to drainage tile. Prediction of evapotranspiration is another model output.

It is shown that the model prediction agreed reasonably close to the measured value of surface runoff and sediment yield for the 1972 calibration period. Surface runoff prediction for testing periods of 1972 on SM watershed, 1973, 1974, and 1975 on NE watershed was reasonable. Considering the quality of the measured sediment data, sediment yield prediction was reasonable. Surface runoff and sediment yield prediction for longer periods (growing season) were more accurate when compared with predictions made on an individual storm basis.

The model at this stage is able to predict surface runoff, soil moisture movement throughout the soil profile, deep percolation, evapotranspiration, and sediment yield from small agricultural watersheds throughout a growing season. To be applicable on larger agricultural watersheds continuously throughout a year, the following changes should be considered:

1) Addition of a channel routing component to rout the surface runoff to the outlet of the watershed through the channel system.

2) Addition of a channel scour component to express the channel contribution to the total sediment yield.

3) Addition of interflow and ground water components to express their contributions to the total runoff.

4) Addition of a snowmelt component to express snowfall effects on soil moisture movement and surface runoff.

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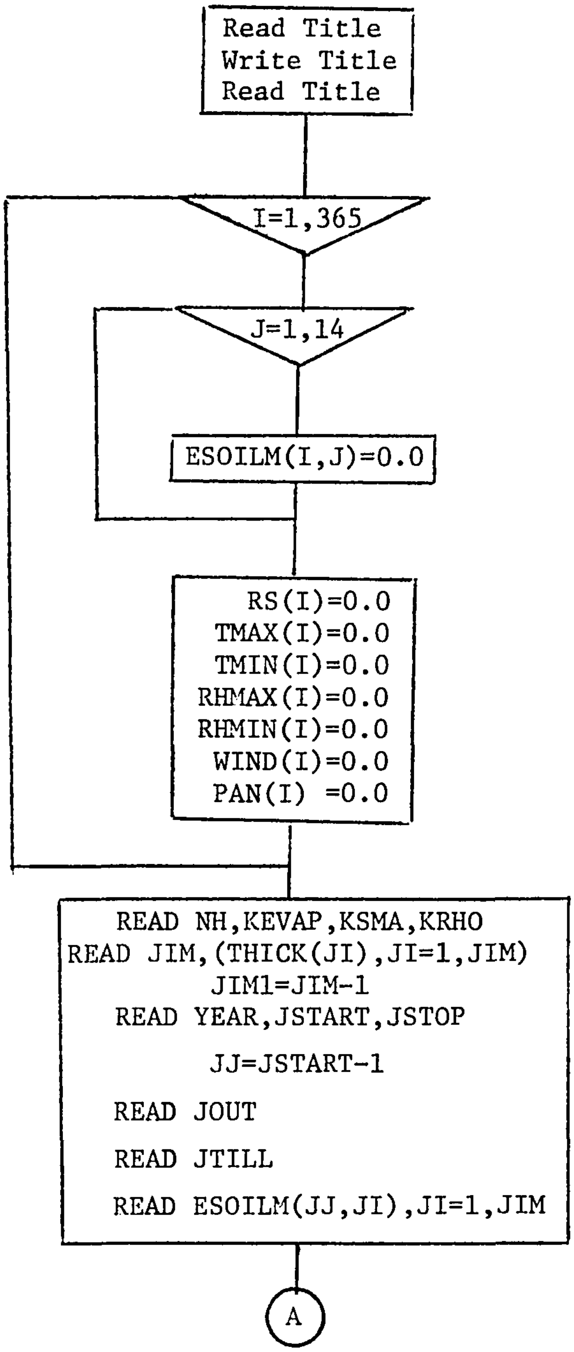
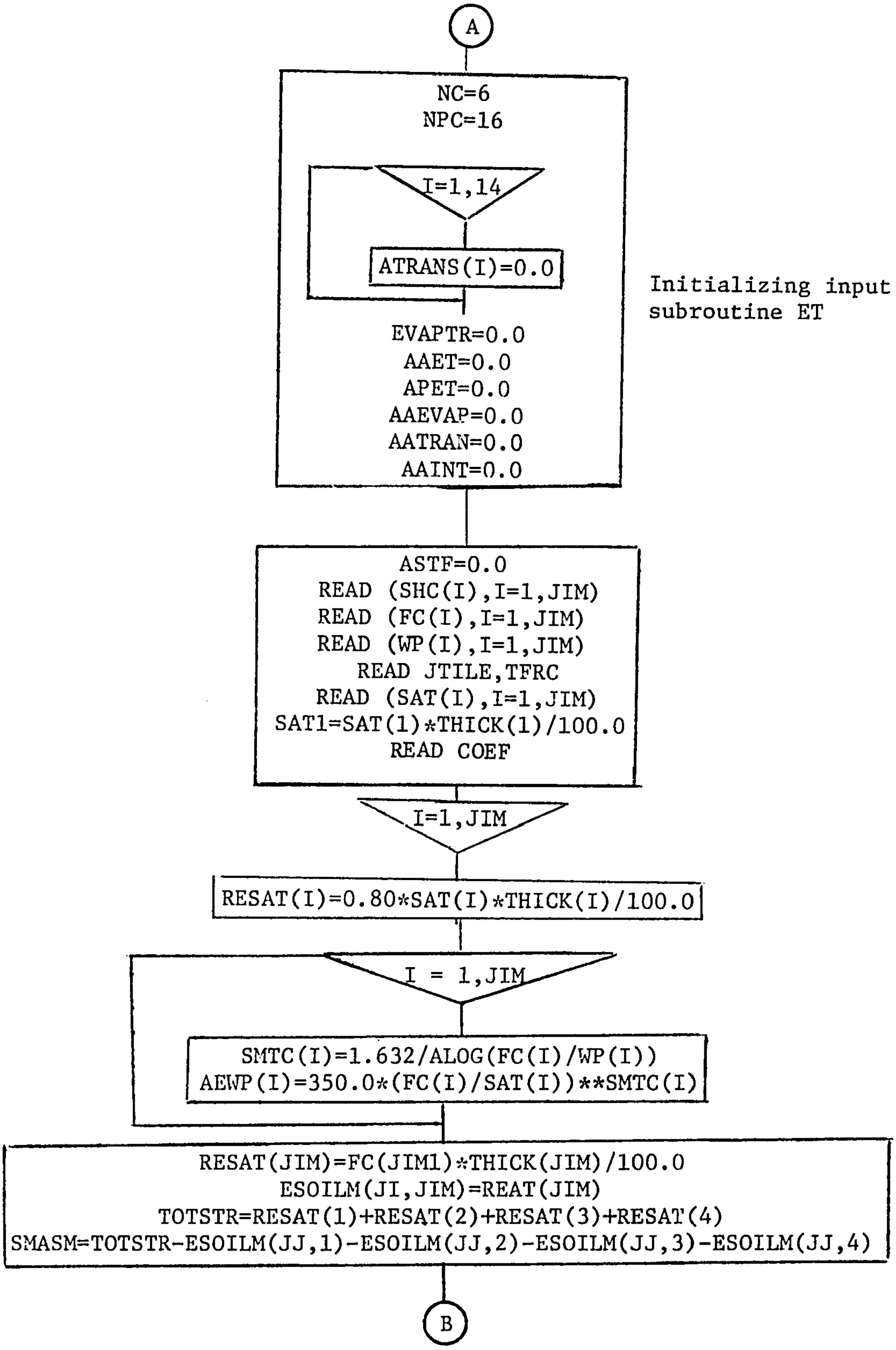
APPENDIX A:

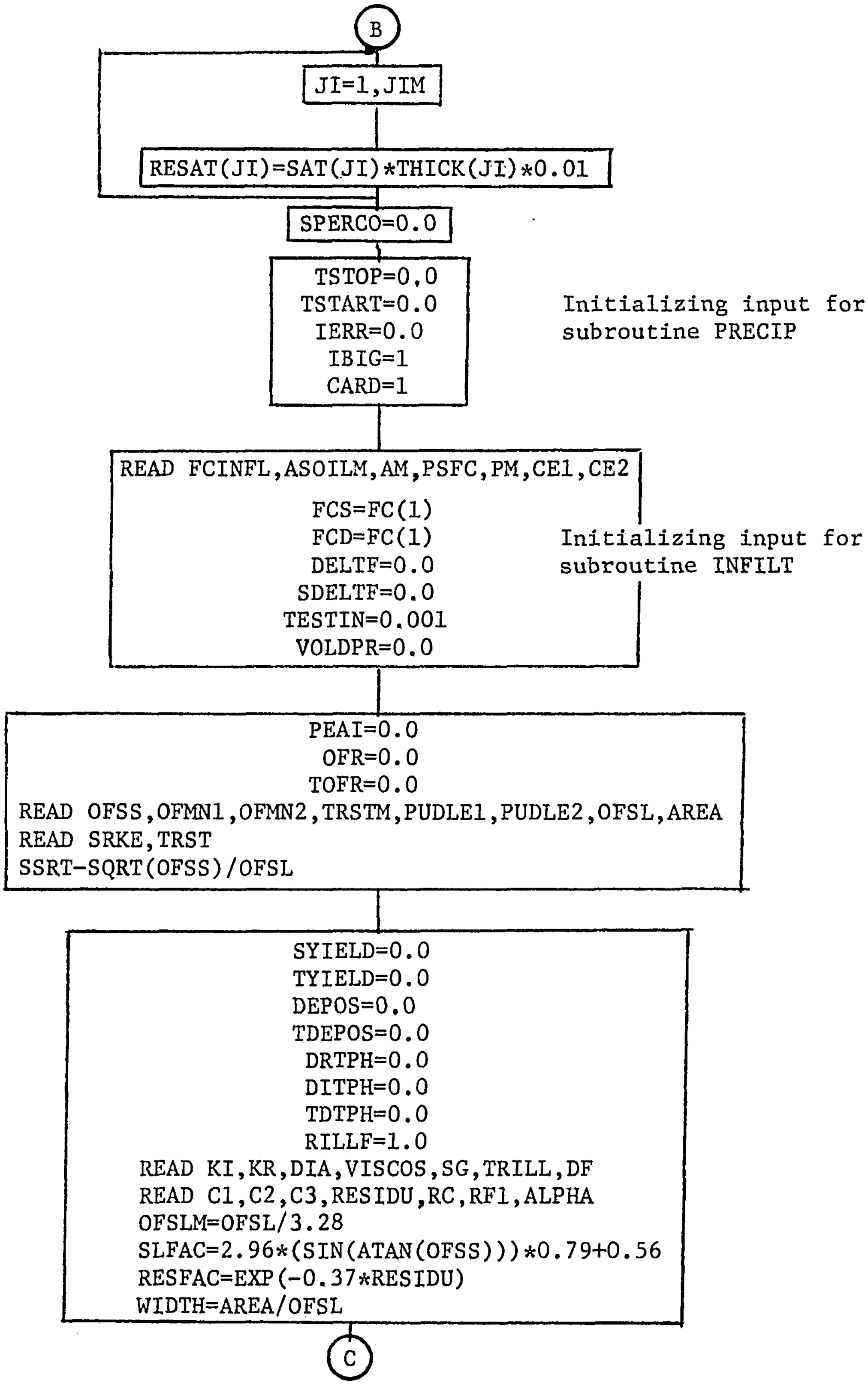
LISTING OF DETAILED FLOW CHART FOR COMPUTER MODEL

Flow Chart of the Main Program





Initializing input for subroutine ET



```
JI=1,JIM
RESAT(JI)=SAT(JI)*THICK(JI)*0.01
SPERCO=0.0
TSTOP=0.0
TSTART=0.0
IERR=0.0
IBIG=1
CARD=1
```

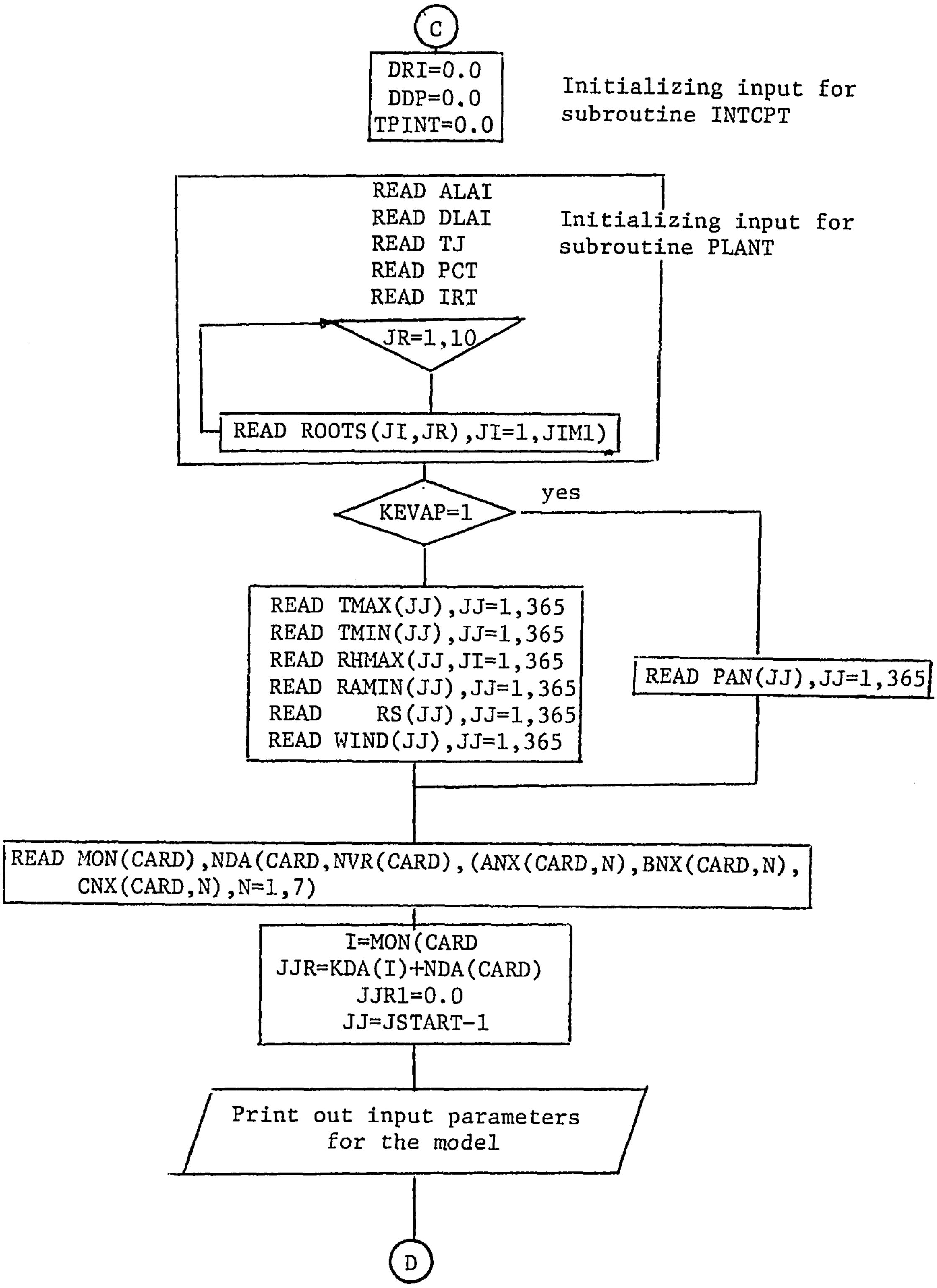
Initializing input for subroutine PRECIP

```
READ FCINFL,ASOILM,AM,PSFC,PM,CE1,CE2
FCS=FC(1)
FCD=FC(1)
DELTF=0.0
SDELTF=0.0
TESTIN=0.001
VOLDPR=0.0
```

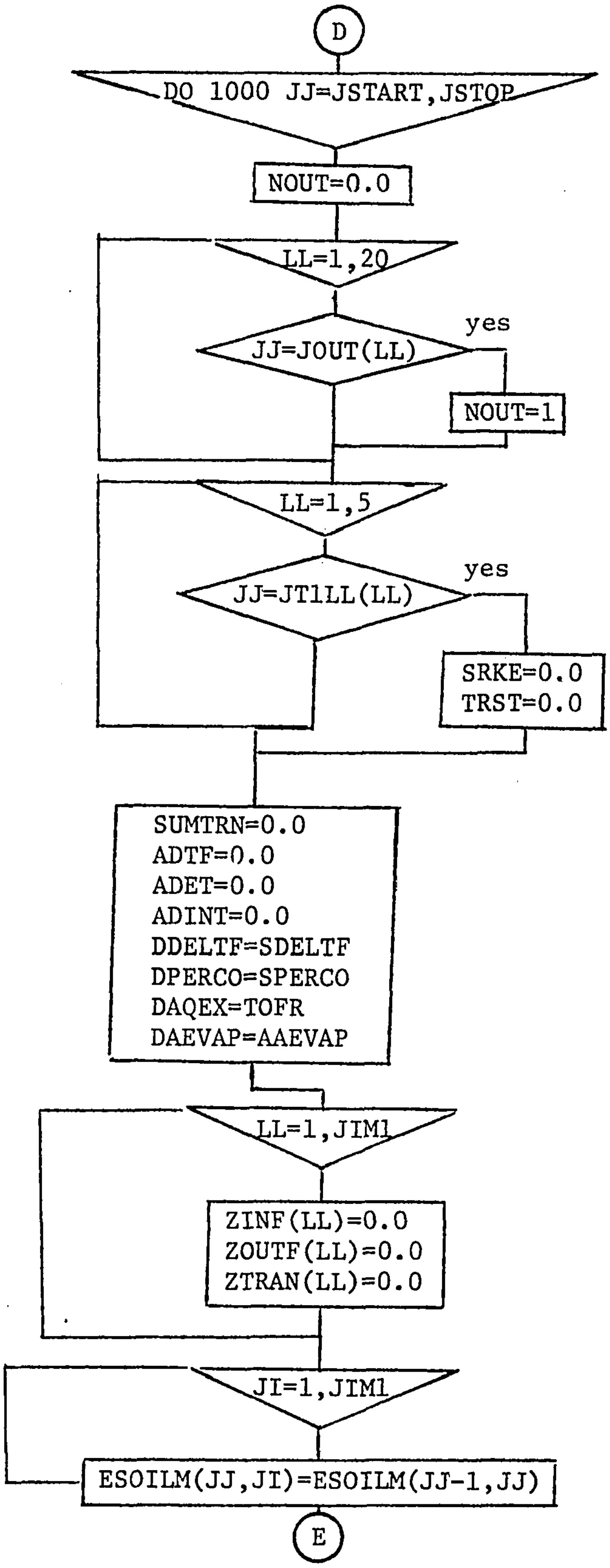
Initializing input for subroutine INFILT

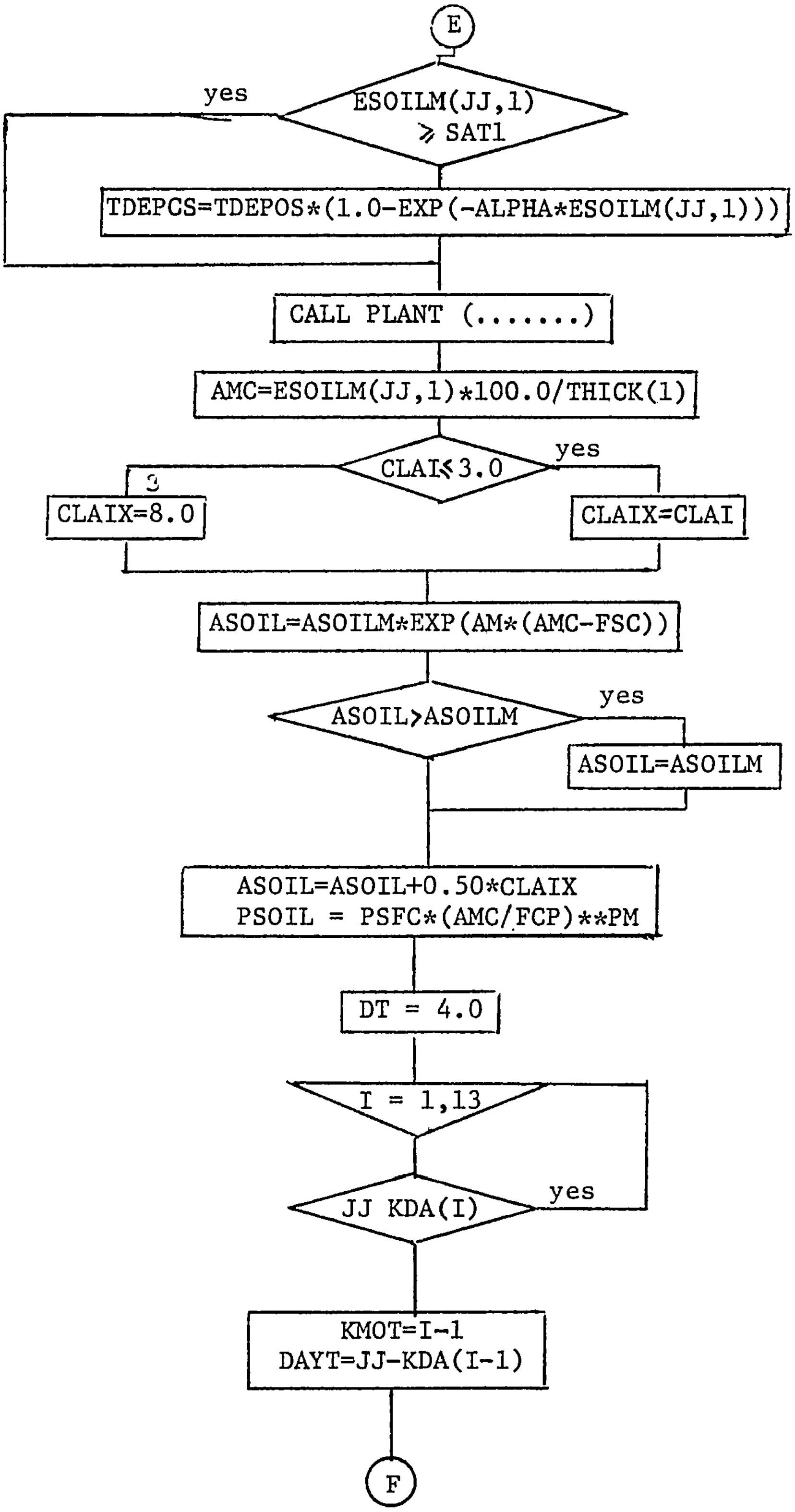
```
PEAI=0.0
OFR=0.0
TOFR=0.0
READ OFSS,OFMN1,OFMN2,TRSTM,PUDLE1,PUDLE2,OFSL,AREA
READ SRKE,TRST
SSRT-SQRT(OFSS)/OFSL
```

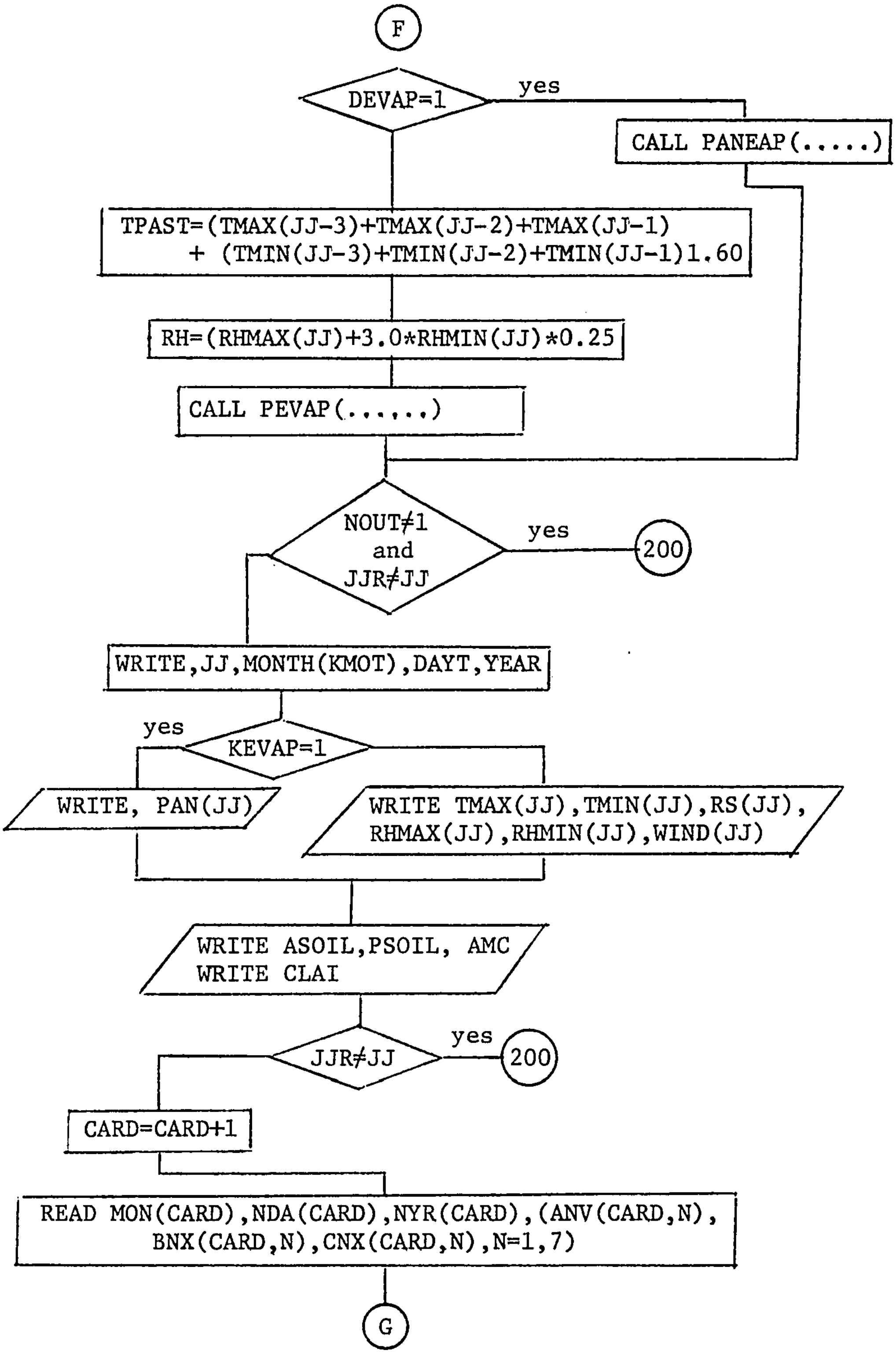
```
SYIELD=0.0
TYIELD=0.0
DEPOS=0.0
TDEPOS=0.0
DRTPH=0.0
DITPH=0.0
TDTPH=0.0
RILLF=1.0
READ KI,KR,DIA,VISCOS,SG,TRILL,DF
READ C1,C2,C3,RESIDU,RC,RF1,ALPHA
OFSLM=OFSL/3.28
SLFAC=2.96*(SIN(ATAN(OFSS)))*0.79+0.56
RESFAC=EXP(-0.37*RESIDU)
WIDTH=AREA/OFSL
```

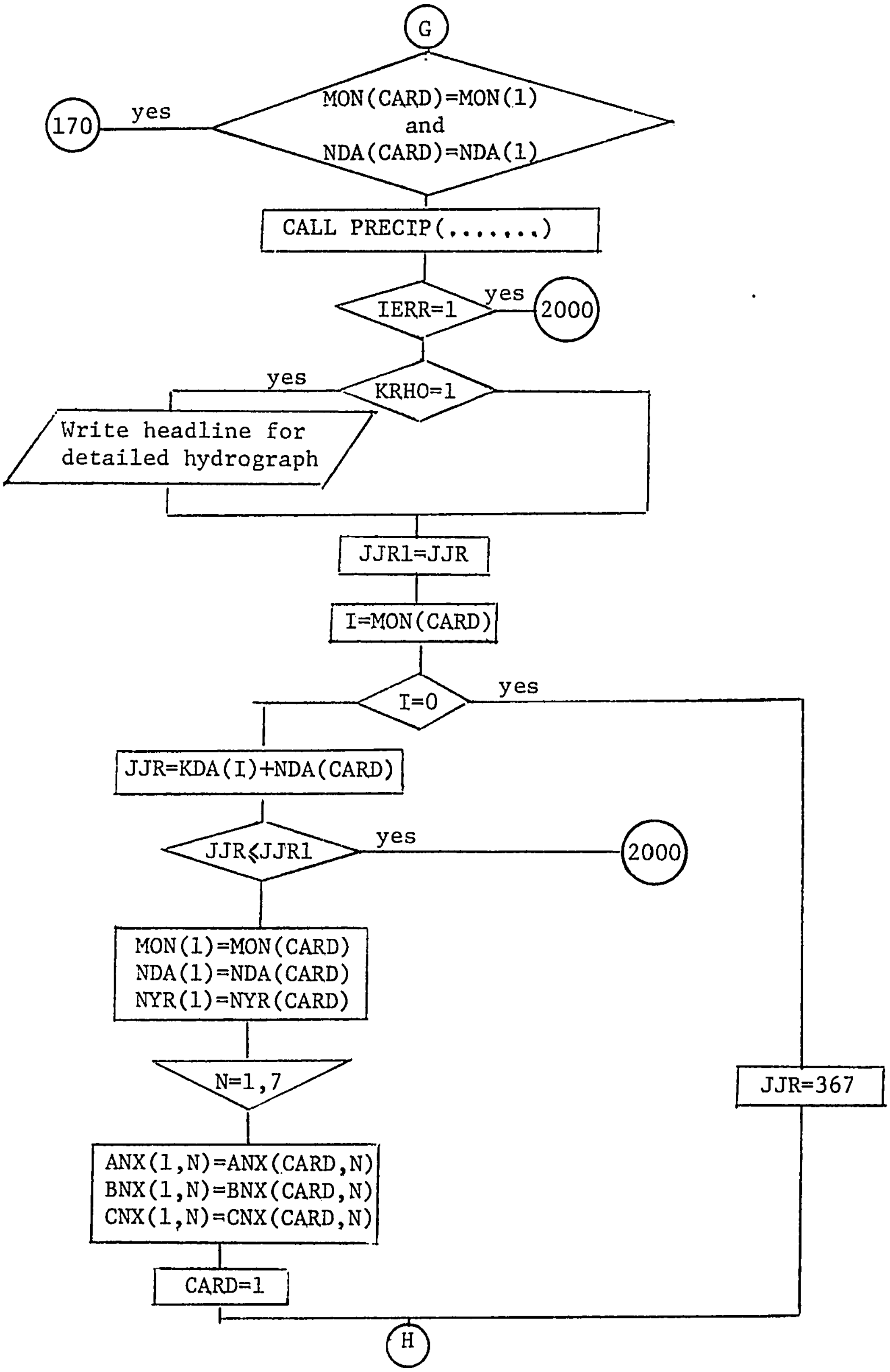

C
DRI=0.0
DDP=0.0
TPINT=0.0
Initializing input for subroutine INTCPT
READ ALAI
READ DLAI
READ TJ
READ PCT
READ IRT
Initializing input for subroutine PLANT
JR=1,10
READ ROOTS(JI,JR),JI=1,JIM1)
KEVAP=1
yes
READ TMAX(JJ),JJ=1,365
READ TMIN(JJ),JJ=1,365
READ RHMAX(JJ,JI=1,365
READ RAMIN(JJ),JJ=1,365
READ RS(JJ),JJ=1,365
READ WIND(JJ),JJ=1,365
READ PAN(JJ),JJ=1,365
READ MON(CARD),NDA(CARD,NVR(CARD),(ANX(CARD,N),BNX(CARD,N),
CNX(CARD,N),N=1,7)
I=MON(CARD
JJR=KDA(I)+NDA(CARD)
JJR1=0.0
JJ=JSTART-1
Print out input parameters for the model
D

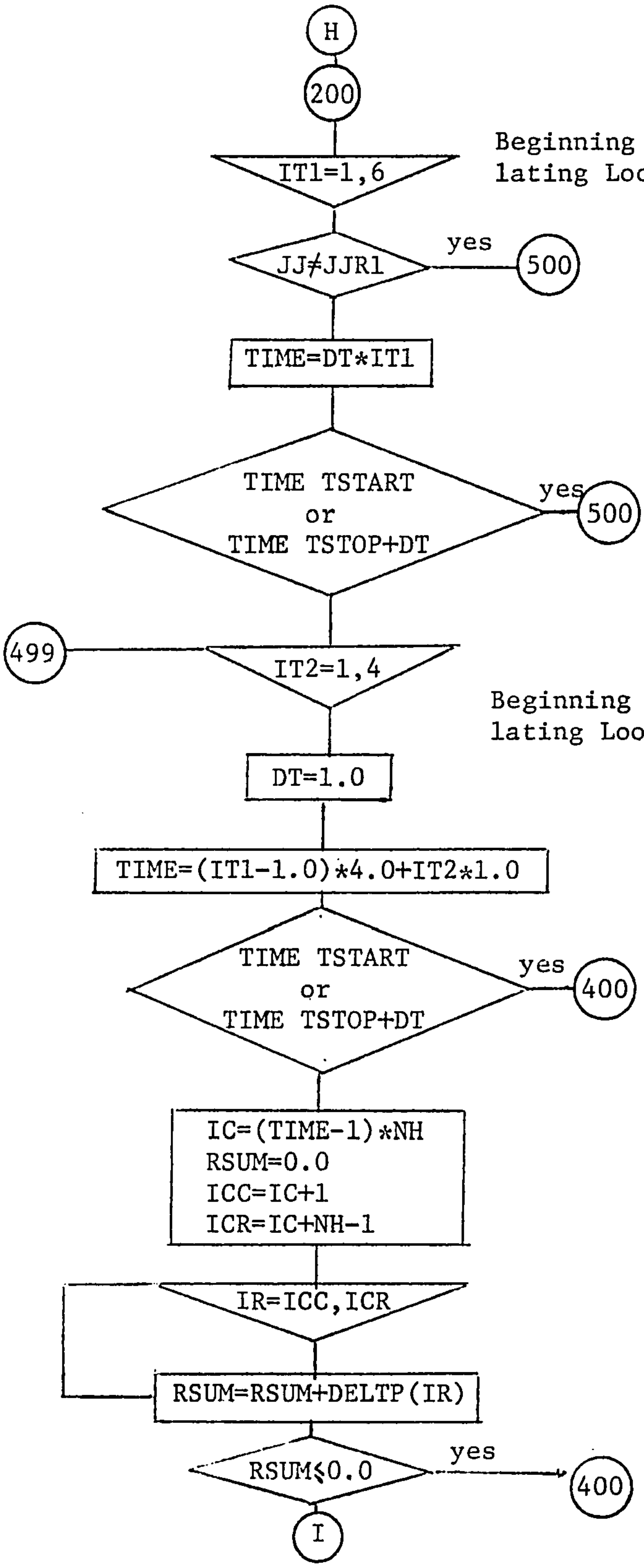
Beginning of major calculating loop No. 1




E
ESOILM(JJ,1) ≥ SAT1
yes
TDEPCS=TDEPOS*(1.0-EXP(-ALPHA*ESOILM(JJ,1)))
CALL PLANT (.......)
AMC=ESOILM(JJ,1)*100.0/THICK(1)
CLAI≤3.0
yes
CLAIX=8.0
CLAIX=CLAI
ASOIL=ASOILM*EXP(AM*(AMC-FSC))
ASOIL>ASOILM
yes
ASOIL=ASOILM
ASOIL=ASOIL+0.50*CLAIX
PSOIL = PSFC*(AMC/FCP)**PM
DT = 4.0
I = 1,13
JJ KDA(I)
yes
KMOT=I-1
DAYT=JJ-KDA(I-1)
F

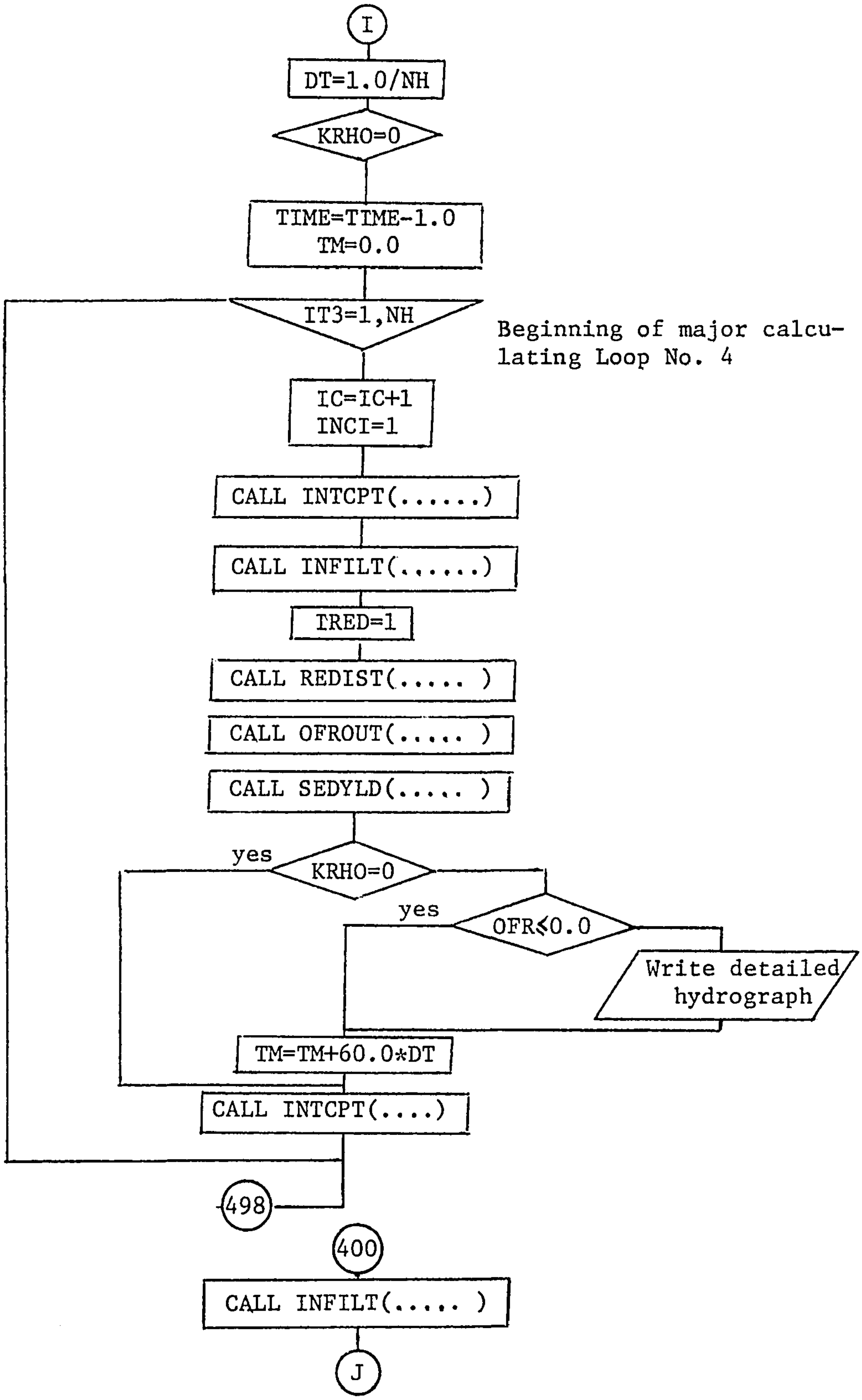

F
DEVAP=1
yes
CALL PANEAP(.....)
TPAST=(TMAX(JJ-3)+TMAX(JJ-2)+TMAX(JJ-1)
+ (TMIN(JJ-3)+TMIN(JJ-2)+TMIN(JJ-1)1.60
RH=(RHMAX(JJ)+3.0*RHMIN(JJ)*0.25
CALL PEVAP(.......)
NOUT≠1 and JJR≠JJ
yes
200
WRITE,JJ,MONTH(KMOT),DAYT,YEAR
yes
KEVAP=1
WRITE, PAN(JJ)
WRITE TMAX(JJ),TMIN(JJ),RS(JJ), RHMAX(JJ),RHMIN(JJ),WIND(JJ)
WRITE ASOIL,PSOIL, AMC
WRITE CLAI
JJR≠JJ
yes
200
CARD=CARD+1
READ MON(CARD),NDA(CARD),NYR(CARD),(ANV(CARD,N), BNX(CARD,N),CNX(CARD,N),N=1,7)
G

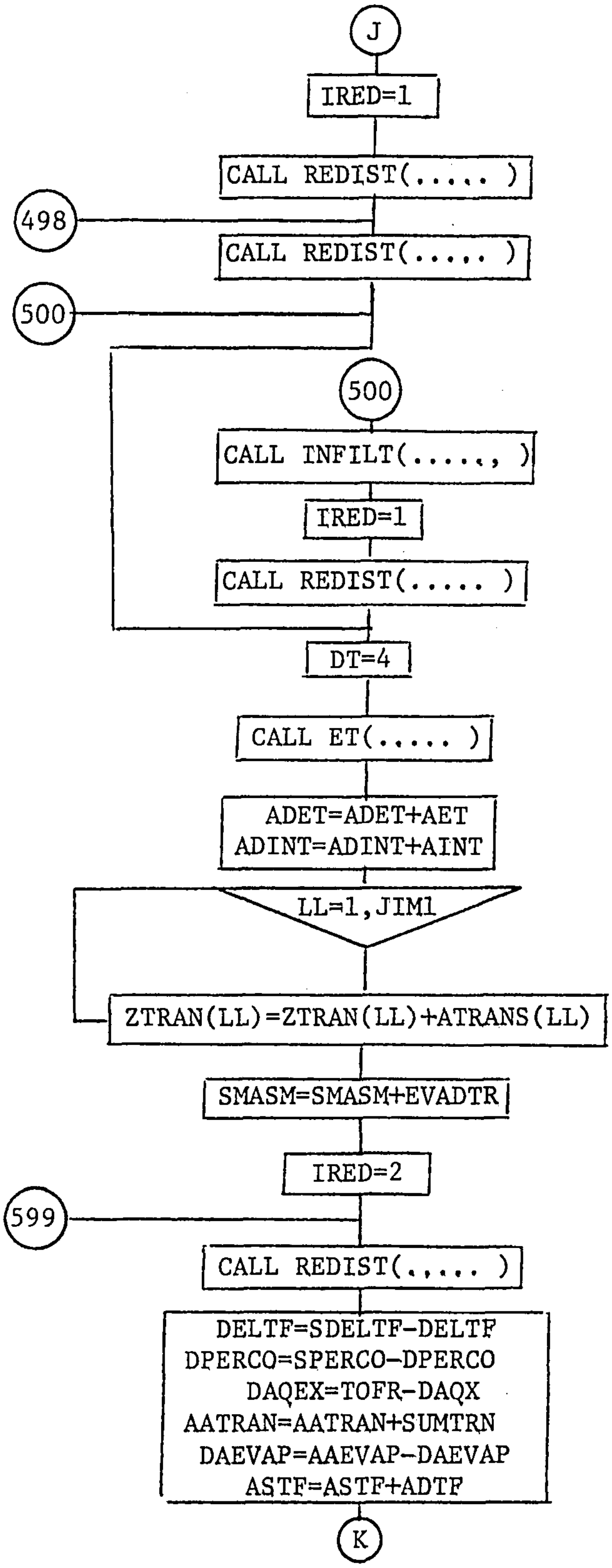

G
MON(CARD)=MON(1)
and
NDA(CARD)=NDA(1)
yes
170
CALL PRECIP(.......)
IERR=1
yes
2000
KRHO=1
yes
Write headline for detailed hydrograph
JJR1=JJR
I=MON(CARD)
I=0
yes
JJR=KDA(I)+NDA(CARD)
JJR≤JJR1
yes
2000
MON(1)=MON(CARD)
NDA(1)=NDA(CARD)
NYR(1)=NYR(CARD)
N=1,7
ANX(1,N)=ANX(CARD,N)
BNX(1,N)=BNX(CARD,N)
CNX(1,N)=CNX(CARD,N)
CARD=1
JJR=367
H

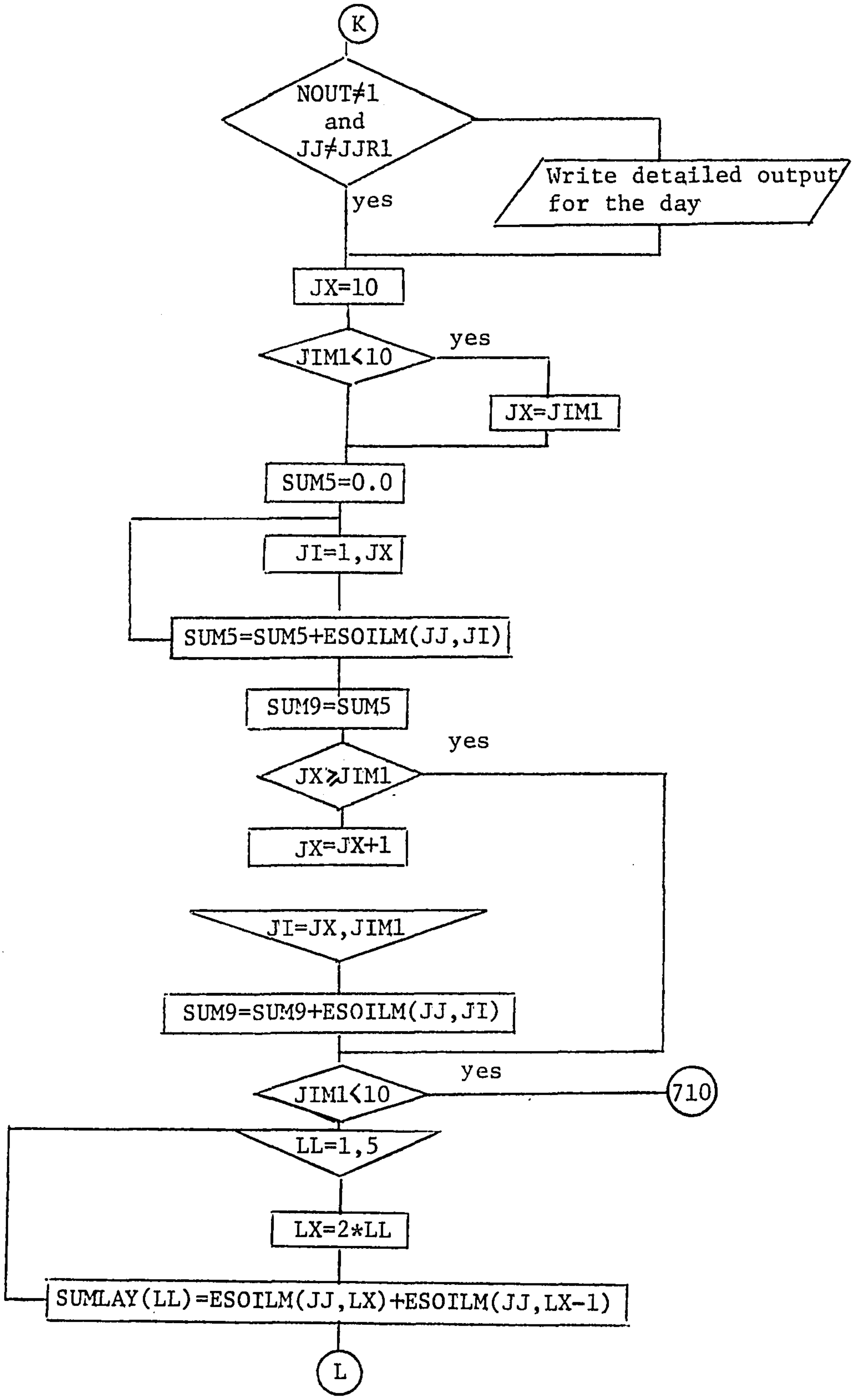


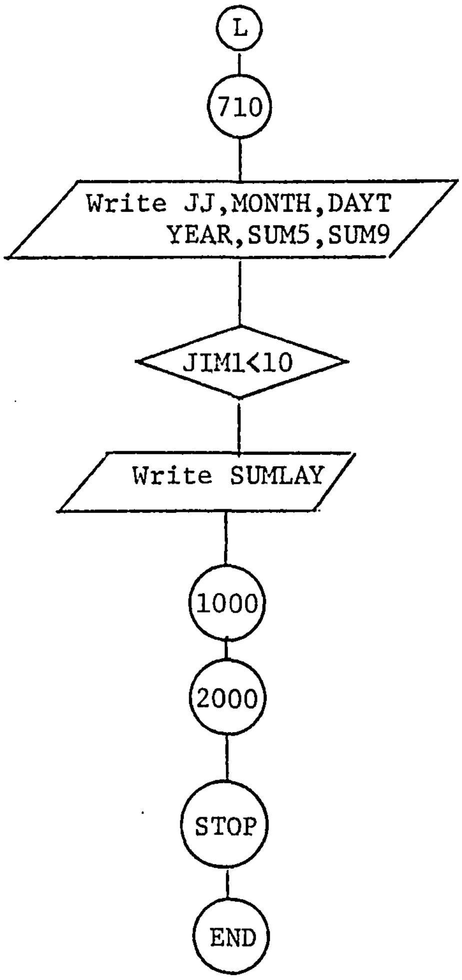
Beginning of major calculating Loop No. 2

Beginning of major calculating Loop No. 3

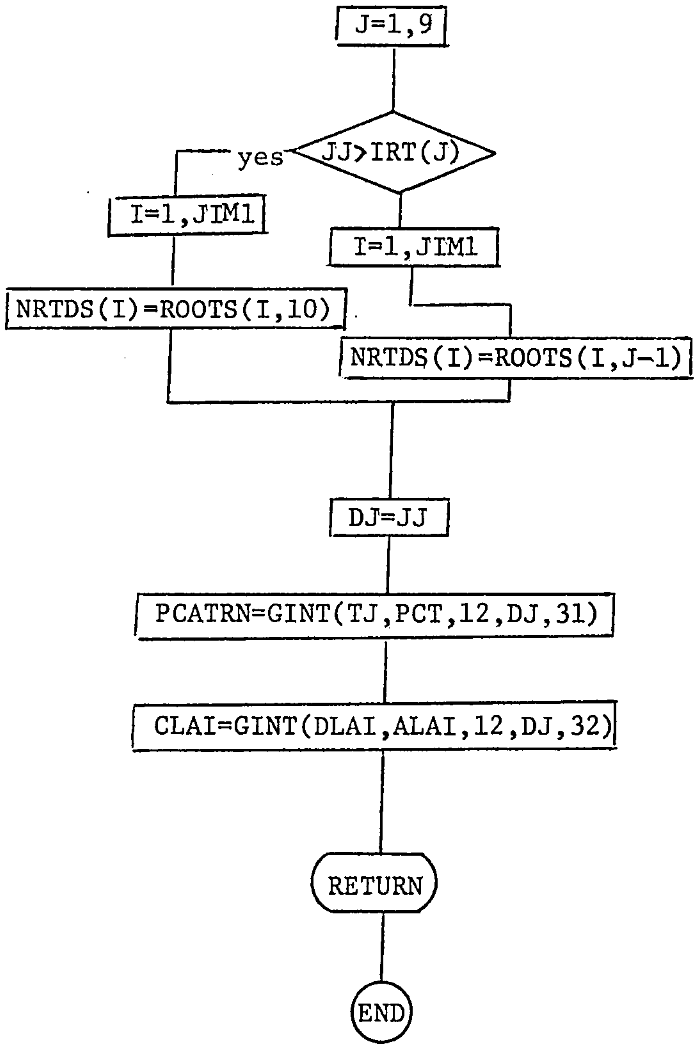

I
DT=1.0/NH
KRHO=0
TIME=TIME-1.0
TM=0.0
IT3=1,NH
Beginning of major calculating Loop No. 4
IC=IC+1
INCI=1
CALL INTCPT(......)
CALL INFILT(......)
IRED=1
CALL REDIST(.....)
CALL OFROUT(.....)
CALL SEDYLD(.....)
yes
KRHO=0
yes
OFR≤0.0
Write detailed hydrograph
TM=TM+60.0*DT
CALL INTCPT(....)
498
400
CALL INFILT(.....)
J


J
IRED=1
CALL REDIST(.....)
498
CALL REDIST(.....)
500
500
CALL INFILT(.....,)
IRED=1
CALL REDIST(.....)
DT=4
CALL ET(.....)
ADET=ADET+AET
ADINT=ADINT+AINT
LL=1,JIM1
ZTRAN(LL)=ZTRAN(LL)+ATRANS(LL)
SMASM=SMASM+EVADTR
IRED=2
599
CALL REDIST(.....)
DELTF=SDELTF-DELTF
DPERCO=SPERCO-DPERCO
DAQEX=TOFR-DAQX
AATRAN=AATRAN+SUMTRN
DAEVAP=AAEVAP-DAEVAP
ASTF=ASTF+ADTF
K

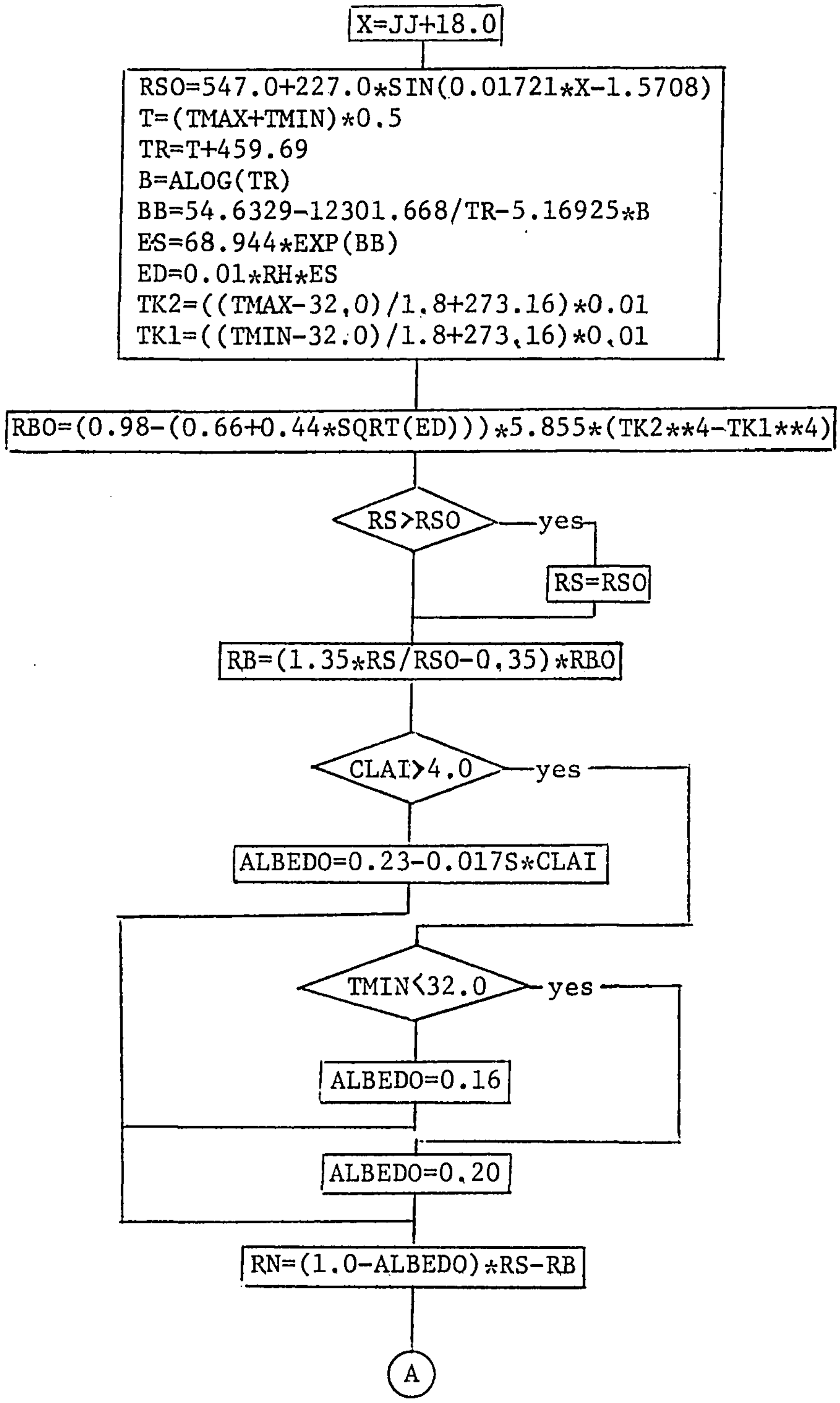

K
NOUT≠1
and
JJ≠JJR1
Write detailed output
for the day
yes
JX=10
JIM1<10
yes
JX=JIM1
SUM5=0.0
JI=1,JX
SUM5=SUM5+ESOILM(JJ,JI)
SUM9=SUM5
yes
JX≯JIM1
JX=JX+1
JI=JX,JIM1
SUM9=SUM9+ESOILM(JJ,JI)
yes
JIM1<10
710
LL=1,5
LX=2*LL
SUMLAY(LL)=ESOILM(JJ,LX)+ESOILM(JJ,LX-1)
L


L
710
Write JJ,MONTH,DAYT
YEAR,SUM5,SUM9
JIM1<10
Write SUMLAY
1000
2000
STOP
END

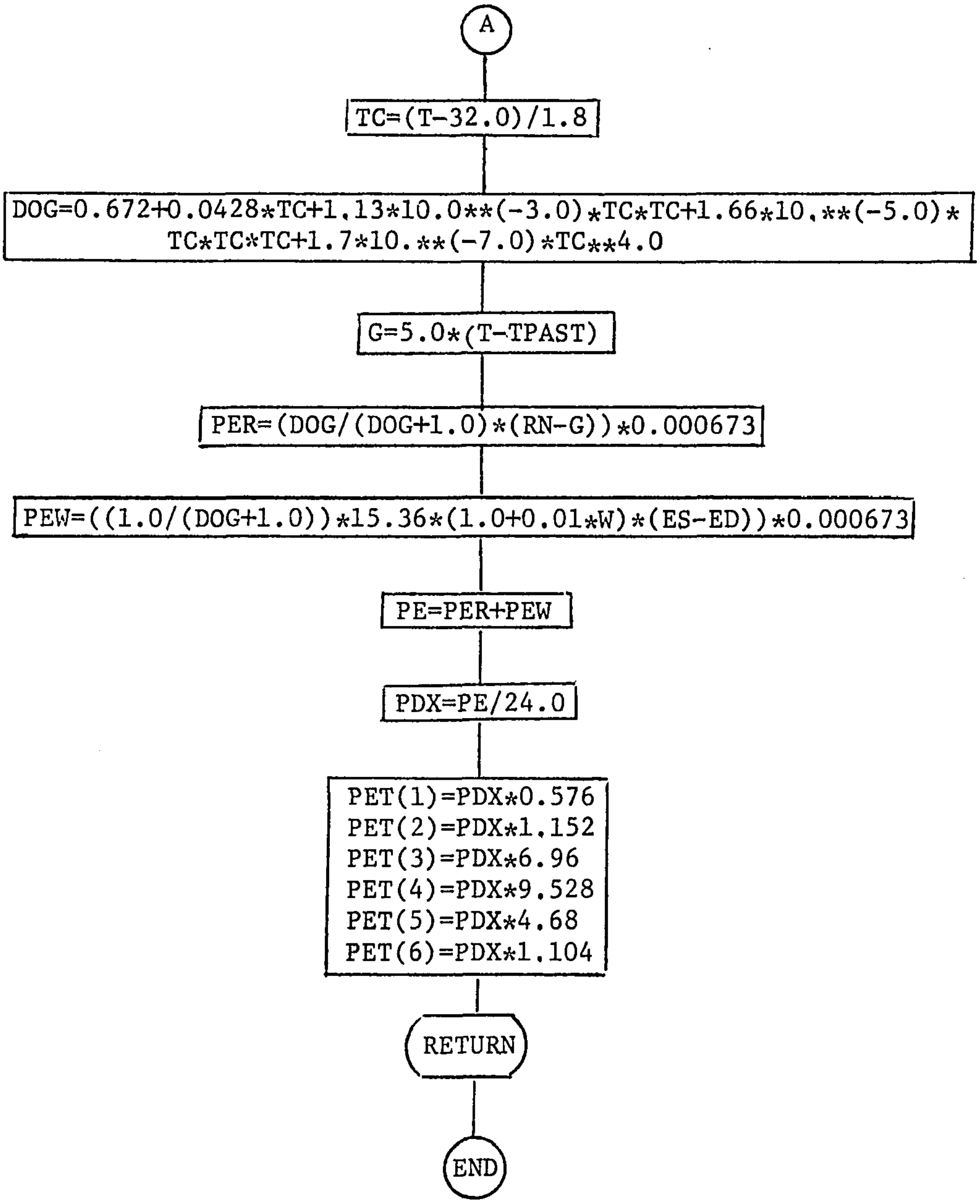
SUBROUTINE PLANT(JJ,NRTDS,PCATRN,CLAI,IRT,ROOTS,ALAI,DALI,TJ PCT,J1M1)



```
SUBROUTINE PEVAP(JJ,TMAX,TMIN,CLAI,RH,RS,W,TPAST,PE,PET)
```

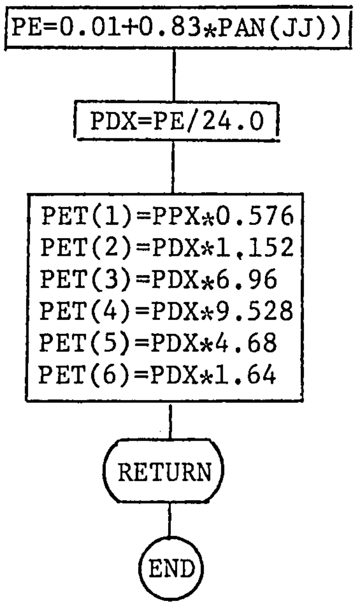


```
X=JJ+18.0

RSO=547.0+227.0*SIN(0.01721*X-1.5708)
T=(TMAX+TMIN)*0.5
TR=T+459.69
B=ALOG(TR)
BB=54.6329-12301.668/TR-5.16925*B
ES=68.944*EXP(BB)
ED=0.01*RH*ES
TK2=((TMAX-32.0)/1.8+273.16)*0.01
TK1=((TMIN-32.0)/1.8+273.16)*0.01

RBO=(0.98-(0.66+0.44*SQRT(ED)))*5.855*(TK2**4-TK1**4)

RS>RSO

RS=RSO

RB=(1.35*RS/RSO-0.35)*RBO

CLAI>4.0

ALBEDO=0.23-0.017S*CLAI

TMIN<32.0

ALBEDO=0.16

ALBEDO=0.20

RN=(1.0-ALBEDO)*RS-RB
```

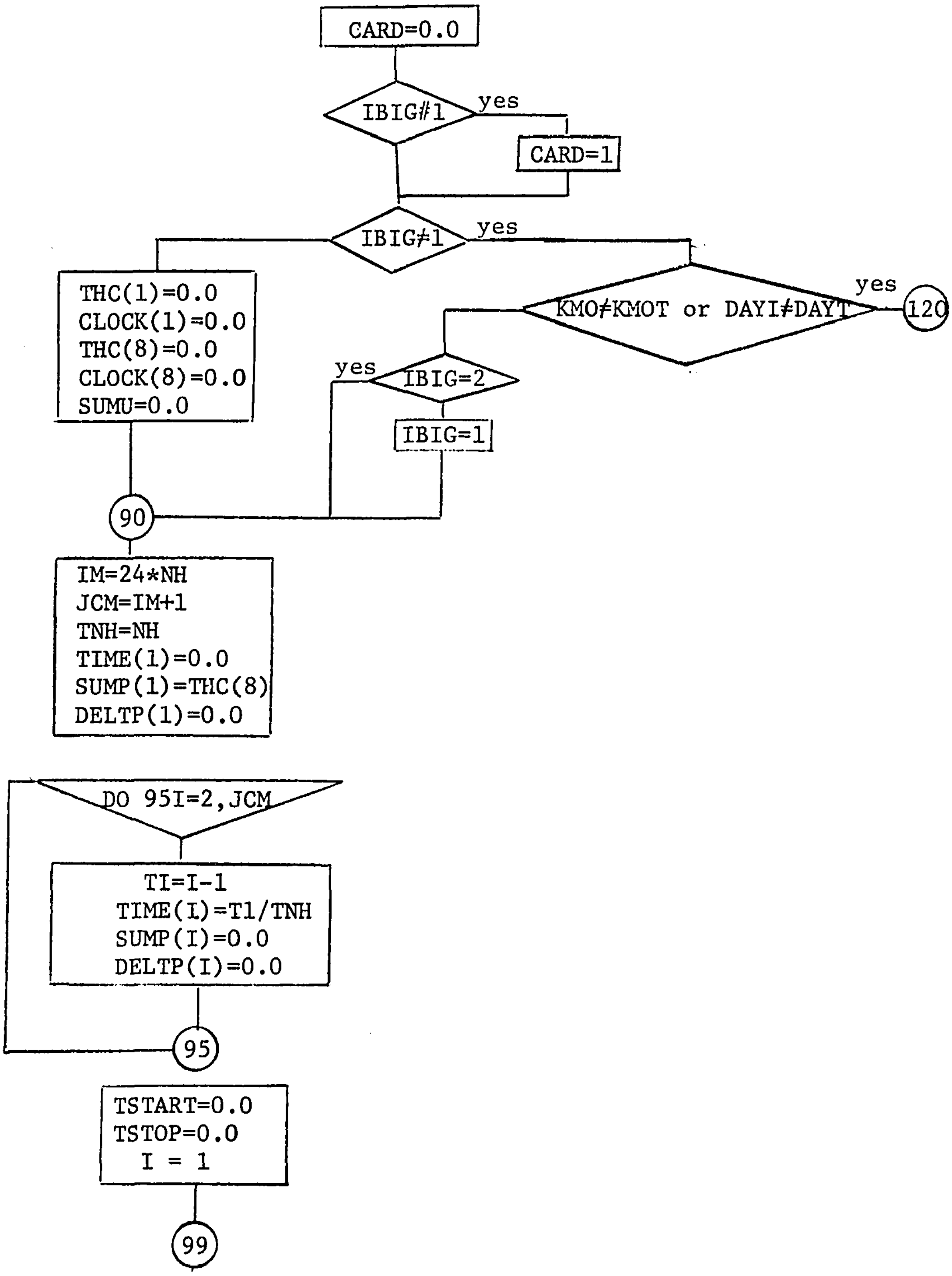


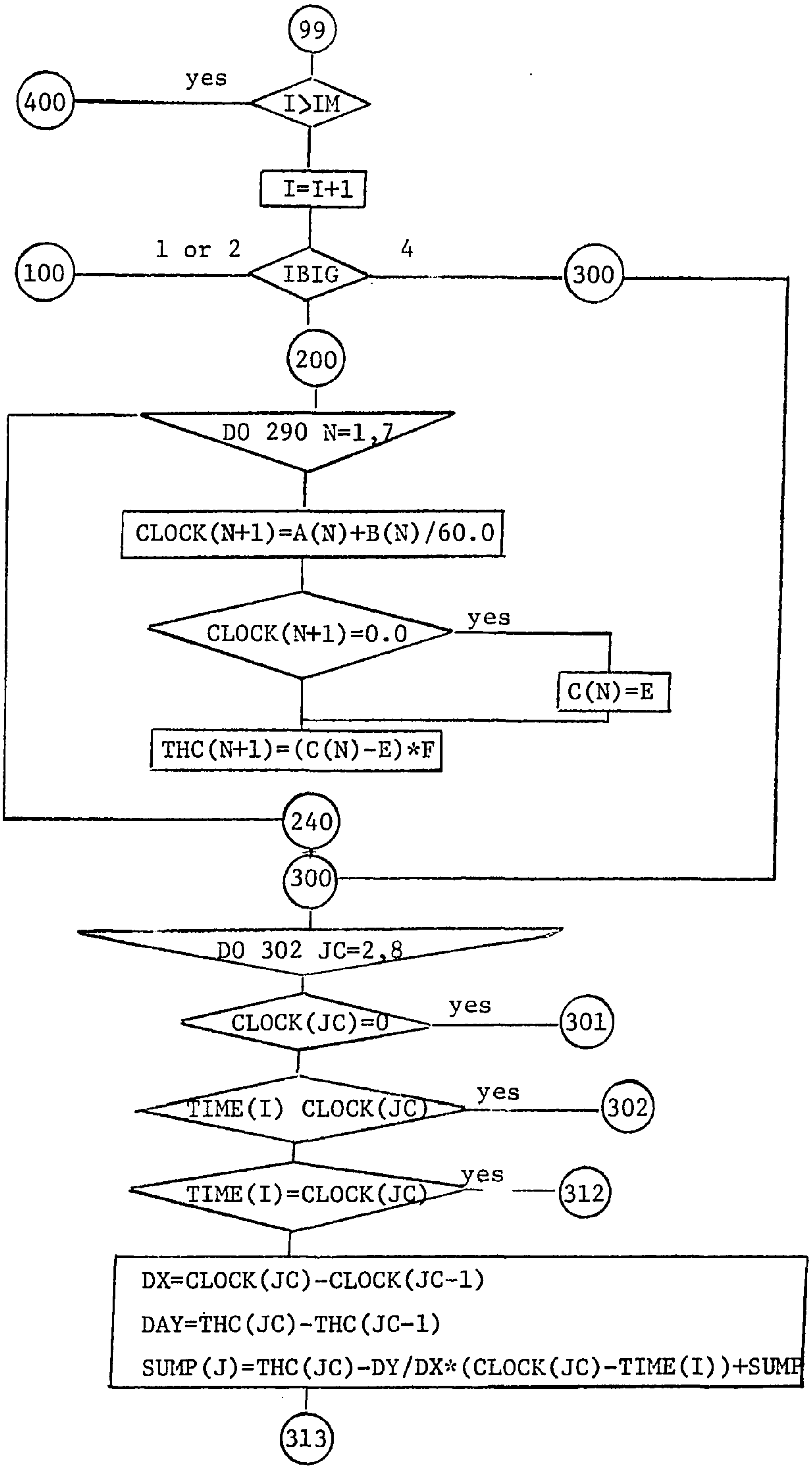
```
TC=(T-32.0)/1.8
DOG=0.672+0.0428*TC+1.13*10.0**(-3.0)*TC*TC+1.66*10.**(-5.0)*
     TC*TC*TC+1.7*10.**(-7.0)*TC**4.0
G=5.0*(T-TPAST)
PER=(DOG/(DOG+1.0)*(RN-G))*0.000673
PEW=((1.0/(DOG+1.0))*15.36*(1.0+0.01*W)*(ES-ED))*0.000673
PE=PER+PEW
PDX=PE/24.0
PET(1)=PDX*0.576
PET(2)=PDX*1.152
PET(3)=PDX*6.96
PET(4)=PDX*9.528
PET(5)=PDX*4.68
PET(6)=PDX*1.104
```

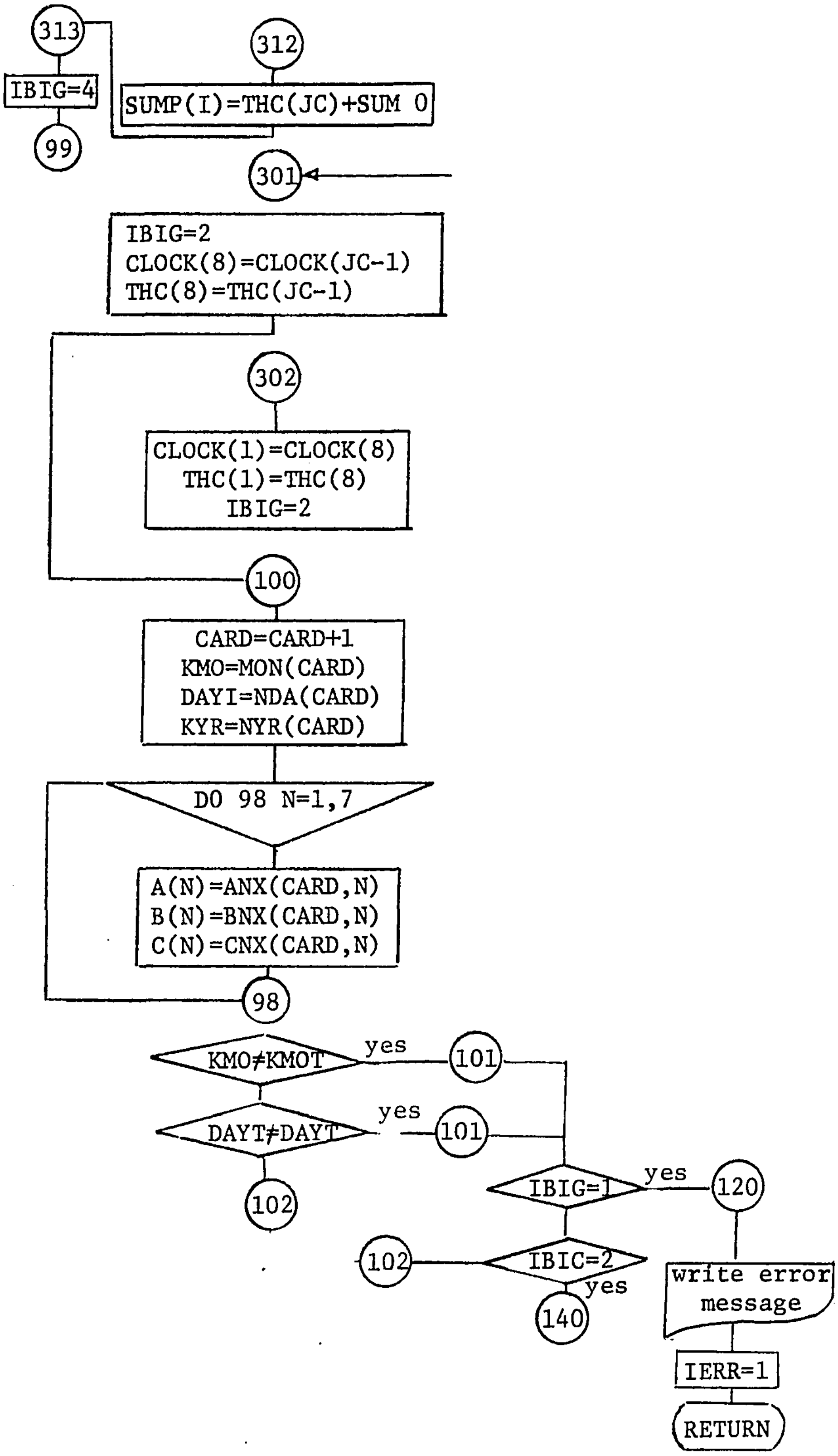
SUBROUTINE PANEVP(PAN,JJ,PE,PET)

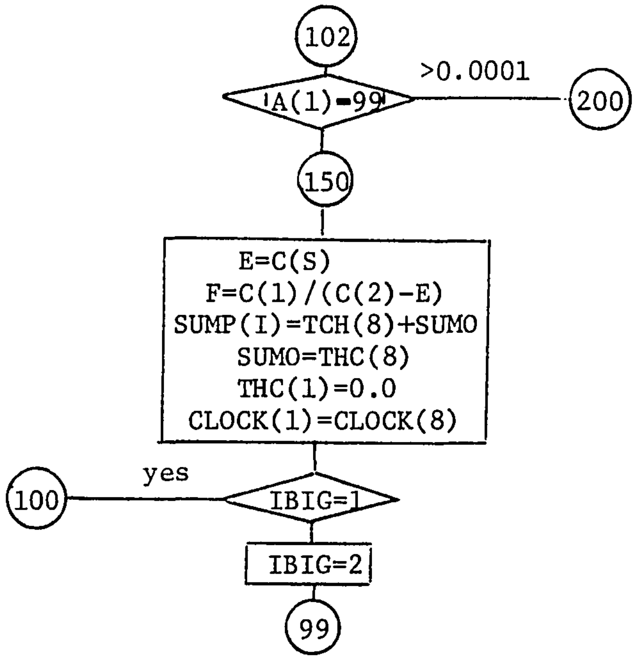


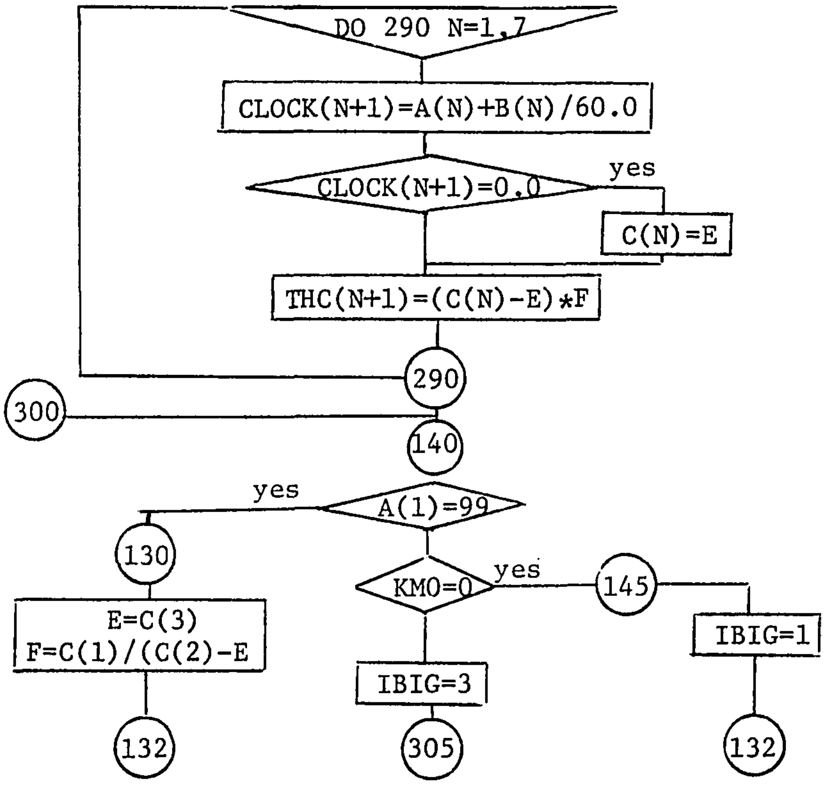
SUBROUTINE PRECIP(KMOT,DAYT,YEAR,IBIG,NH,DELTP,IERR,TSTART,TSTOP,
MON,NPA,NYR,ANX,BNX,CNX)

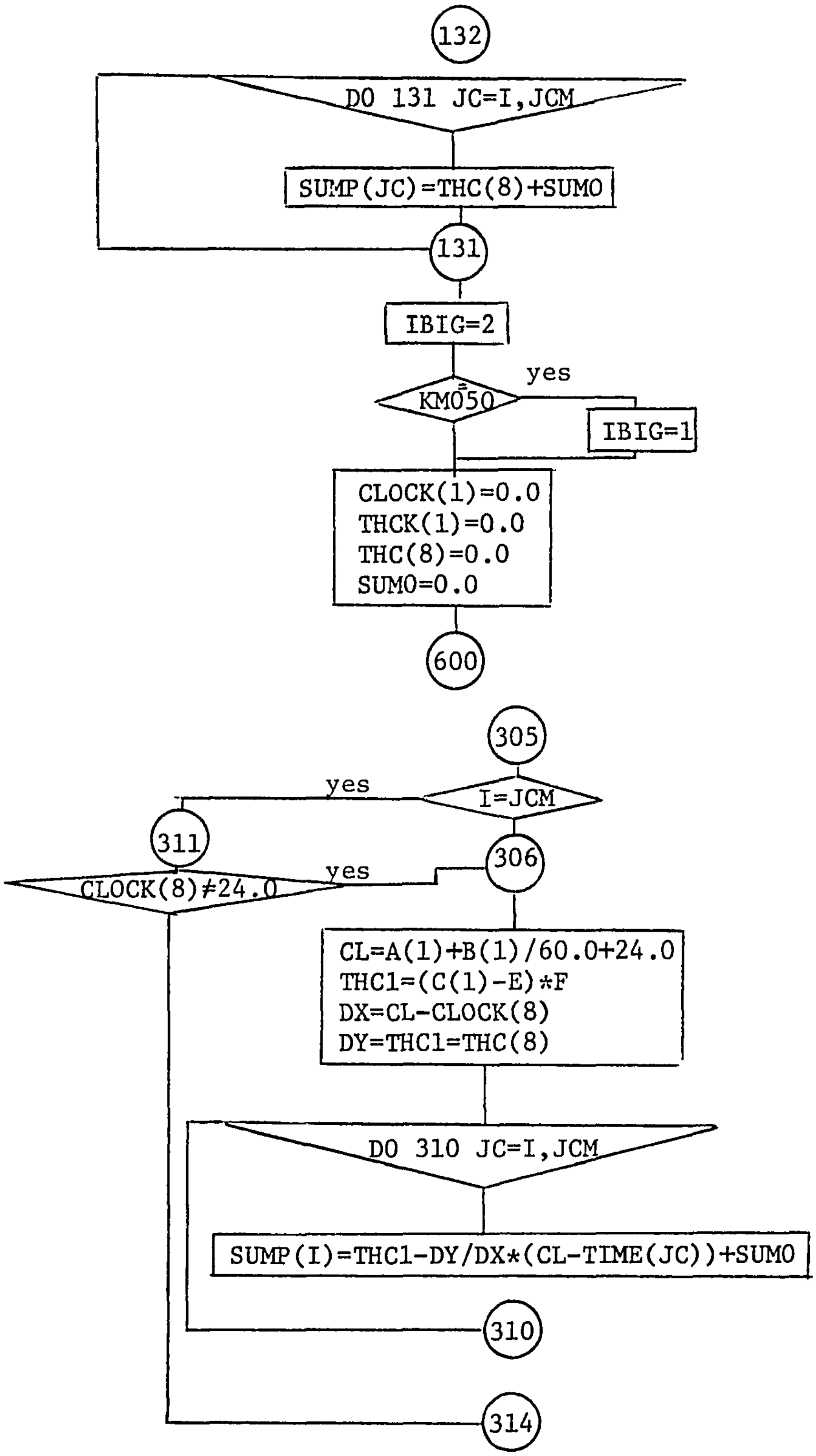


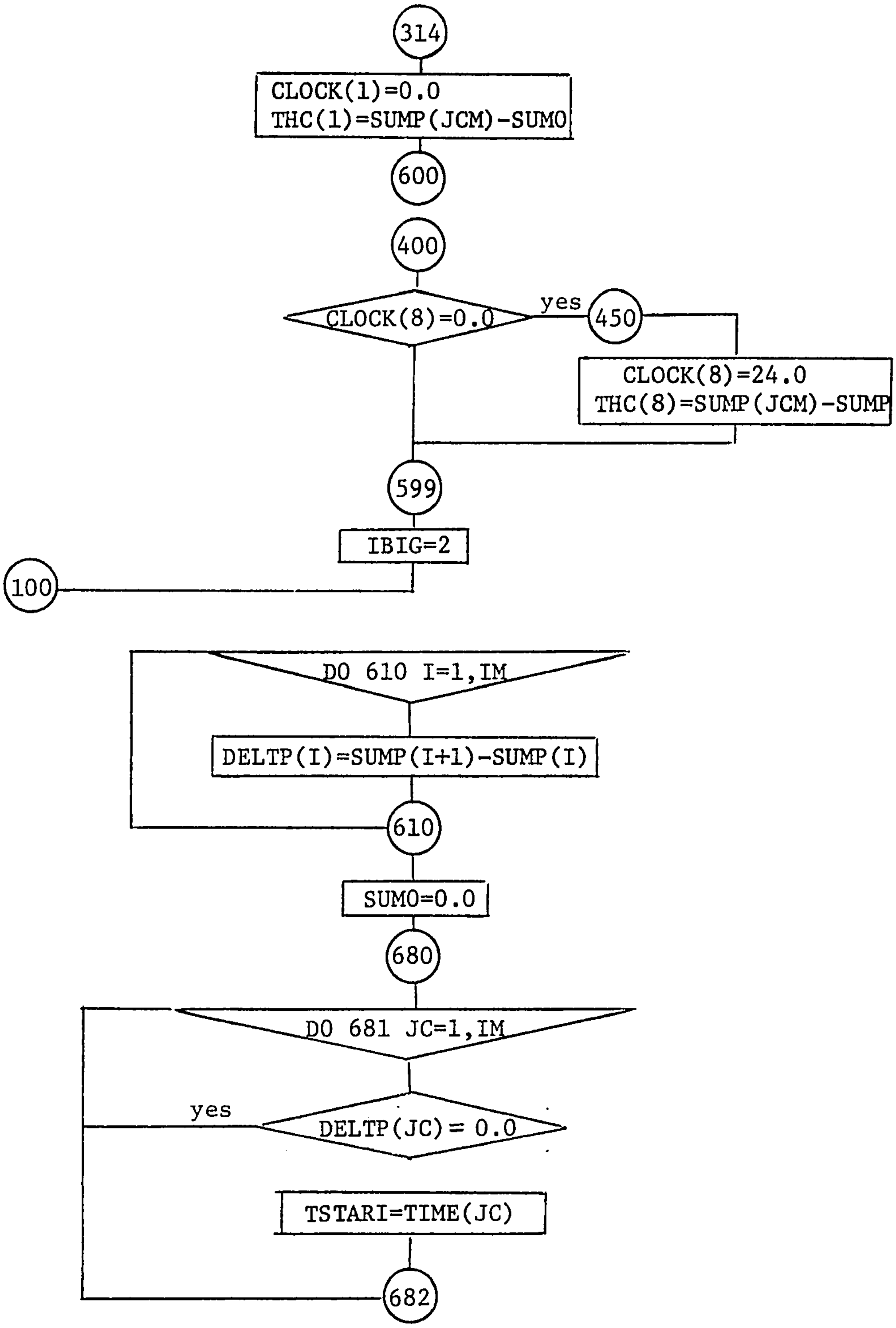

99
yes
400
I>IM
I=I+1
1 or 2
4
100
IBIG
300
200
DO 290 N=1,7
CLOCK(N+1)=A(N)+B(N)/60.0
CLOCK(N+1)=0.0
yes
C(N)=E
THC(N+1)=(C(N)-E)*F
240
300
DO 302 JC=2,8
CLOCK(JC)=0
yes
301
TIME(I) CLOCK(JC)
yes
302
TIME(I)=CLOCK(JC)
yes
312
DX=CLOCK(JC)-CLOCK(JC-1)
DAY=THC(JC)-THC(JC-1)
SUMP(J)=THC(JC)-DY/DX*(CLOCK(JC)-TIME(I))+SUMP
313

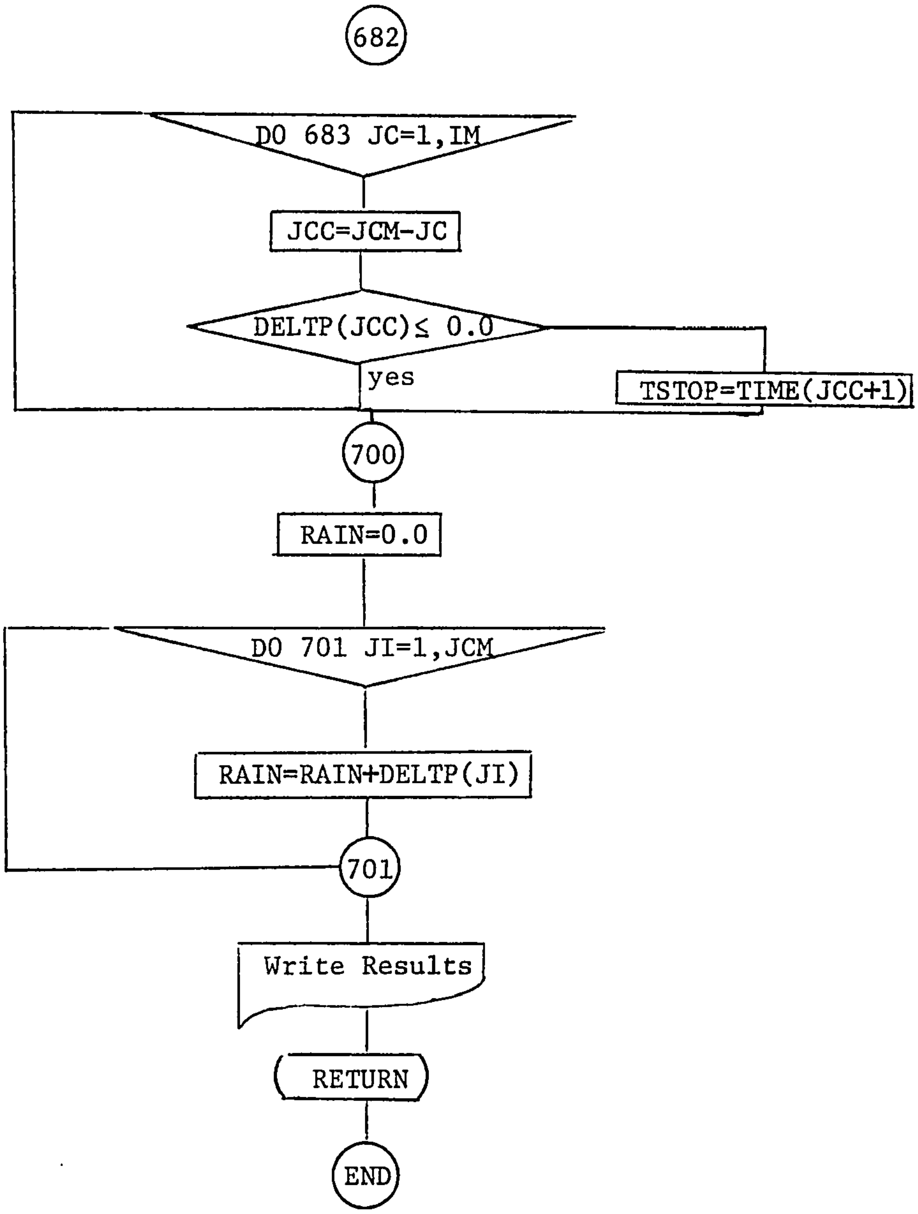

313
IBIG=4
99
312
SUMP(I)=THC(JC)+SUM 0
301
IBIG=2
CLOCK(8)=CLOCK(JC-1)
THC(8)=THC(JC-1)
302
CLOCK(1)=CLOCK(8)
THC(1)=THC(8)
IBIG=2
100
CARD=CARD+1
KMO=MON(CARD)
DAYI=NDA(CARD)
KYR=NYR(CARD)
DO 98 N=1,7
A(N)=ANX(CARD,N)
B(N)=BNX(CARD,N)
C(N)=CNX(CARD,N)
98
KMO≠KMOT
yes
101
DAYI≠DAYT
yes
101
102
IBIG=1
yes
120
write error message
IERR=1
RETURN
102
IBIG=2
yes
140


102
A(1)-99
>0.0001
200
150
E=C(S)
F=C(1)/(C(2)-E)
SUMP(I)=TCH(8)+SUMO
SUMO=THC(8)
THC(1)=0.0
CLOCK(1)=CLOCK(8)
yes
100
IBIG=1
IBIG=2
99

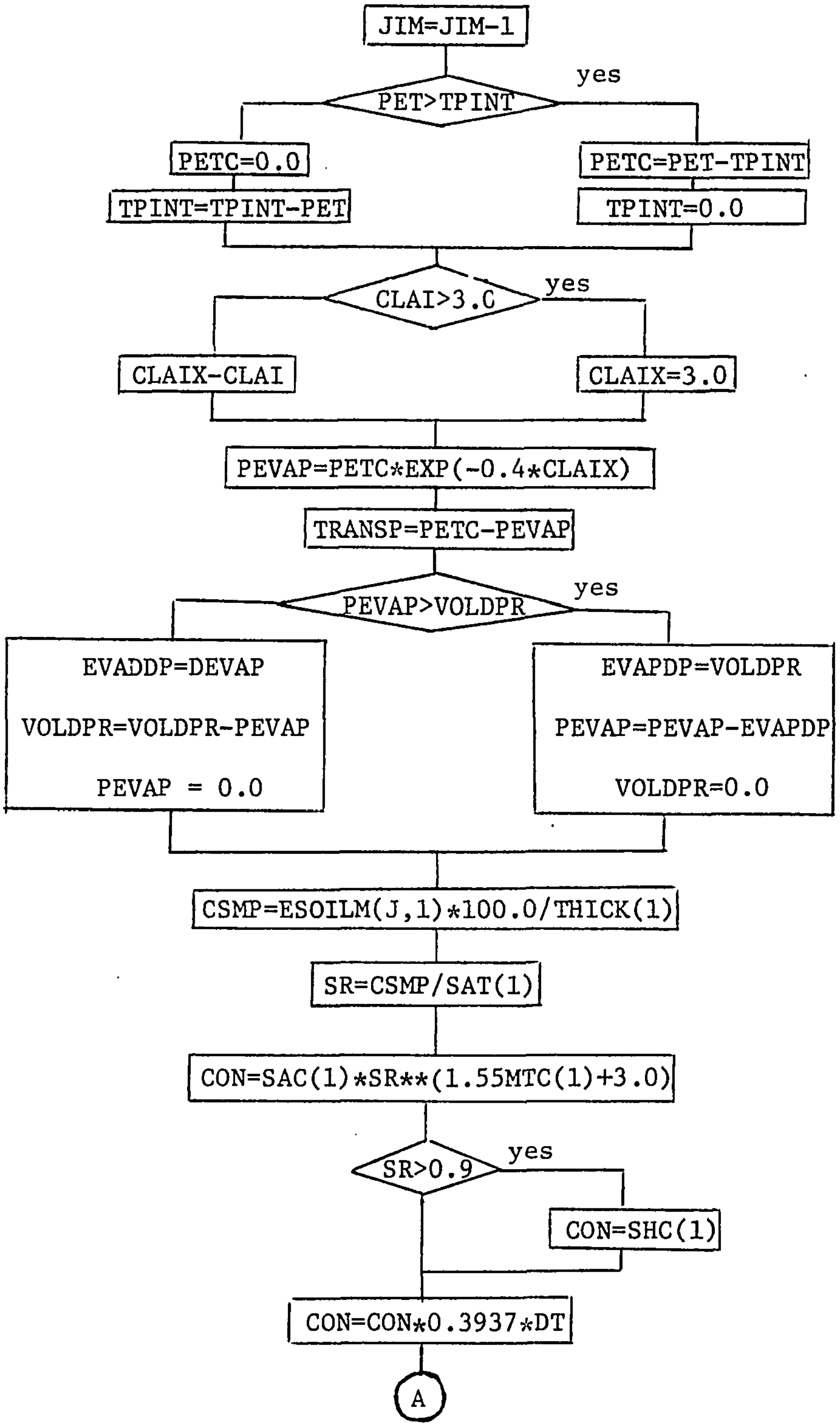

DO 290 N=1,7
CLOCK(N+1)=A(N)+B(N)/60.0
CLOCK(N+1)=0.0
yes
C(N)=E
THC(N+1)=(C(N)-E)*F
290
300
140
yes
A(1)=99
130
E=C(3)
F=C(1)/(C(2)-E
KMO=0
yes
145
IBIG=1
IBIG=3
132
305
132

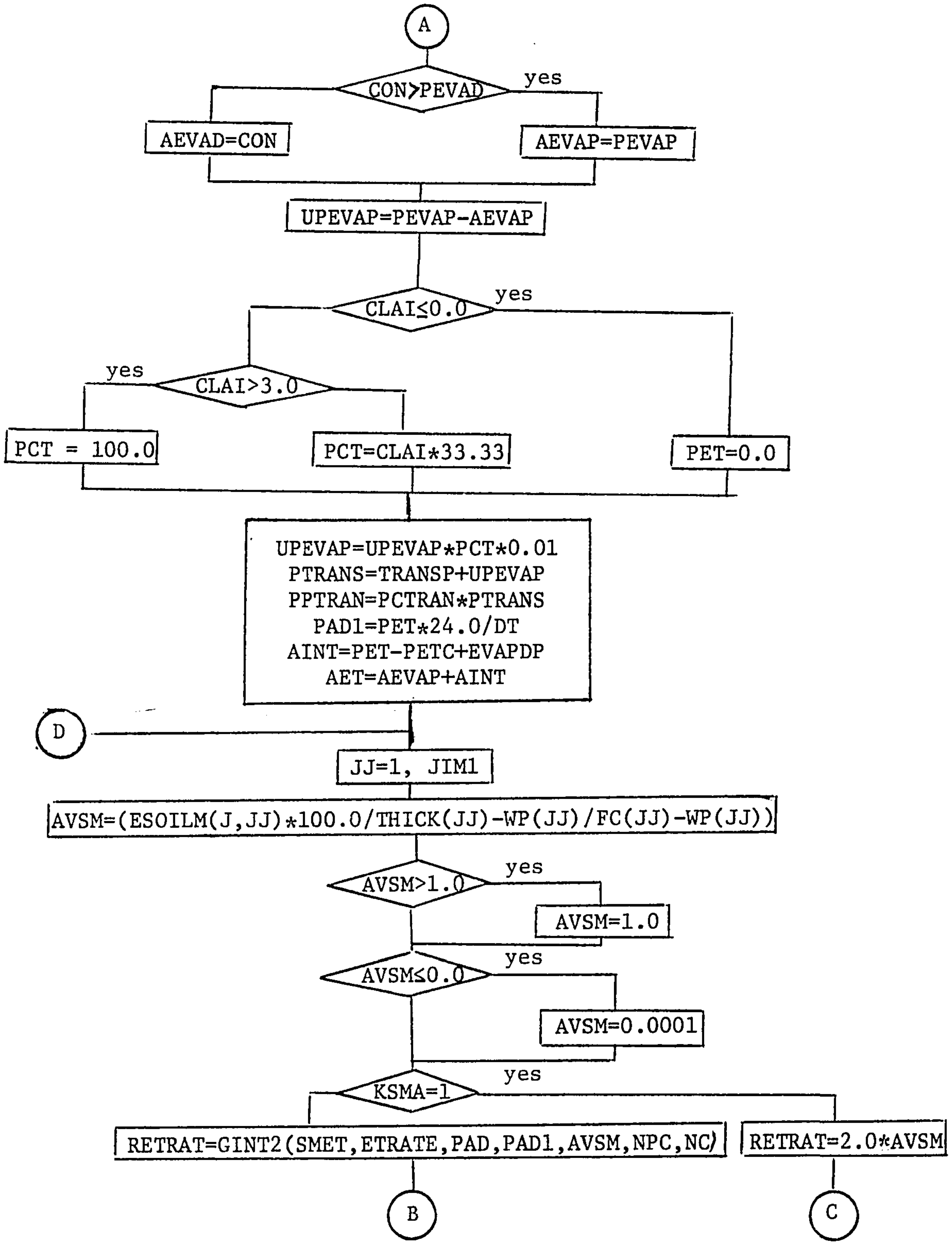

132
DO 131 JC=I,JCM
SUMP(JC)=THC(8)+SUMO
131
IBIG=2
yes
KM0=50
IBIG=1
CLOCK(1)=0.0
THCK(1)=0.0
THC(8)=0.0
SUMO=0.0
600
305
yes
I=JCM
311
306
yes
CLOCK(8)≠24.0
CL=A(1)+B(1)/60.0+24.0
THC1=(C(1)-E)*F
DX=CL-CLOCK(8)
DY=THC1=THC(8)
DO 310 JC=I,JCM
SUMP(I)=THC1-DY/DX*(CL-TIME(JC))+SUMO
310
314

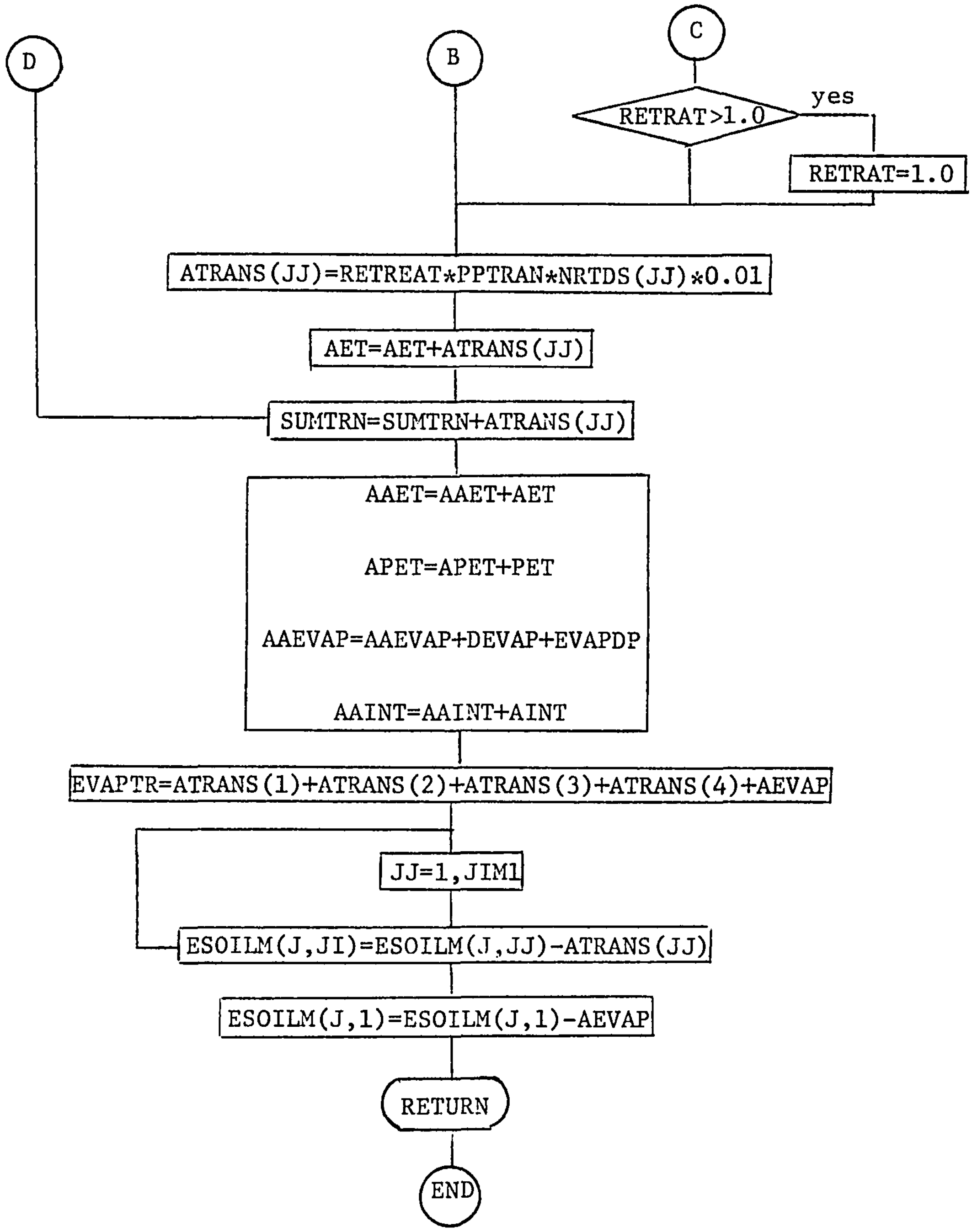

314
CLOCK(1)=0.0
THC(1)=SUMP(JCM)-SUMO
600
400
CLOCK(8)=0.0
yes
450
CLOCK(8)=24.0
THC(8)=SUMP(JCM)-SUMP
599
IBIG=2
100
DO 610 I=1,IM
DELTP(I)=SUMP(I+1)-SUMP(I)
610
SUMO=0.0
680
DO 681 JC=1,IM
yes
DELTP(JC) = 0.0
TSTARI=TIME(JC)
682


682
DO 683 JC=1,IM
JCC=JCM-JC
DELTP(JCC)≤ 0.0
yes
TSTOP=TIME(JCC+1)
700
RAIN=0.0
DO 701 JI=1,JCM
RAIN=RAIN+DELTP(JI)
701
Write Results
RETURN
END

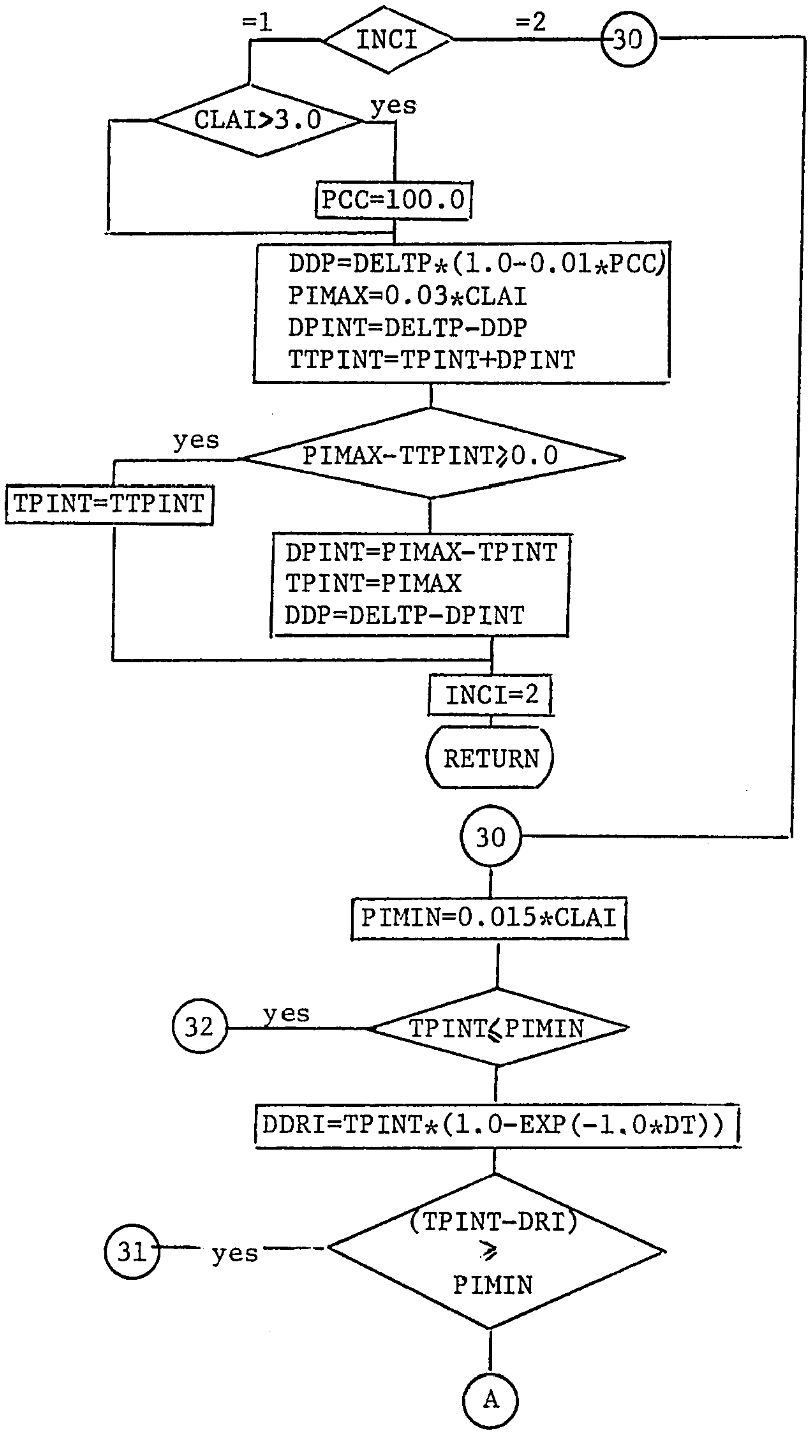
```
SUBROUTINE ET(J,TPINT,PCATRN,NRTOS,ATRANS,EVAPTR,PET,DDET,APET
              AAEVAP,AAINT,CLAI,NPC,NC,DT,SUMTRN,AINT,AET,YOLDPR,
              JLM,SAT,SMTC,KSMA)
```

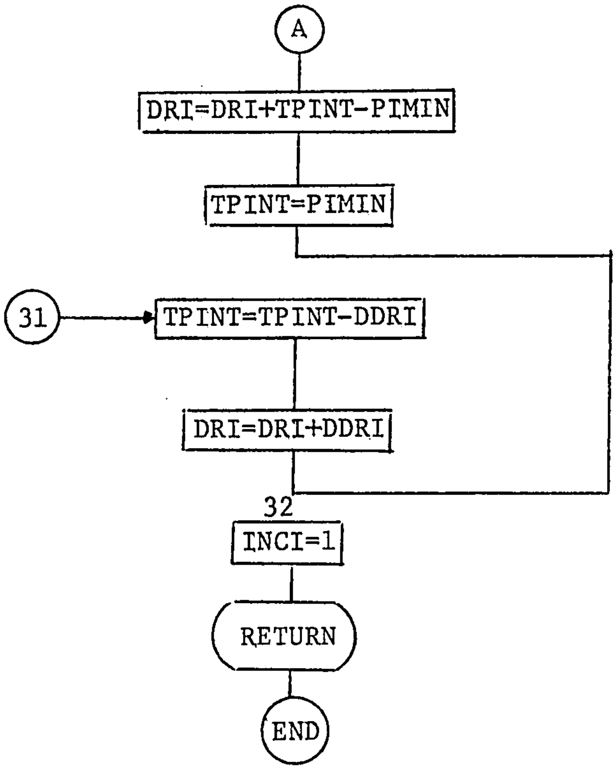



A
CON>PEVAD
yes
AEVAD=CON
AEVAP=PEVAP
UPEVAP=PEVAP-AEVAP
CLAI≤0.0
yes
yes
CLAI>3.0
PCT = 100.0
PCT=CLAI*33.33
PET=0.0
UPEVAP=UPEVAP*PCT*0.01
PTRANS=TRANSP+UPEVAP
PPTRAN=PCTRAN*PTRANS
PAD1=PET*24.0/DT
AINT=PET-PETC+EVAPDP
AET=AEVAP+AINT
D
JJ=1, JIM1
AVSM=(ESOILM(J,JJ)*100.0/THICK(JJ)-WP(JJ)/FC(JJ)-WP(JJ))
AVSM>1.0
yes
AVSM=1.0
AVSM≤0.0
yes
AVSM=0.0001
KSMA=1
yes
RETRAT=GINT2(SMET,ETRATE,PAD,PAD1,AVSM,NPC,NC)
RETRAT=2.0*AVSM
B
C

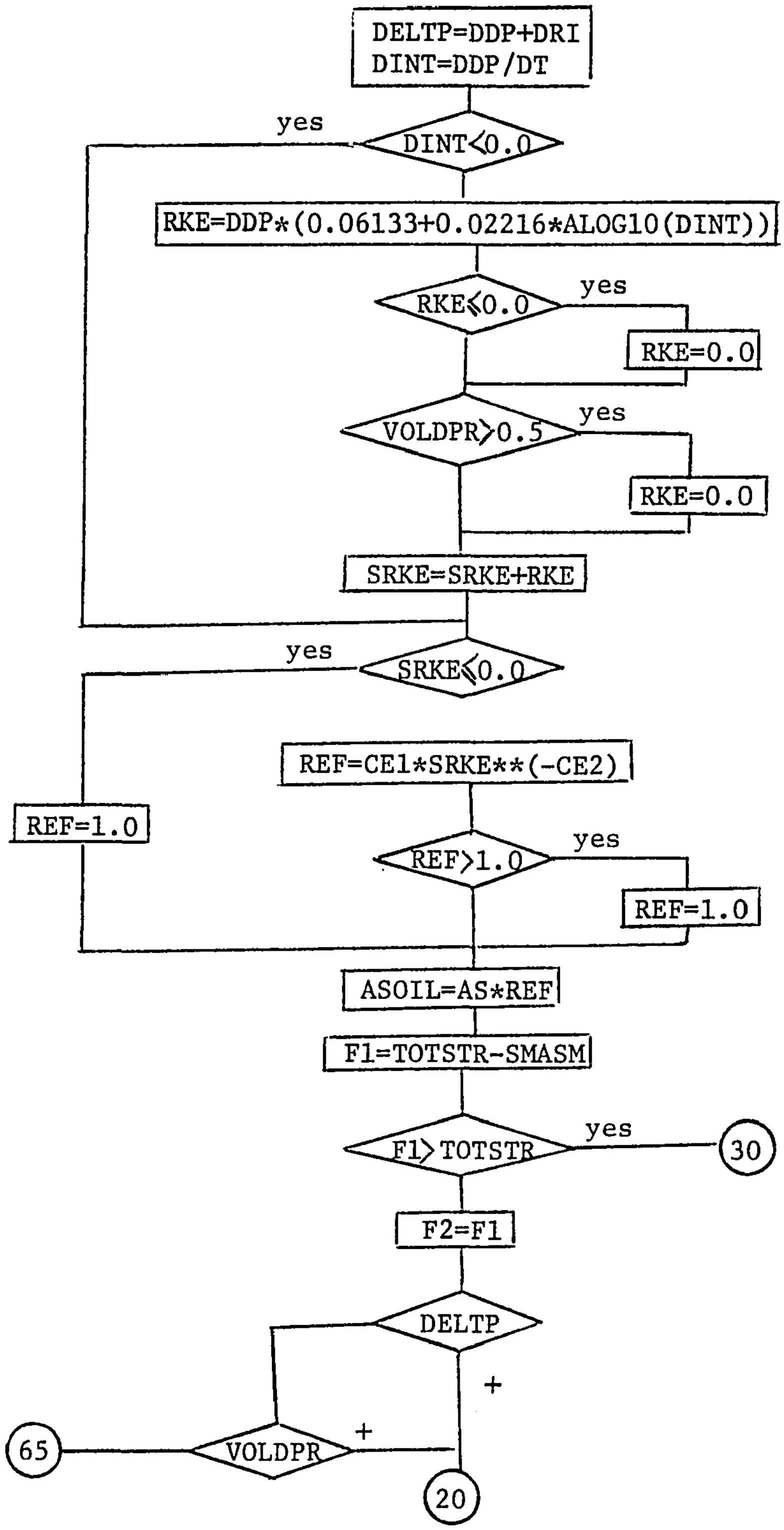

D
B
C
RETRAT>1.0
yes
RETRAT=1.0
ATRANS(JJ)=RETREAT*PPTRAN*NRTDS(JJ)*0.01
AET=AET+ATRANS(JJ)
SUMTRN=SUMTRN+ATRANS(JJ)
AAET=AAET+AET
APET=APET+PET
AAEVAP=AAEVAP+DEVAP+EVAPDP
AAINT=AAINT+AINT
EVAPTR=ATRANS(1)+ATRANS(2)+ATRANS(3)+ATRANS(4)+AEVAP
JJ=1,JIM1
ESOILM(J,JI)=ESOILM(J,JJ)-ATRANS(JJ)
ESOILM(J,1)=ESOILM(J,1)-AEVAP
RETURN
END

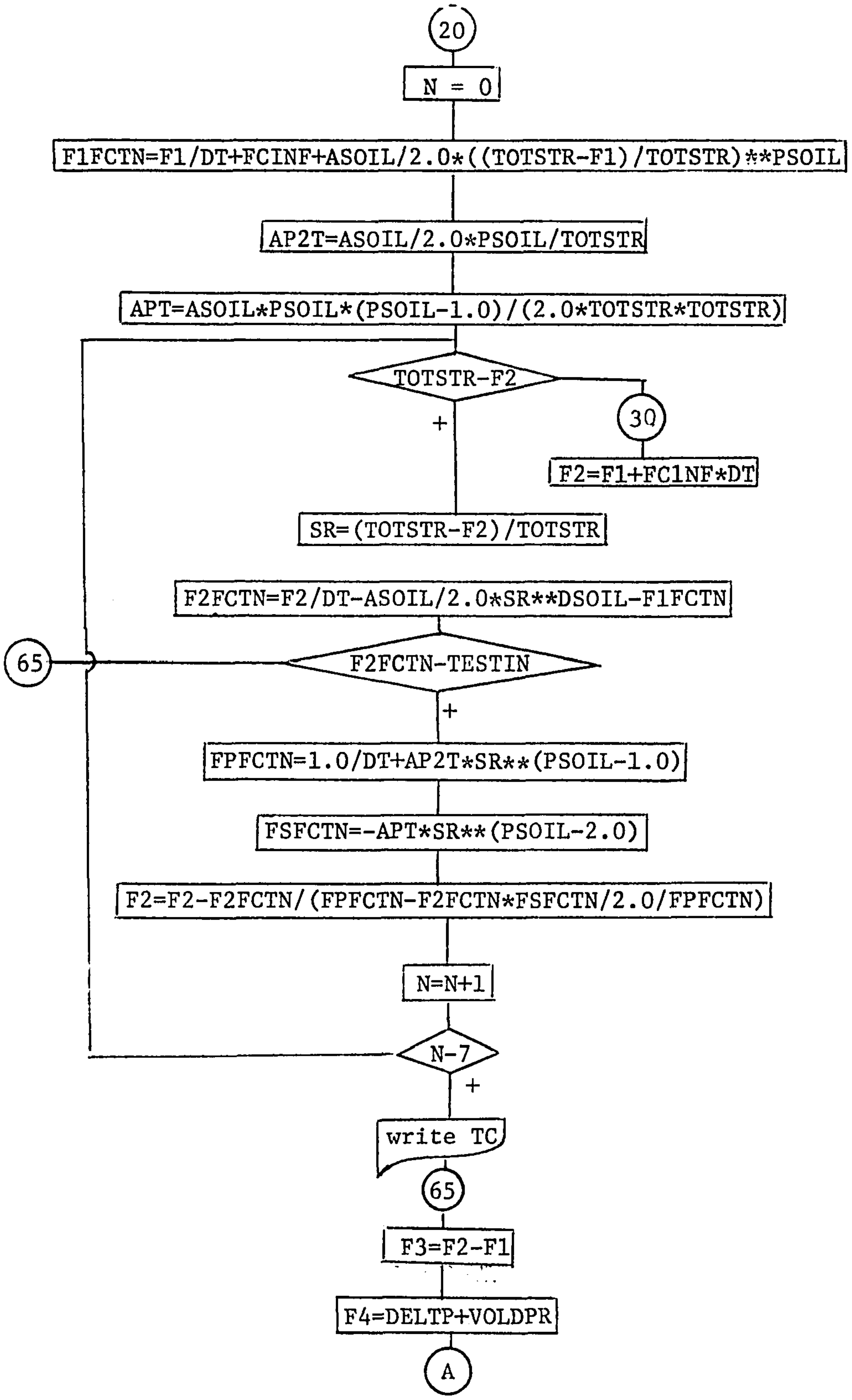
SUBROUTINE INTCPT(CLAI,DELTP,DPINT,TPINT,DDP,INCI,DT,DRI,PCC)

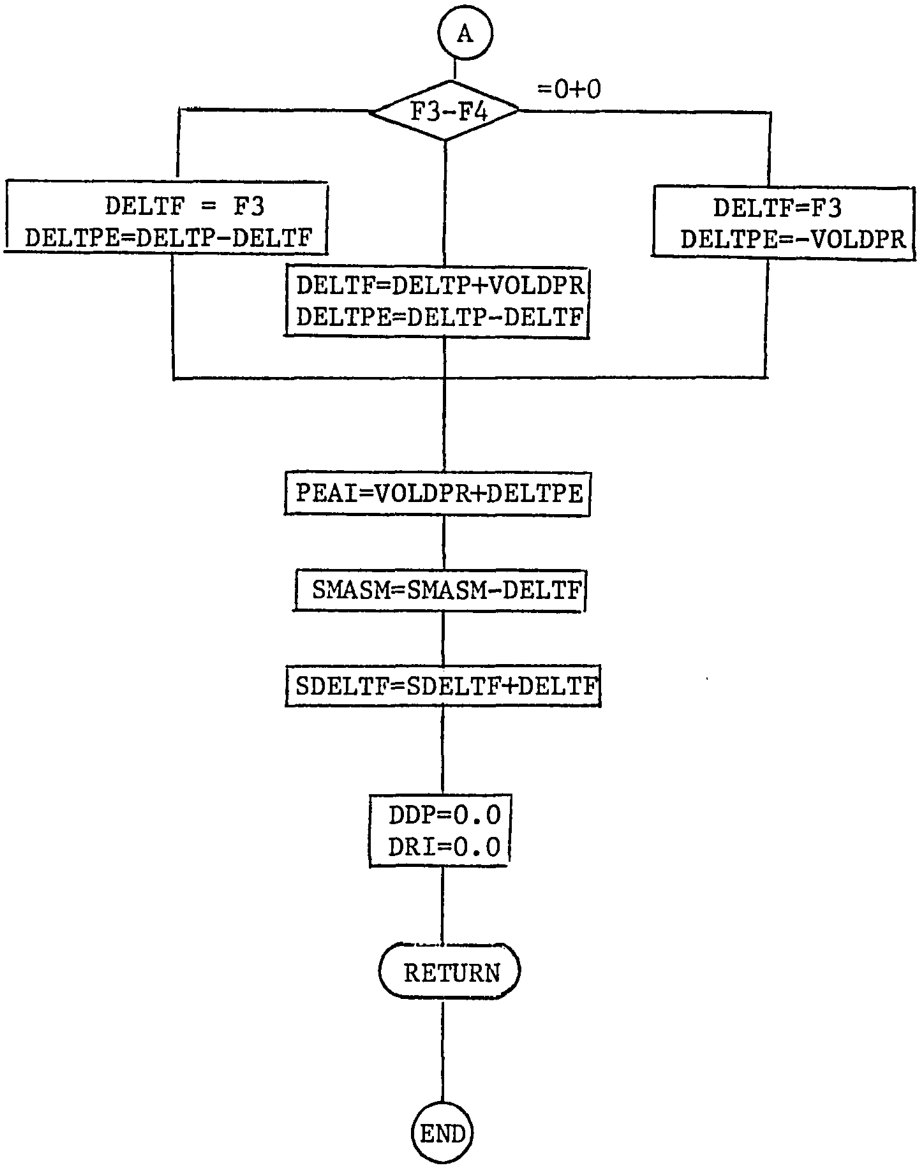



A
DRI=DRI+TPINT-PIMIN
TPINT=PIMIN
31
TPINT=TPINT-DDRI
DRI=DRI+DDRI
32
INCI=1
RETURN
END

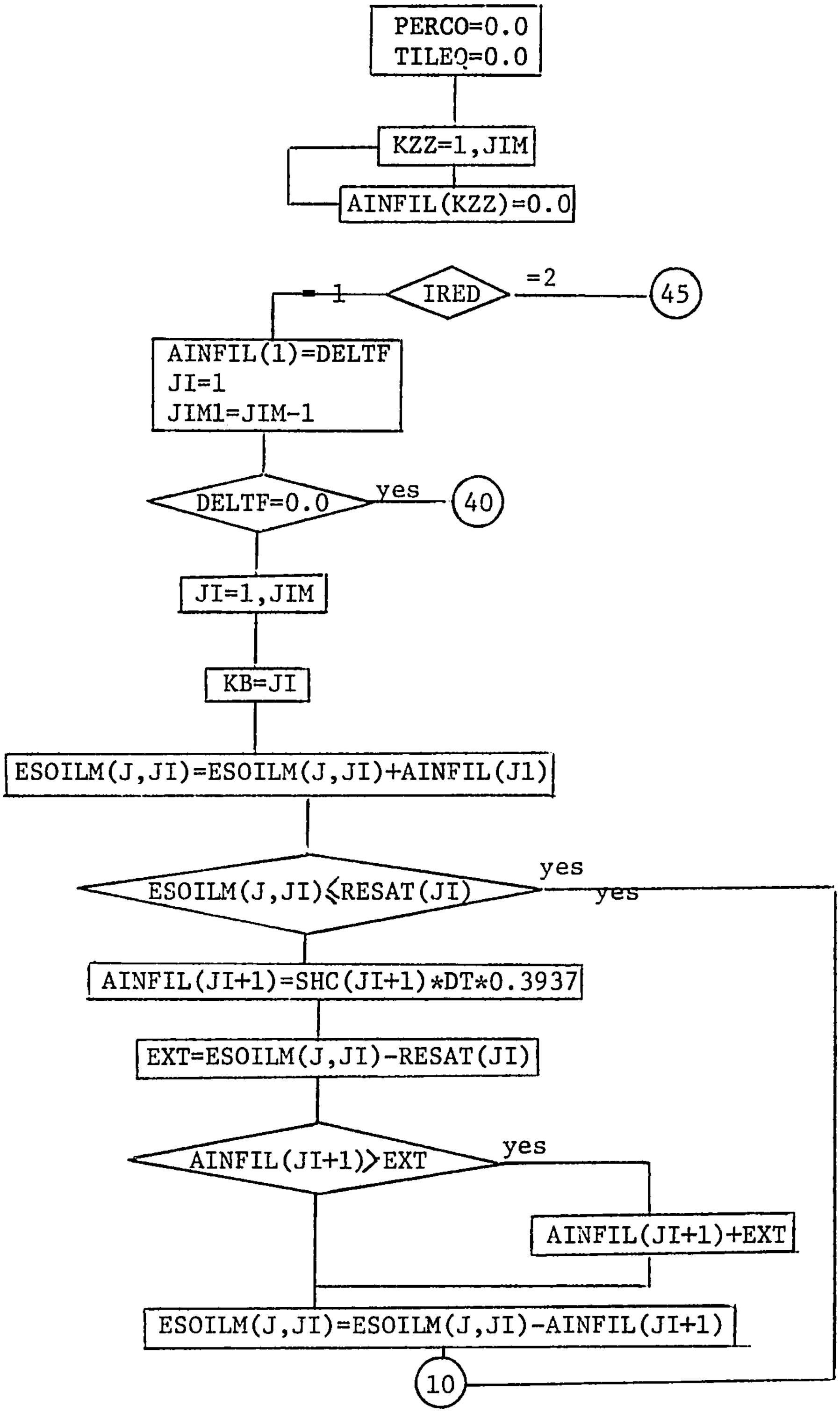
```
SUBROUTINE INFILT(AS,PSOIL,TOTSTR,FCINFL,SMASM,DT,DDP,IC,DELTF,VOLDPR,
          DRI,TESTIN,SDELTF,DINT,PEAI,SRKE,CE1,CE2
```

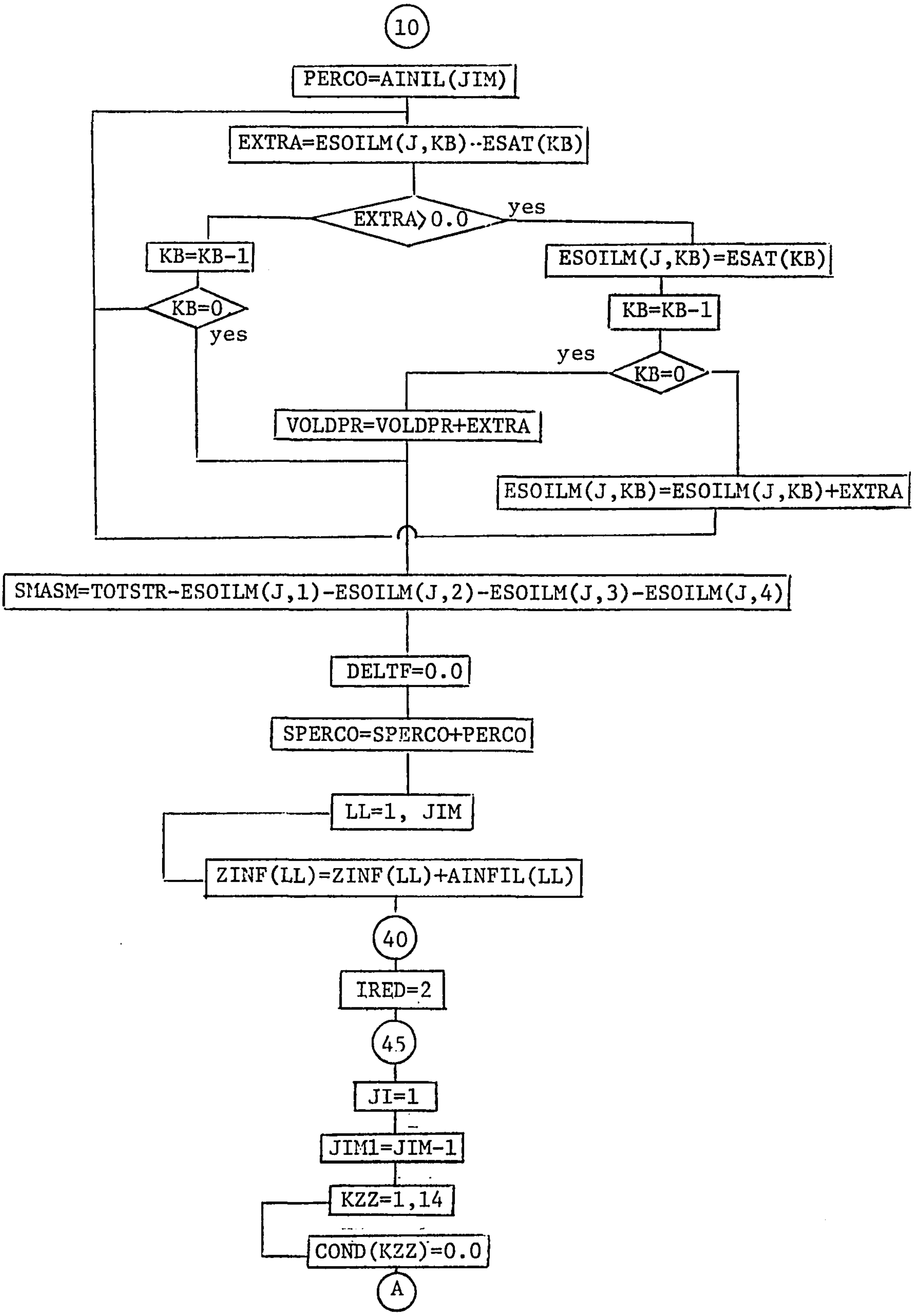


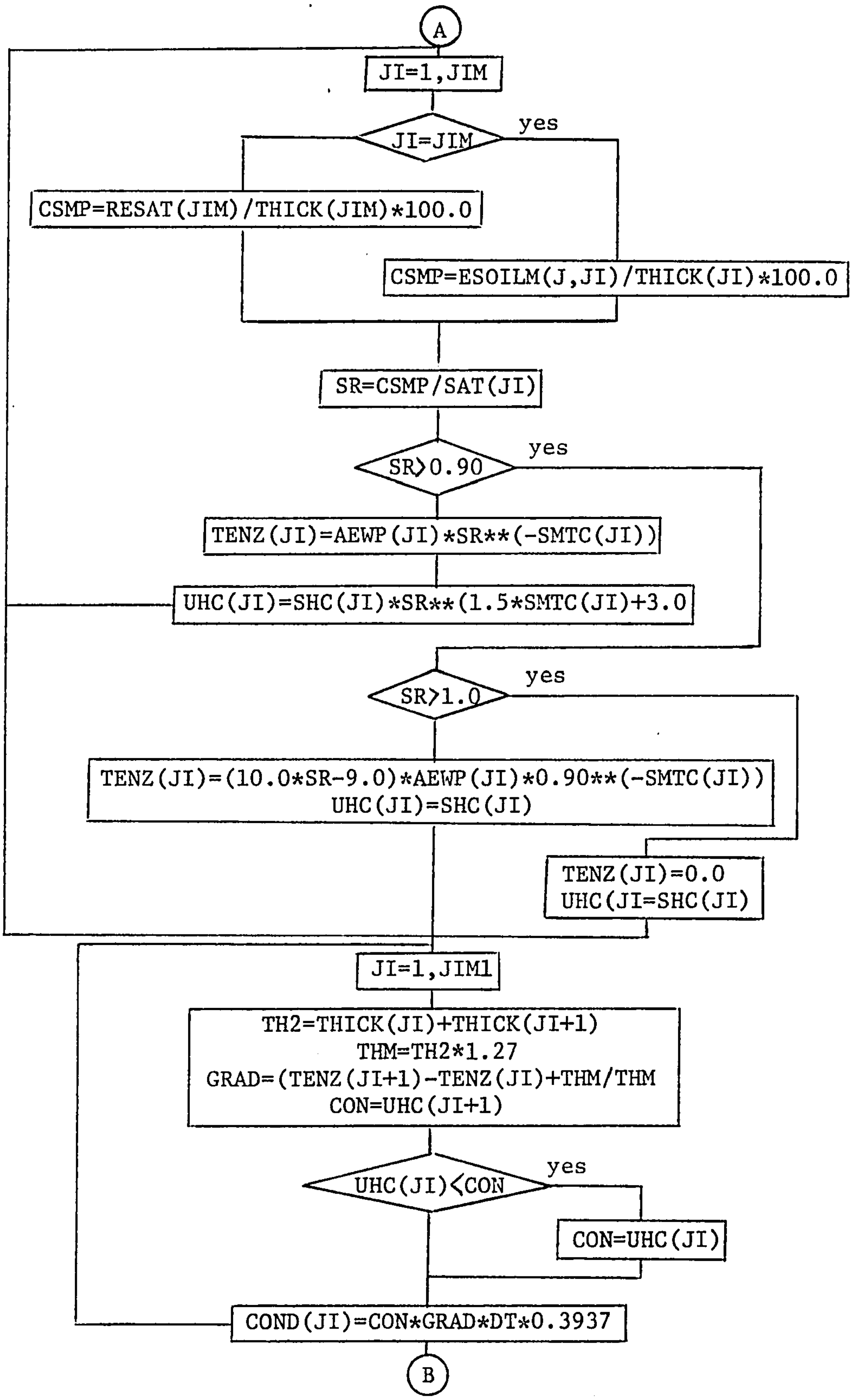

20
N = 0
F1FCTN=F1/DT+FCINF+ASOIL/2.0*((TOTSTR-F1)/TOTSTR)**PSOIL
AP2T=ASOIL/2.0*PSOIL/TOTSTR
APT=ASOIL*PSOIL*(PSOIL-1.0)/(2.0*TOTSTR*TOTSTR)
TOTSTR-F2
+
30
F2=F1+FC1NF*DT
SR=(TOTSTR-F2)/TOTSTR
F2FCTN=F2/DT-ASOIL/2.0*SR**DSOIL-F1FCTN
65
F2FCTN-TESTIN
+
FPFCTN=1.0/DT+AP2T*SR**(PSOIL-1.0)
FSFCTN=-APT*SR**(PSOIL-2.0)
F2=F2-F2FCTN/(FPFCTN-F2FCTN*FSFCTN/2.0/FPFCTN)
N=N+1
N-7
+
write TC
65
F3=F2-F1
F4=DELTP+VOLDPR
A

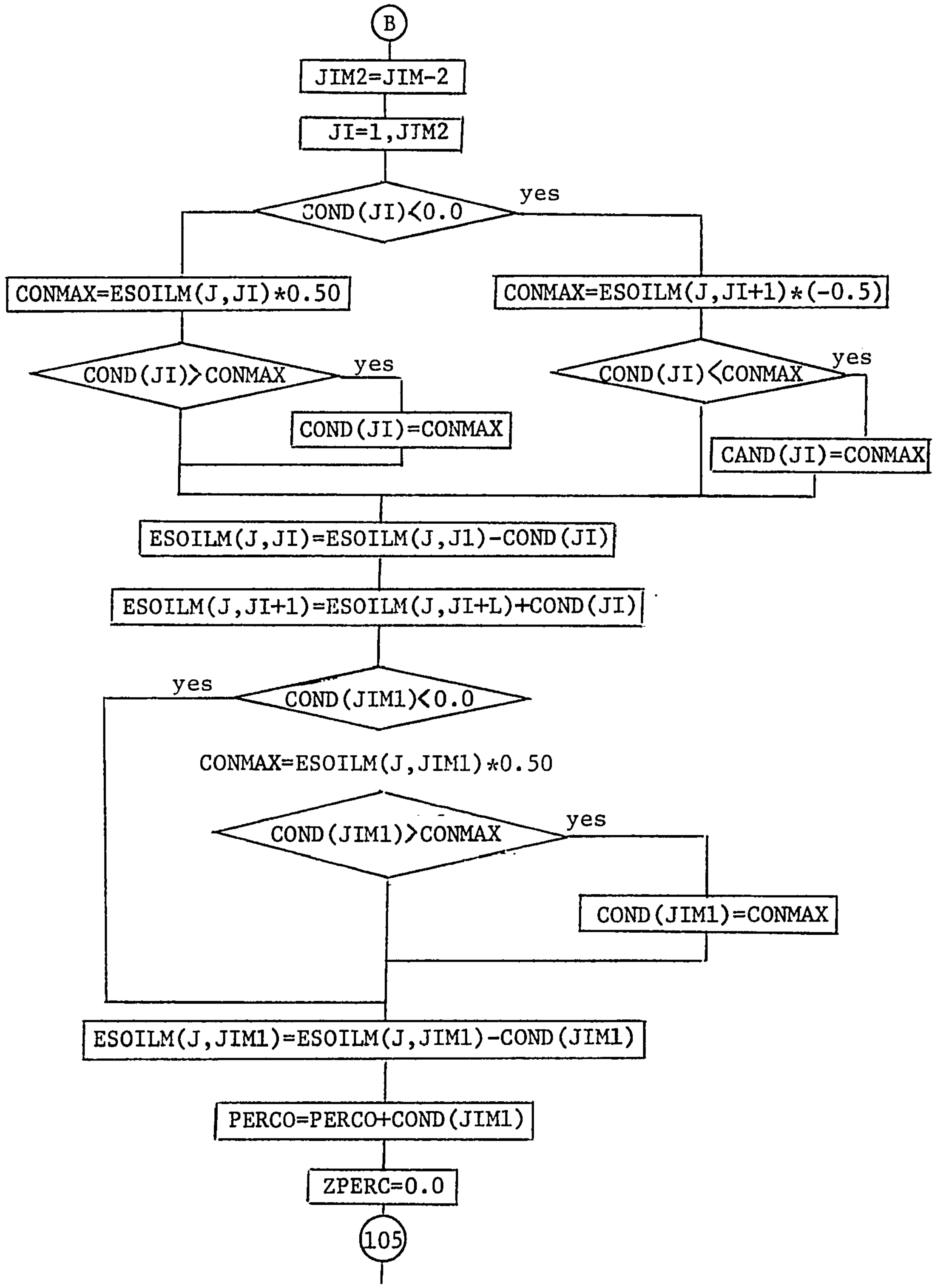

A
F3-F4
=0+0
DELTF = F3
DELTPE=DELTP-DELTF
DELTF=DELTP+VOLDPR
DELTPE=DELTP-DELTF
DELTF=F3
DELTPE=-VOLDPR
PEAI=VOLDPR+DELTPE
SMASM=SMASM-DELTF
SDELTF=SDELTF+DELTF
DDP=0.0
DRI=0.0
RETURN
END

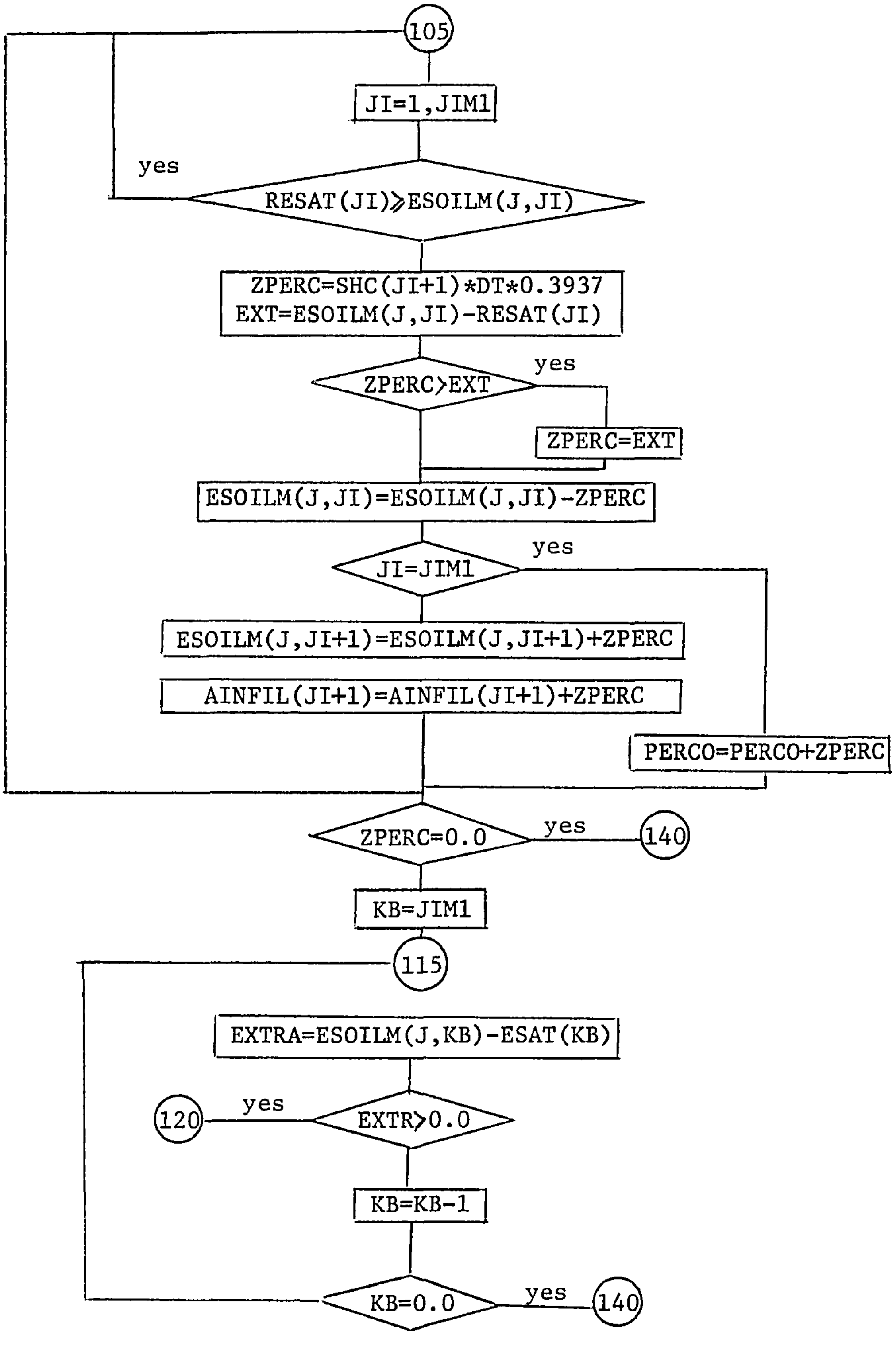
SUBROUTINE REDIST (IRED,DELTF,PERCO,SPERCO,J,TFRC,ADTF,VOLDPR
DT,COND ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC

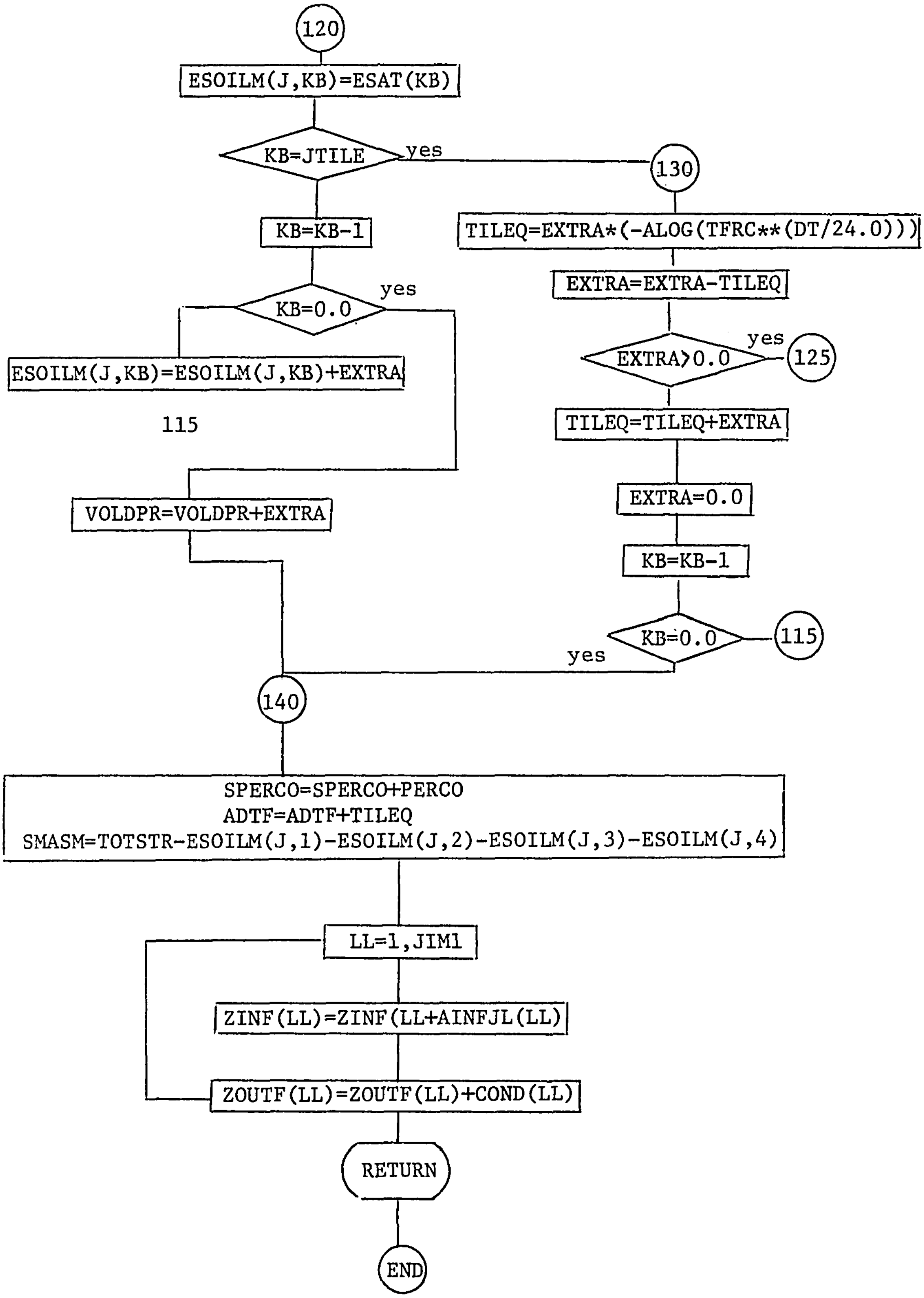



10
PERCO=AINIL(JIM)
EXTRA=ESOILM(J,KB)-ESAT(KB)
EXTRA>0.0
yes
KB=KB-1
ESOILM(J,KB)=ESAT(KB)
KB=0
yes
KB=KB-1
yes
KB=0
VOLDPR=VOLDPR+EXTRA
ESOILM(J,KB)=ESOILM(J,KB)+EXTRA
SMASM=TOTSTR-ESOILM(J,1)-ESOILM(J,2)-ESOILM(J,3)-ESOILM(J,4)
DELTF=0.0
SPERCO=SPERCO+PERCO
LL=1, JIM
ZINF(LL)=ZINF(LL)+AINFIL(LL)
40
IRED=2
45
JI=1
JIM1=JIM-1
KZZ=1,14
COND(KZZ)=0.0
A

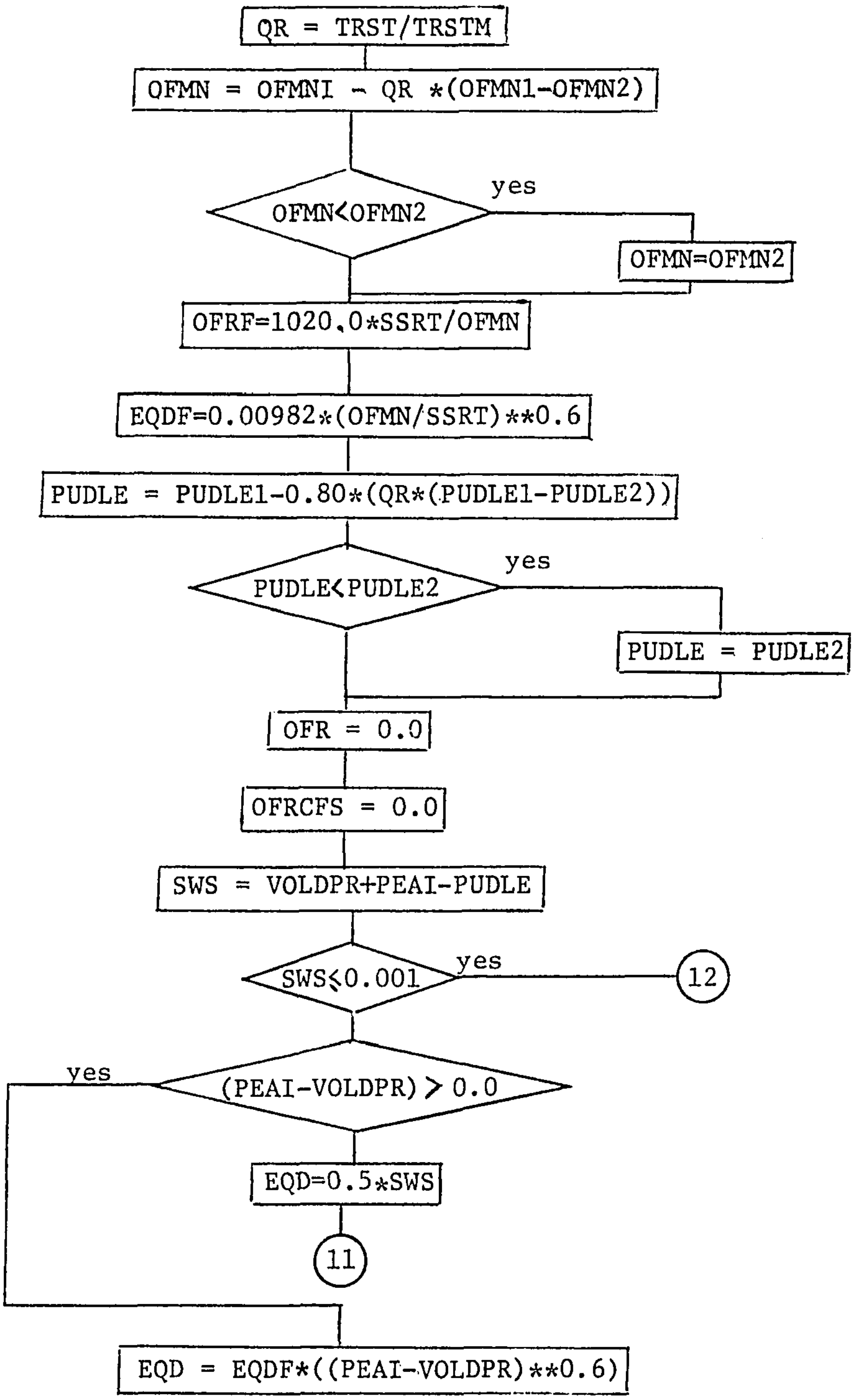

A
JI=1,JIM
JI=JIM
yes
CSMP=RESAT(JIM)/THICK(JIM)*100.0
CSMP=ESOILM(J,JI)/THICK(JI)*100.0
SR=CSMP/SAT(JI)
SR>0.90
yes
TENZ(JI)=AEWP(JI)*SR**(-SMTC(JI))
UHC(JI)=SHC(JI)*SR**(1.5*SMTC(JI)+3.0
SR>1.0
yes
TENZ(JI)=(10.0*SR-9.0)*AEWP(JI)*0.90**(-SMTC(JI))
UHC(JI)=SHC(JI)
TENZ(JI)=0.0
UHC(JI=SHC(JI)
JI=1,JIM1
TH2=THICK(JI)+THICK(JI+1)
THM=TH2*1.27
GRAD=(TENZ(JI+1)-TENZ(JI)+THM/THM
CON=UHC(JI+1)
UHC(JI)<CON
yes
CON=UHC(JI)
COND(JI)=CON*GRAD*DT*0.3937
B

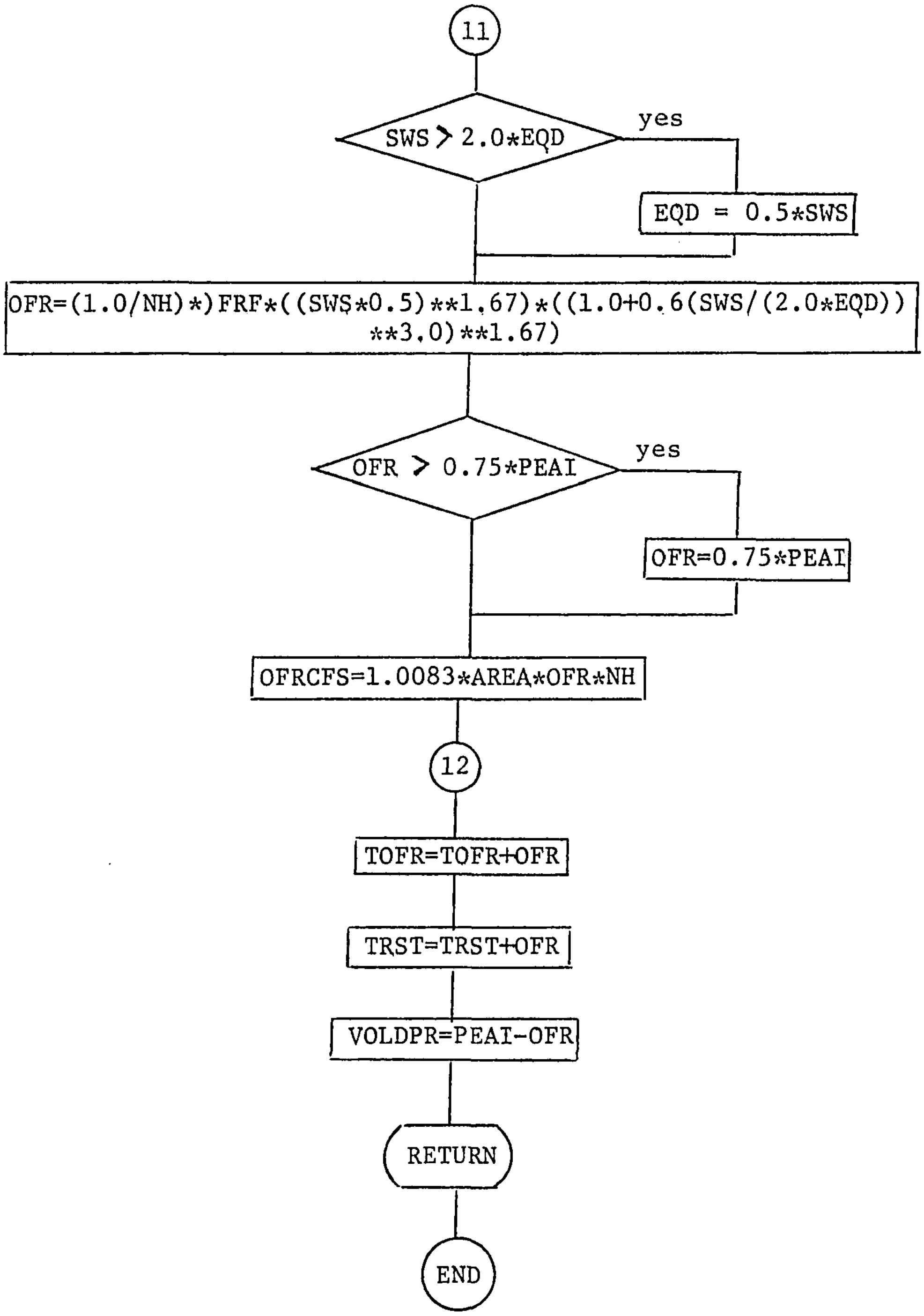

B
JIM2=JIM-2
JI=1,JJM2
COND(JI)<0.0
yes
CONMAX=ESOILM(J,JI)*0.50
CONMAX=ESOILM(J,JI+1)*(-0.5)
COND(JI)>CONMAX
yes
COND(JI)=CONMAX
COND(JI)<CONMAX
yes
CAND(JI)=CONMAX
ESOILM(J,JI)=ESOILM(J,J1)-COND(JI)
ESOILM(J,JI+1)=ESOILM(J,JI+L)+COND(JI)
yes
COND(JIM1)<0.0
CONMAX=ESOILM(J,JIM1)*0.50
COND(JIM1)>CONMAX
yes
COND(JIM1)=CONMAX
ESOILM(J,JIM1)=ESOILM(J,JIM1)-COND(JIM1)
PERCO=PERCO+COND(JIM1)
ZPERC=0.0
105


105
JI=1,JIM1
yes
RESAT(JI)≥ESOILM(J,JI)
ZPERC=SHC(JI+1)*DT*0.3937
EXT=ESOILM(J,JI)-RESAT(JI)
ZPERC>EXT
yes
ZPERC=EXT
ESOILM(J,JI)=ESOILM(J,JI)-ZPERC
JI=JIM1
yes
ESOILM(J,JI+1)=ESOILM(J,JI+1)+ZPERC
AINFIL(JI+1)=AINFIL(JI+1)+ZPERC
PERCO=PERCO+ZPERC
ZPERC=0.0
yes
140
KB=JIM1
115
EXTRA=ESOILM(J,KB)-ESAT(KB)
120
yes
EXTR>0.0
KB=KB-1
KB=0.0
yes
140

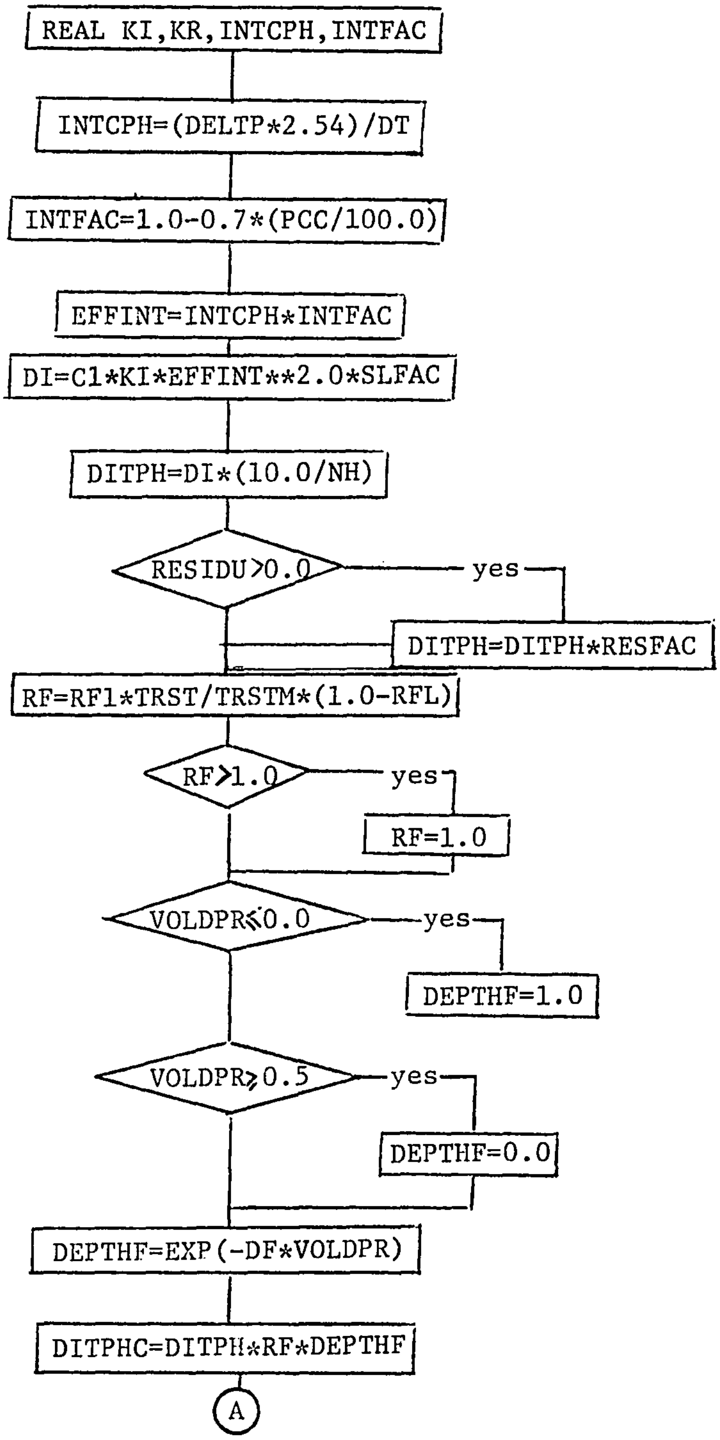

120
ESOILM(J,KB)=ESAT(KB)
KB=JTILE
yes
130
TILEQ=EXTRA*(-ALOG(TFRC**(DT/24.0)))
KB=KB-1
EXTRA=EXTRA-TILEQ
yes
KB=0.0
yes
EXTRA>0.0
125
ESOILM(J,KB)=ESOILM(J,KB)+EXTRA
115
TILEQ=TILEQ+EXTRA
EXTRA=0.0
VOLDPR=VOLDPR+EXTRA
KB=KB-1
KB=0.0
115
yes
140
SPERCO=SPERCO+PERCO
ADTF=ADTF+TILEQ
SMASM=TOTSTR-ESOILM(J,1)-ESOILM(J,2)-ESOILM(J,3)-ESOILM(J,4)
LL=1,JIM1
ZINF(LL)=ZINF(LL+AINFJL(LL)
ZOUTF(LL)=ZOUTF(LL)+COND(LL)
RETURN
END

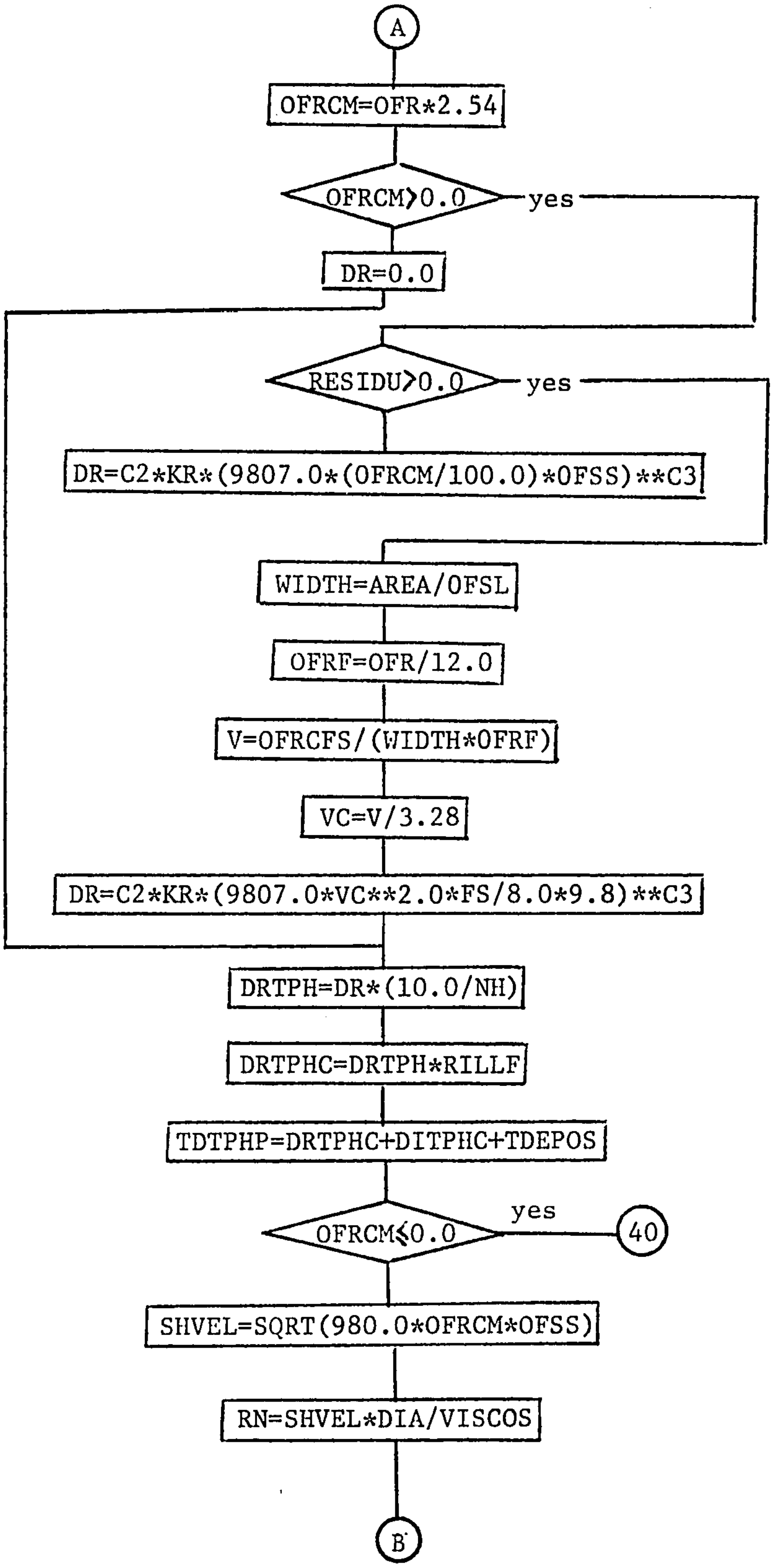
```
SUBROUTINE OFROUT(PEAI,VOLDPR,EQD,EQDF,OFR,TOFR,AREA
           OFMN,NH,QFRF,OFRCFS,PUDLE,TRST,TRSTM,OFMNI,
           OFMN2,SSRT,PUDLE1,PUDLE2)
```

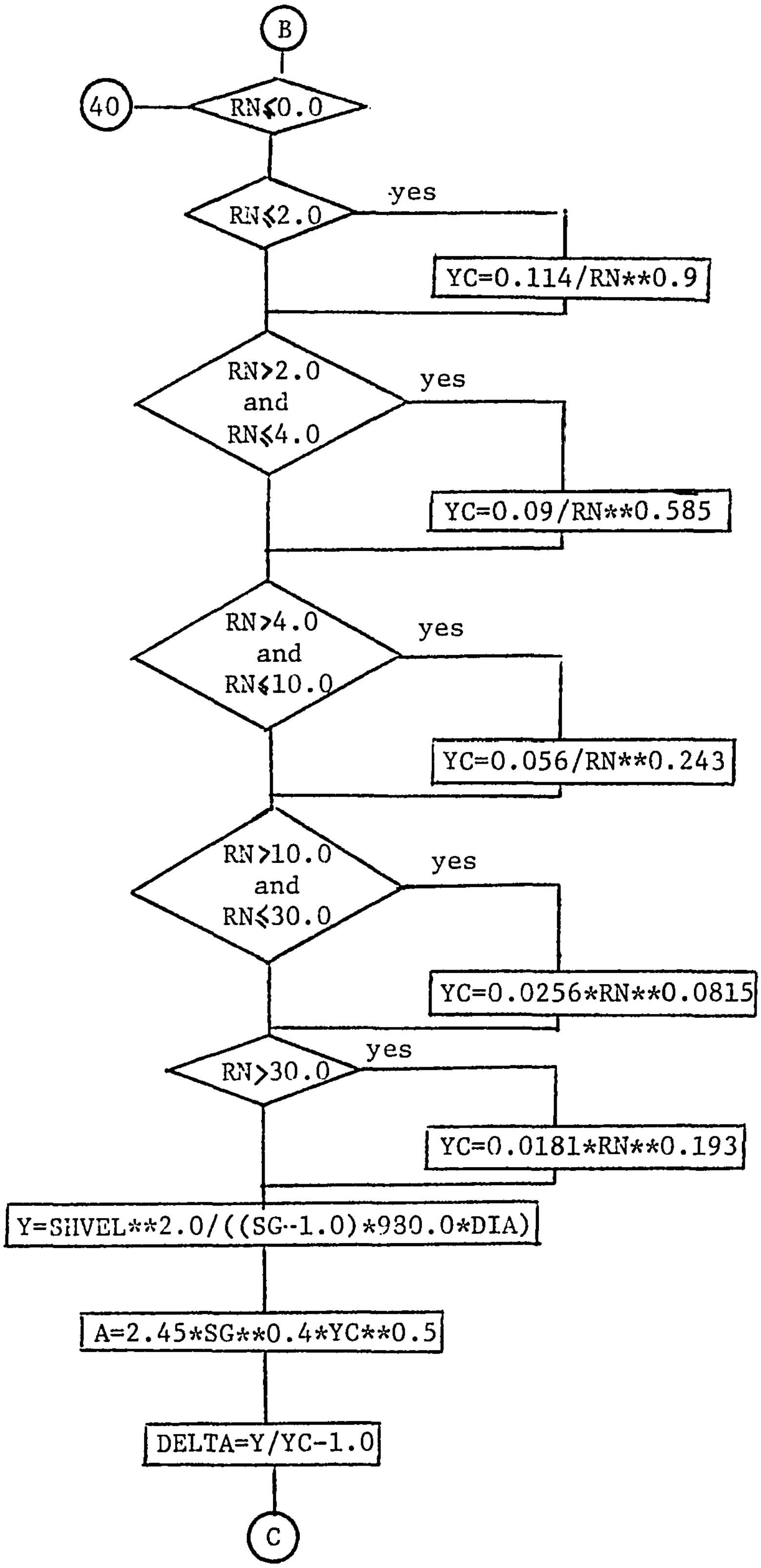


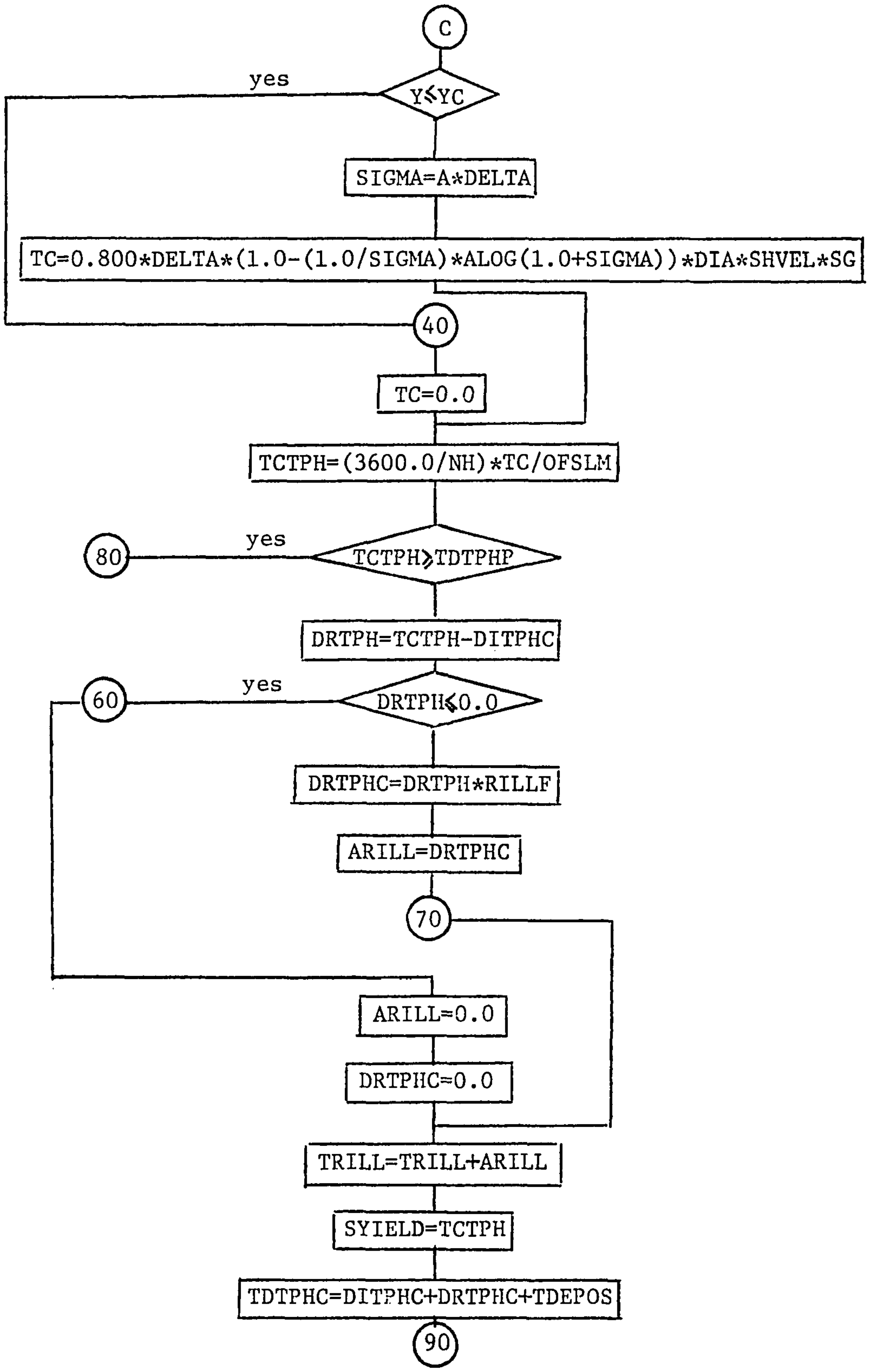

11
SWS > 2.0*EQD
yes
EQD = 0.5*SWS
OFR=(1.0/NH)*)FRF*((SWS*0.5)**1.67)*((1.0+0.6(SWS/(2.0*EQD))
3.0)1.67)
OFR > 0.75*PEAI
yes
OFR=0.75*PEAI
OFRCFS=1.0083*AREA*OFR*NH
12
TOFR=TOFR+OFR
TRST=TRST+OFR
VOLDPR=PEAI-OFR
RETURN
END

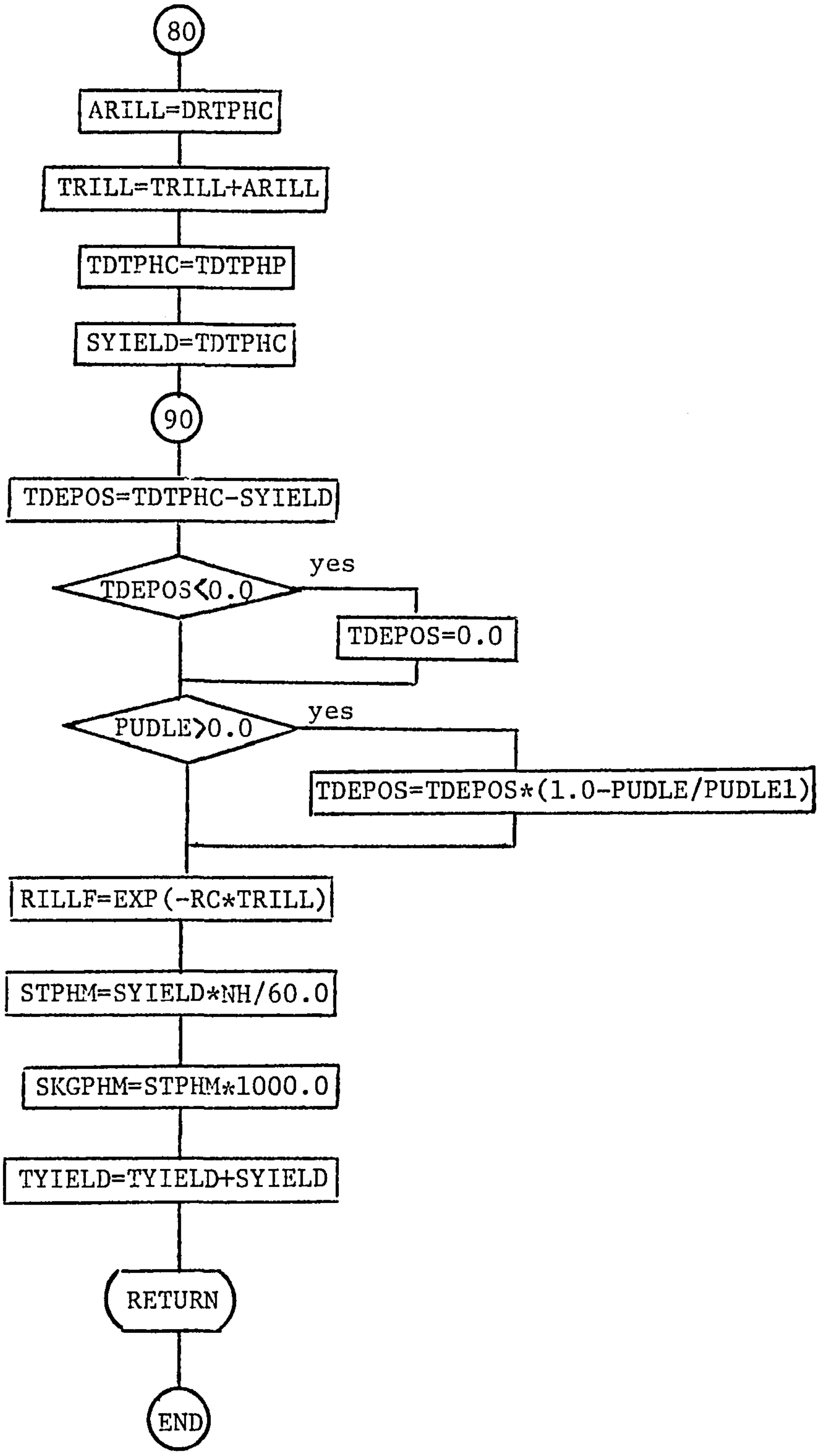
```
SUBROUTINE SEDYLD(DELTP,DT,NH,SLFAC,C1,C2,C3,KI,KR,RF1,TRST,
          TRSTM,OFR,OFRCFS,OFSS,OFSLM,RILLF,TRILL,WIDTH,FS,
          DIA,VISCOS,SG,SKGPHM,PUDLE,PUDLE1,PCC,RC,OFRCM,
          INTCPH,DITPH,DRTPH,TDTPHC,EFFINT,VOLDPR,DF)
```




A
OFRCM=OFR*2.54
OFRCM>0.0
yes
DR=0.0
RESIDU>0.0
yes
DR=C2*KR*(9807.0*(OFRCM/100.0)*OFSS)**C3
WIDTH=AREA/OFSL
OFRF=OFR/12.0
V=OFRCFS/(WIDTH*OFRF)
VC=V/3.28
DR=C2*KR*(9807.0*VC**2.0*FS/8.0*9.8)**C3
DRTPH=DR*(10.0/NH)
DRTPHC=DRTPH*RILLF
TDTPHP=DRTPHC+DITPHC+TDEPOS
OFRCM≤0.0
yes
40
SHVEL=SQRT(980.0*OFRCM*OFSS)
RN=SHVEL*DIA/VISCOS
B


B
40
RN≤0.0
RN≤2.0
yes
YC=0.114/RN**0.9
RN>2.0 and RN≤4.0
yes
YC=0.09/RN**0.585
RN>4.0 and RN≤10.0
yes
YC=0.056/RN**0.243
RN>10.0 and RN≤30.0
yes
YC=0.0256*RN**0.0815
RN>30.0
yes
YC=0.0181*RN**0.193
Y=SHVEL**2.0/((SG-1.0)*980.0*DIA)
A=2.45*SG**0.4*YC**0.5
DELTA=Y/YC-1.0
C


C
yes
Y≤YC
SIGMA=A*DELTA
TC=0.800*DELTA*(1.0-(1.0/SIGMA)*ALOG(1.0+SIGMA))*DIA*SHVEL*SG
40
TC=0.0
TCTPH=(3600.0/NH)*TC/OFSLM
80
yes
TCTPH≥TDTPHP
DRTPH=TCTPH-DITPHC
60
yes
DRTPH≤0.0
DRTPHC=DRTPH*RILLF
ARILL=DRTPHC
70
ARILL=0.0
DRTPHC=0.0
TRILL=TRILL+ARILL
SYIELD=TCTPH
TDTPHC=DITPHC+DRTPHC+TDEPOS
90


80
ARILL=DRTPHC
TRILL=TRILL+ARILL
TDTPHC=TDTPHP
SYIELD=TDTPHC
90
TDEPOS=TDTPHC-SYIELD
TDEPOS<0.0
yes
TDEPOS=0.0
PUDLE>0.0
yes
TDEPOS=TDEPOS*(1.0-PUDLE/PUDLE1)
RILLF=EXP(-RC*TRILL)
STPHM=SYIELD*NH/60.0
SKGPHM=STPHM*1000.0
TYIELD=TYIELD+SYIELD
RETURN
END

APPENDIX B:

PRINT OUT OF COMPUTER MODEL

```
C* ==================================================================
C*   THIS PROGRAM IS A MODEL OF HYDROLOGY,EROSION,AND SEDIMENT TRANSPOPT
C*   FOR A HOMOGENOUS AGRICULTURAL FIELD.  IT IS A MODIFICATION OF THE
C*   PROGRAM DEVELOPED BY C. E. ANDERSON FOR DEEP LOESS SOILS IN WESTERN
C*   IOWA AS DESCRIBED IN TRANSACTIONS OF THE ASAE,VOL. 21,NO. 2, PAGES
C*   314-320, 1978.  THE OVERLAND FLOW,EROSION AND SEDIMENT TRANSPORT
C*   COMPONENTS WERE ADDED
C*
C*             EBRAHIM SHAHGHASEMI
C*             DEPARTMENT OF AGRICULTURAL ENGINEERING
C*             IOWA STATE UNIVERSITY
C*            AMES IOWA 50010
C*             FEB.  18, 1980
C*   ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***
C*   ************* PARAMETER DEFINITION  ************                  *
C*                                                                     *
C*                                                                     *
C*   AAET = ACCUMULATED ACTUAL EVAPOTRANSPIRATION DEPTH (INCHES) SINCE
C*          THE BEGINNING OF THE YEAR, GROWING SEASON, OR OTHER
C*          CALCULATING PERIOD.
C* AAEVAP = ACCUMULATED DIRECT SOIL EVAPORATION (INCHES) FROM THE
C*          SURFACE SOIL LAYER SINCE THE BEGINNING OF THE YEAR OR OTHER
C*          CALCULATING PERIOD.
C*  AAINT = ACCUMULATED EVAPORATION FROM INTERCEPTION STORAGE
C*          SINCE THE BEGINNING OF THIS MODEL RUN. (INCHES)
C* AATRAN = ACCUMULATED ACTUAL TRANSPIRATION (INCHES) SINCE THE
C*          BEGINNING OF THIS MODEL RUN.
C*   ADET = CALCULATED ACTUAL DAILY EVAPOTRANSPIRATION (INCHES)
C*  ADINT = CALCULATED ACTUAL DAILY INTERCEPTION EVAPORATION (INCHES).
C*   ADTF = ACCUMULATED DAILY TILE FLOW IN INCHES
C*    AET = CALCULATED TOTAL EVAPOTRANSPIRATION (INCHES) DURING THIS
C*          PERIOD.
C*  AEVAP = CALCULATED DIRECT EVAPORATION FROM THE TOP LAYER OF
C*          SOIL DURING THE PERIOD (INCHES).
C*   AEWP = AIR ENTRY WATER POTENTIAL, CM.
```

```
C* AINFIL = INFILTRATION DEPTH TO EACH SOIL LAYER DURING A SINGLE
C*          CALCULATING PERIOD (INCHES) IN SUBROUTINE REDIST.
C*   AINT = CALCULATED EVAPORATION FROM INTERCEPTION STORAGE DURING
C*          THIS MODEL RUN (INCHES).
C*   ALAI = INPUT VARIABLE NAME FOR CLAI VALUES USED IN PLANT
C* ALBEDO = SURFACE REFLECTIONS OF SHORTWAVE RADIATION.
C*     AM = EXPONENT COEFFICIENT USED IN EQUATION TO CALCULATE ASOIL.
C*          SLOPE OF THE CURVE OF ASOIL VS AMC ON SEMI-LOG PAPER.
C*          WILL BE NEGATIVE.
C*    AMC = SOIL MOISTURE (% BY VOLUME) IN TOP LAYER USED TO CALCULATE
C*          ASOIL AND PSOIL.
C*    ANX = DUMMY VARIABLE NAME USED TO INPUT HOUR ON PRECIP DATA CARDS.
C*   APET = ACCUMULATED POTENTIAL EVAPORATION (INCHES) SINCE THE
C*          BEGINNING OF THE YEAR, GROWING SEASON, OR OTHER CALCULATING
C*          PERIOD.
C*   AREA = AREA OF THE WATERSHED,SQUARE FEET.
C*  ARILL = THE AMOUNT OF RILL EROSION WHICH IS ACTUALLY OCCURRED,
C*          T/HA
C*  ASOIL = SOIL PARAMETER IN THE INFILTRATION EQUATION WHICH
C*          REPRESENTS THE MAXIMUM INCREASE IN INFILTRATION CAPACITY
C*          OVER THE WET SOIL RATE.
C* ASOILM = MAXIMUM VALUE FOR ASOIL
C*   ASTF = ACCUMULATED SEASONAL TILE DRAINAGE FLOW (INCHES)
C* ATRANS = CALCULATED TRANSPIRATION FROM EACH SOIL LAYER DURING
C*          THE CALCULATING PERIOD. (INCHES)
C*    BNX = DUMMY VARIABLE NAME USED TO INPUT MINUTES FOR PRECIP
C*          DATA CARDS.
C*     C1 = A CONSTANT IN EXPRESSION TO CALCULATE INTERRILL EROSION
C*     C2 = A COEFFICIENT IN EXPRESSION TO CALCULATE RILL EROSION.
C*     C3 = AN EXPONENT USED IN EXPRESSION TO CALCULATE RILL EROSION.
C*   CARD = COUNTER USED TO DETERMINE THE NUMBER OF CARDS READ FOR
C*          PRECIPITATION DATA ON A PARTICULAR DAY.
C*   CLAI = CROP LEAF AREA INDEX.
C*  CLAIX = VALUE OF CLAI USED TO ADJUST ASOIL
C*    CNX = DUMMY VARIABLE NAME USED TO INPUT ACCUMULATED PRECIP.
```

```
C*           DATA ON PRECIP. CARDS.
C*    COND = CALCULATED AMOUNT OF SOIL MOISTURE MOVEMENT BETWEEN
C*           ADJACENT SOIL LAYERS DUE TO POTENTIAL GRADIENTS DURING ANY
C*           ONE CALCULATING PERIOD (INCHES).  A POSITIVE VALUE MEANS
C*           DOWNWARD MOVEMENT AND A NEGATIVE VALUE MEANS UPWARD
C*           MOVEMENT.
C*  DAEVAP = DAILY ACTUAL SOIL EVAPORATION TOTAL (INCHES)
C*   DAQEX = CALCULATED DAILY SUM OF SURFACE RUNOFF (INCHES).
C*    DAYT = DAY OF THE MONTH INPUT VALUE TO SUBROUTINE PRECIP TO
C*           IDENTIFY THE DATE OF A PARTICULAR RAINFALL EVENT.
C*  DDELTF = CALCULATED ACTUAL DAILY SUM OF INFILTRATION (INCHES).
C*     DDP = DIRECT PRECIPITATION ON THE SOIL SURFACE DURING A
C*           CALCULATION PERIOD IN INCHES.
C*   DELTF = INFILTRATION DEPTH DURING THE PRESENT CALCULATING PERIOD
C*           (INCHES).
C*   DELTP = TOTAL PRECIPITATION DURING THE PERIOD (INCHES).
C*   DELTQ = INCREMENT OF SURFACE RUNOFF DEPTH WHICH OCCURS DURING A
C*           PARTICULAR CALCULATING PERIOD. (INCHES)
C*  DEPTHF = A REDUCTION FACTOR RELATED TO THE EFFECT OF THE DEPTH OF
C*           OVERLAND FLOW WATER ON INTERRILL EROSION.
C*      DF = A DECAY COEFFICIENT IN EXPRESSION TO CALCULATE DEPTHF.
C*      DI = DETACHMENT BY RAINFALL(INTERRILL EROSION),KG/SQUARE METER.HR
C*     DIA = MEAN DIAMETER OF DETACHED PARTICLES,CM.
C*  DITPH  = DETACHMENT BY RAINFALL(INTERRILL EROSION),T/HA.
C*  DITPHC = DETACHMENT BY RAINFALL CORRECTED FOR SURFACE ROUGHNESS AND
C*           THE EFFECT OF SURFACE WATER DEPTH,T/HA.
C*    DLAI = INPUT VARIABLE NAME FOR THE JULIAN DAY NUMBER ASSOCIATED
C*           WITH INPUT CLAI VALUES TO PLANT.  PAIRED WITH ALAI VALUES.
C*     DOG = SLOPE OF SATURATION VAPOR PRESSURE-TEMPERATURE CURVE
C*           DIVIDED BY THE PSYCHROMETRIC CONSTANT.
C*  DPERCO = CALCULATED ACTUAL DAILY ACCUMULATED DEEP PERCOLATION TO
C*           OR FROM THE SUBSOIL  (INCHES).  A NEGATIVE VALUE
C*           OF DPERCO MEANS MOVEMENT HAS BEEN UPWARD FROM BELOW.
C*   DPINT = INTERCEPTION ON THE PLANT SURFACES DURING THE PRESENT
C*           CALCULATING PERIOD (INCHES).
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C* DPSTOR = MAXIMUM POTENTIAL DEPTH OF WATER IN STORAGE IN SURFACE
C*          DEPRESSIONS AT ANY TIME (INCHES).
C*     DR = DETACHMENT BY RUNOFF(RILL EROSION),KG/SQUARE METER.HR.
C*    DRI = DRAINAGE FROM INTERCEPTION STORAGE (INCHES)
C*  DRTPH = RILL EROSION, T/HA.
C* DRTPHC = RILL EROSION  CORRECTED FOR STABILIZATION OF RILLS,T/HA.
C*     DT = LENGTH OF THE CALCULATION PERIOD (HOURS).
C*     ED = ACTUAL VAPOR PRESSURE IN MILLIBARS.
C* EFFINT = EFFECTIVE INTENSITY TO BE USED IN ESTIMATING THE DETACHMENT
C*          BY RAINFALL.IT IS THE PRODUCT OF INTCPH AND INTFAC
C*   EPCM = EVAPORATION PAN COEFFICIENT FOR THE MONTH
C*    EQD = EQUILLIBRIUM DEPTH.SEE CRAWFORD AND LINSLEY,1966.
C*  EQDF  = EQUILLIBRIUM DEPTH FACTOR.SEE CRAWFORD AND LINSLEY,1966.
C*     ES = SATURATION VAPOR PRESSURE AT AIR TEMPERATURE TR IN
C*          MILLIBARS.
C*   ESAT = SATURATION WATER CONTENT IN EACH LAYER EXPRESSED IN INCHES.
C* ESOILM = ESTIMATED SOIL MOISTURE IN EACH SOIL LAYER FOR EACH
C*          DAY (INCHES).
C*     ET = SUBROUTINE NAME FOR CALCULATING ACTUAL EVAPOTRANSPIRATION
C* ETRATE = THE RATIO OF ACTUAL TO POTENTIAL TRANSPIRATION, INPUT
C*          VALUES FOR CURVES OF THIS RATIO VS. SOIL MOISTURE AND
C*          ATMOSPHERIC DEMAND.  (CURVES TAKEN FROM DENMEAD AND SHAW).
C*          RELATED TO SMET AND PAD AND USED IN SUBROUTINE ET.
C* EVAPTR = TOTAL WITHDRAWL BY EVAPORATION AND TRANSPIRATION FROM
C*          THE TOP TWO FEET OF SOIL DURING A CALCULATING PERIOD. (IN.)
C*     F1 = ACCUMULATED INFILTRATION AT THE START OF A CALCULATING
C*          PERIOD IN SUBROUTINE INFILT (INCHES).
C*     FC = FIELD CAPACITY (PERCENT BY VOLUME) OF EACH SOIL LAYER.
C* FCINFL = WET SOIL INFILTRATION CAPACITY (IN./HR.)
C*          FOR USE IN THE INFILTRATION SUBROUTINE.
C*    FCP = FIELD CAPACITY OF THE SURFACE LAYER (% BY VOLUME) FOR USE
C*          IN CALCULATING PSOIL.
C*    FCS = MAXIMUM VALUE OF AMC FOR WHICH ASOIL = ASOILM.  IN THE
C*          CURRENT VERSION OF THE PROGRAM SET AT FC(1).
C*     FS = SOIL FRICTION FACTOR,USED IN EXPRESSION TO CALCULATE RILL
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C*              EROSION IF ANY CROP RESIDUE IS AVAILABLE.
C*         G = SOIL HEAT FLUX IN LY/DAY ESTIMATED BY THE METHOD OF JENSEN,
C*              WRIGHT AND PRATT.
C*      GINT = FUNCTION NAME FOR THE X-Y PLOT INTERPOLATION.
C*     GINT2 = FUNCTION FOR INTERPOLATING ON A FAMILY OF CURVES.
C*      IBIG = INDEX TO INDICATE WHETHER WE ARE READING THE FIRST CARD OF
C*              RAINFALL DATA FOR A GIVEN DAY.
C*        IC = NUMBER OF THE CALCULATING PERIOD DURING A DAY IN WHICH
C*              RAINFALL OCCURS.  THERE WILL BE 24*NH SUCH PERIODS IN A DAY.
C*       ICC = INDICATOR OF LOWER BOUNDRY ON RANGE OF DAILY TIME INCREMENTS
C*              TO BE ADDED TO DETERMINE IF RAINFALL OCCURRED DURING A
C*              PARTICULAR PERIOD.
C*       ICR = UPPER BOUNDRY OF TIME PERIOD RELATED TO ICC.
C*      IERR = INDEX TO INDICATE WHEN SOME ERROR HAS BEEN DETECTED IN DATA
C*              INPUT OR CALCULATED VALUES IN A SUBROUTINE.  IERR = 0 MEANS
C*              ALL IS WELL.  IERR = 1 MEANS AN ERROR IS DETECTED AND
C*              PROGRAM EXECUTION SHOULD BE TERMINATED.
C*      INCI = INDEX TO INDICATE WHETHER IT IS THE FIRST OR SECOND CALL
C*              OF SUBROUTINE INTCPT DURING THE CALCULATION PERIOD.
C*    INFILT = NAME OF SUBROUTINE TO CALCULATE INFILTRATION.
C*    INTCPT = SUBROUTINE NAME FOR COMPUTING INTERCEPTION.
C*    INTCPH = INTENSITY OF RAINFALL,CM/HR.
C*    INTFAC = A FACTOR TO BE MULTIPLIED BY INTCPH TO OBTAIN THE EFFECTIVE
C*              INTENSITY(EFFINT).
C*      IRED = INDEX TO INDICATE WHETHER THIS IS THE FIRST OR SECOND
C*              ENTRY INTO SUBROUTINE REDIST FOR THIS CALCULATING PERIOD.
C*       IRT = JULIAN DAY NUMBER ON WHICH NEW ROOT SYSTEM DISTRIBUTION
C*              BECOMES EFFECTIVE.  INPUT DAY VALUES FOR ROOT SYSTEM
C*              DEVELOPMENT DATA.
C*        JI = INDEX NUMBER FOR EACH SOIL LAYER STARTING WITH JI = 1 FOR
C*              THE TOP  SOIL LAYER  AND ENDING WITH JI=JIM FOR THE SUBSOIL.
C*       JIM = NUMBER OF SOIL LAYERS BEING SIMULATED
C*      JIM1 = NUMBER OF SOIL LAYERS ABOVE THE BOTTOM LAYER (= JIM - 1).
C*        JJ = CUMULATIVE NUMBER OF DAYS FROM THE BEGINNING OF THE YEAR.
C*       JJR = JULIAN DAY OF LATEST PRECIP. DATA CARD READ.  USED TO
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C*            COMPARE WITH PRESENT DAY NUMBER DURING SIMULATION TO
C*            INITIATE READING AND PROCESSING DATA ON DAYS WHEN
C*            RAINFALL OCCURS.
C*    JJR1 =  VALUE OF JJR SAVED TO CHECK DATES ON REMAINING PRECIP.
C*            CARDS READ FOR A GIVEN DAY.
C*    JOUT =  JULIAN DAY OF THE YEAR WHEN DETAILED OUTPUT IS REQUESTED.
C*            UP TO 20 DIFFERENT DAYS MAY BE SPECIFIED IN THIS ARRAY.
C*            THESE ARE GENERALLY CHOSEN AS DAYS ON WHICH PRECIP OCCURRED,
C*            OR DAYS ON WHICH SOIL MOISTURE MEASURMENTS WERE TAKEN WHICH
C*            ARE BEING USED FOR COMPARISON WITH MODEL SIMULATION DATA.
C* JSTART =  DAY OF THE YEAR (1 - 365) WHEN THE PROGRAM IS TO BEGIN.
C*  JSTOP =  DAY OF THE YEAR WHEN THE PROGRAM IS TO END CALCULATIONS
C*  JTILE =  NUMBER OF THE SOIL LAYER IN WHICH TILE IS LOCATED
C*  JTILL =  JULIAN DAY OF THE YEAR WHEN TILLAGE OR CULTIVATION IS
C*            OCCURRED
C*     KDA =  TOTAL ACCUMULATED DAYS IN THE YEAR TO THE BEGINNING OF A
C*            MONTH.
C*   KEVAP =  INPUT INDICATOR FOR METHOD OF DETERMINING POTENTIAL ET
C*            IF KEVAP = 0 INPUT IS DATA FOR PENMAN EQUATION
C*            IF KEVAP = 1 INPUT IS PAN EVAPORATION DATA
C*      KI =  SOIL ERODIBILITY FACTOR FOR DETACHMENT BY RAINDROP IMPACT,
C*            KG.HR/N.SQURE METER.
C*    KMOT =  INPUT MONTH NUMBER FOR THE DATE OF A PARTICULAR STORM EVENT
C*            TO SUBROUTINE PRECIP.
C*      KR =  SOIL ERODIBILITY FACTOR FOR DETACHMENT BY RUNOFF,
C*            KG.HR/N.SQURE METER.
C*    KSMA =  INDICATOR OF SOIL MOISTURE AVAILABILITY FUNCTION USED
C*            IF KSMA = 0 SHAW'S CURVES WILL BE USED.
C*            IF KSMA = 1 ALL MOISTURE WILL BE AVAILABLE ABOVE 50% OF
C*            TOTAL HOLDING CAPACITY BETWEEN FC AND WP, AND A LINEARLY
C*            DECREASING AVAILABILITY WILL BE USED BETWEEN 50% AND THE
C*            WILTING POINT.
C*     MON =  DUMMY INPUT VARIABLE NAME FOR MONTH ON PRECIP DATA CARDS
C*   MONTH =  ALPHABETIC VARIABLE TO OUTPUT THE MONTH WHEN WRITING OUT
C*            DATES.
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C*      NC = NUMBER OF CURVES USED TO DESCRIBE THE ACTUAL ET, POTENTIAL
C*           ET, SOIL MOISTURE RELATIONSHIP (SHAW'S CURVES).
C*     NDA = DUMMY INPUT VARIABLE FOR DAY ON PRECIP DATA CARDS.
C*      NH = NUMBER OF PERIODS INTO WHICH AN HOUR IS DIVIDED FOR
C*           CALCULATING DURING A RAINFALL EVENT.
C*    NOUT = INDICATOR CALCULATED BY PROGRAM TO PRODUCE DETAILED OUTPUT
C*           ON DAYS WHEN PRECIP OCCURS OR WHEN MEASURED SOIL MOISTURE
C*           DATA IS AVAILABLE FOR COMPARISON.
C*     NPC = NUMBER OF POINTS PER CURVE IN SHAWS RELATIONSHIP.
C*   NRTDS = THE ROOT ACTIVITY IN EACH LAYER EXPRESSED AS A PERCENT OF
C*           THE TOTAL ROOT ACTIVITY IN THE ROOT ZONE.
C*     NYR = DUMMY VARIABLE FOR INPUT OF YEAR ON PRECIP DATA CARDS.
C*    OFMN = ROUGHNESS COEFFICIENT IN MANNING'S EQUATION.
C*   OFMN1 = MAXIMUM ROUGHNESS COEFFICIENT IN MANNING'S EQUATION.VALUE OF
C*           OFMN IMMEDIATELY AFTER TILLAGE WHEN TRST=0.0.
C*   OFMN2 = MINIMUM ROUGHNESS COEFFICIENT IN MANNING'S EQUATION.VALUE OF
C*           OFMN WHEN TRST>TRSTM.
C*     OFR = OVERLAND FLOW RUNOFF DEPTH,INCHES.
C*  OFRCFS = OVERLAND FLOW RUNOFF RATE,C.F.S.
C*   OFRCM = DEPTH OF OVERLAND FLOW RUNOFF,CENTIMETERS.
C*   OFRF  = OVERLAND FLOW RUNOFF FACTOR.SEE CRAWFORD AND LINSLEY,1966.
C*   OFSLM = AVERAGE OVERLAND FLOW SLOPE LENGTH,METERS.
C*    OFSS = SLOPE STEEPNESS OF THE SOIL SURFACE,PERCENT.
C*     PAD = POTENTIAL ATMOSPHERIC DEMAND, INPUT DATA OF VALUES OF
C*           POTENTIAL DAILY EVAPORATION FOR CURVES OF SOIL MOISTURE VS.
C*           THE RATIO OF ACTUAL TO POTENTIAL TRANSPIRATION (AFTER SHAW).
C*           RELATED TO SMET AND ETRATE AND USED IN SUBROUTINE ET.
C*     PAN = DAILY EVAPORATION PAN INPUT DATA (INCHES)
C*  PCATRN = THE DECIMAL FRACTION OF THE PLANT CANOPY WHICH IS
C*           ACTIVELY TRANSPIRING AT ANY TIME PERIOD.  USED TO DETERMINE
C*           ACTUAL TRANSPIRATION IN SUBROUTINE ET.  THE VALUE IS
C*           DETERMINED IN SUBROUTINE PLANT.
C*     PCC = PERCENT CANOPY COVER.
C*     PCT = INPUT VALUES OF PERCENT CANOPY ACTIVELY TRANSPIRING
C*           CURVE FOR USE IN PLANT.  PAIRED WITH VALUES OF TJ
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C*      PE = POTENTIAL EVAPORATION RATE IN INCHES PER DAY.
C*    PEAI = PRECIPITATION EXCESS AFTER INFILTRATION,INCHES.
C*   PERCO = DEPTH OF WATER PERCOLATING TO OR FROM THE BOTTOM SOIL
C*           LAYER DURING THE CALCULATING PERIOD (INCHES). A NEGATIVE
C*           VALUE INDICATES UPWARD MOVEMENT OF SOIL MOISTURE.
C*     PET = POTENTIAL EVAPORATION VALUES IN INCHES FOR EACH FOUR-HOUR
C*           PERIOD IN THE DAY.
C*   PEVAP = SUBROUTINE NAME FOR COMPUTING POTENTIAL EVAPORATION.
C*   PIMAX = MAXIMUM POTENTIAL PLANT INTERCEPTION (INCHES).
C*   PIMIN = MINIMUM PLANT INTERCEPTION DEPTH THAT CAN BE REACHED BY
C*           DRAINAGE DOWN THE STEMS AND FALL THROUGH.
C*   PLANT = SUBROUTINE NAME FOR DETERMINING PLANT SYSTEM FUNCTIONS
C*      PM = SLOPE OF THE PSOIL VS AMC CURVE ON LOG-LOG PAPER.
C*           EXPONENT USED IN EQUATION TO CALCULATE PSOIL.
C* PRECIP = SUBROUTINE TO CONVERT BREAK-POINT RECORDING RAIN GAUGE
C*           DATA TO EVEN-TIME INTERVAL INCREMENTS FOR USE IN PROGRAM.
C*    PSFC = VALUE OF PSOIL AT THE FIELD CAPACITY OF THE SURFACE LAYER.
C*           USED IN THE EQUATION TO CALCULATE PSOIL.
C*   PSOIL = SOIL PARAMETER IN THE INFILTRATION EQUATION WHICH
C*           REPRESENTS THE RATE OF DECREASE OF INFILTRATION CAPACITY
C*           WITH INCREASED SOIL MOISTURE.
C*   PUDLE = DEPTH OF SURFACE RUNOFF HELD BY PUDDLES AT ANY TIME DURING
C*           RAINFALL RUNOFF EVENT.INCHES.
C* PUDLE1 = INITIAL VALUE OF PUDLE.VALUE OF PUDLE IMMEDIATELY AFTER
C*           TILLAGE WHEN TRST=0.0
C* PUDLE2 = FINAL VALUE OF PUDLE.VALUE OF PUDLE WHEN TRST>TRSTM.
C* QEXCES = ACCUMULATED SURFACE RUNOFF DEPTH (INCHES) SINCE THE
C*           BEGINNING OF THIS MODEL RUN.
C*    RAIN = TOTAL RAINFALL FOR THE 24-HR PERIOD ON ONE CALANDAR DAY.
C*           CALCULATED FROM RECORDED PRECIP DATA IN SUBROUTINE PRECIP.
C*      RB = NET OUTGOING LONGWAVE RADIATION IN LY/ DAY.
C*     RBO = MAXIMUM VALUE OF NET OUTGOING LONGWAVE RADIATION IN LY/DAY.
C*      RC = A DECAY CONSTANT USED IN EXPRESSION TO CALCULATE THE RILLF.
C* REDIST = SUBROUTINE NAME FOR CALCULATING SOIL MOISTURE MOVEMENT.
C*   RESAT = MOISTURE LEVEL AT WHICH IMMEDIATE FREE DRAINAGE TO LOWER
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C*           SOIL LAYERS OCCURS.  TAKEN AS 0.8*SAT.
C* RESFAC =  A REDUCTION FACTOR DUE TO CROP RESIDUE TO BE USED IN INTERR-
C*           ILL EROSION.
C* RESIDU =  AMOUNT OF CROP RESIDUE LEFT ON THE SOIL,TONS/HA.
C*     RF =  ROUGHNESS FACTOR.REPRESENTING THE EFFECT OF TILLAGE ON
C*           INTERRILL TRANSPORT CAPACITY.
C*    RF1 =  INITIAL ROUGHNESS FACTOR.THE ROUGHNESS FACTOR TO BE USED
C*           IMMEDIATELY AFTER TILLAGE.
C*     RH =  AVERAGE RELATIVE HUMIDITY FOR THE DAY (PERCENT).
C*  RHMAX =  MAXIMUM VALUE OF RELATIVE HUMIDITY RECORDED FOR ANY DAY
C*           (PERCENT).
C*  RHMIN =  MINIMUM RECORDED VALUE OF RELATIVE HUMIDITY FOR ANY DAY
C*           (PERCENT).
C*  RILLF =  A FACTOR REPRESENTING RILL STABILIZATION.
C*     RN =  NET RADIATION IN LY/DAY.
C*     RN =  PARTICLES REYNOLD'S NUMBER TO BE USED WITH SHIELD'S DIAGRAM
C*           TO CALCULATE TRANSPORT CAPACITY.
C*  ROOTS =  INPUT VALUES FOR THE ROOT SYSTEM DEVELOPMENT IN
C*           EACH LAYER (NRTDS) FOR VARIOUS PERIODS OF THE YEAR.
C*           PAIRED WITH VALUES OF IRT.
C*     RS =  DAILY SOLAR RADIATION (LANGLEYS).
C*    RSO =  MAXIMUM POTENTIAL CLEAR DAY SOLAR RADIATION FOR THE DAY
C*           IN LY.
C*   RSUM =  SUM OF PRECIPITATION OCCURING DURING A PERIOD.  USED TO
C*           DETERMINE WHEN A SHORTER TIME INTERVAL IS REQUIRED IN
C*           SIMULATION.
C*    SAT =  MOISTURE CONTENT OF EACH SOIL LAYER AT SATURATION (PERCENT
C*           BY VOLUME).
C* SDELTF =  ACCUMULATED SOIL INFILTRATION DEPTH (INCHES) SINCE THE
C*           BEGINNING OF THE YEAR, GROWING SEASON OR OTHER CALCULATING
C*           PERIOD.
C*     SG =  SPECIFIC GRAVITY OF DETACHED PARTICLES.
C*    SHC =  SATURATED HYDRAULIC CONDUCTIVITY OF A LAYER , CM/HR
C*  SHVEL =  SHEAR VELOCITY OF OVERLAND FLOW,CM/SEC.
C* SLFAC  =  SLOPE FACTOR.IT IS A FACTOR REPRESENTING THE EFFECT OF SLOPE
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C*           STEEPNESS ON INTERRILL EROSION.
C* SKGPHM = SEDIMENT YIELD,KG/HA.MIN.
C*  SMASM = TOTAL REMAINING UNUSED WATER STORAGE CAPACITY IN THE TOP
C*           4 LAYERS OF SOIL (INCHES).
C*   SMET = SOIL MOISTURE VALUE (PERCENT BY VOLUME) EXPRESSED AS A
C*           DECIMAL BETWEEN 0. AND 1. INPUT VALUES FOR RELATIONSHIP
C*           BETWEEN THE RATIO OF ACTUAL TO POTENTIAL TRANSPIRATION, THE
C*           SOIL MOISTURE, AND THE ATMOSPHERIC DEMAND.  RELATED TO PAD
C*           AND ETRATE.  USED IN SUBROUTINE ET.
C*   SMTC = SLOPE OF THE MOISTURE TENSION CURVE ON LOG-LOG PAPER
C* SPERCO = ACCUMULATED DEEP PERCOLATION DEPTH (INCHES) SINCE THE
C*  STPHM = SEDIMENT YIELD,T/HA.MIN.
C* SUMLAY = SIMULATED SOIL MOISTURE IN EACH FOOT OF THE TOP 5-FEET.
C*           (INCHES)
C*   SUM5 = TOTAL SIMULATED SOIL MOISTURE (INCHES) IN TOP 5-FEET.
C*   SUM9 = TOTAL SIMULATED SOIL MOISTURE (INCHES) IN TOP 9-FEET.
C* SUMTRN = CALCULATED ACTUAL DAILY SUM OF TRANSPIRATION FROM ALL
C*           SOIL LAYERS.
C* SYIELD = SEDIMENT YIELD. THE AMOUNT OF SEDIMENT AT THE OUTLET OF THE
C*           WATERSHED,T/HA.
C*      T = AVERAGE DAILY AIR TEMPERATURE IN DEGREES F.
C*     TC = AVERAGE DAILY AIR TEMPERATURE IN DEGREES C.
C*     TC = TRANSPORT CAPACITY OF OVERLAND FLOW,GM/CM.SEC.
C*  TCTPH = TRANSPORT CAPACITY OF OVERLAND FLOW,T/HA.
C* TDTPHC = TOTAL DETACHMENT CORRECTED FOR THE ACTUALL RILL EROSION
C*           WHICH IS OCCURRED,T/HA.
C* TDEPOS = TOTAL AVAILABLE DEPOSITED MATERIAL AT ANY TIME,T/HA.
C* TDTPHP = TOTAL DETACHMENT WHICH POTENTIALLY WOULD BE AVAILABLE(CONSI-
C*           DRING EFFECTS OF REDUCTION FACTORS BOTH FOR RILL AND INTERR-
C*           ILL EROSION),T/HA.
C*   TENZ = SOIL WATER POTENTIAL IN EACH SOIL LAYER AT THE TIME OF
C*           CALCULATION OF SOIL MOISTURE REDISTRIBUTION (CM. WATER).
C* TESTIN = TOLERANCE FACTOR USED TO TERMINATE THE ITERATIVE PROCEDURE
C*           IN SUBROUTINE INFILT.
C*  THICK = THICKNESS OF A LAYER OF SOIL IN INCHES
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C*    TFRC = TILE FLOW RECESSION CONSTANT
C*   TILEQ = TILE OUTFLOW DURING A PERIOD IN INCHES
C*    TIME = HOUR OF BEGINNING OF A CALCULATING PERIOD.
C*           USED TO CHECK FOR INITIATION OF PRECIPITATION.
C*   TITLE = VARIABLE NAME USED TO INPUT TITLES TO BE PRINTED AT THE
C*           TOP OF OUTPUT DATA.
C*      TJ = JULIAN DAY COORDINATE VECTOR FOR CROP CANOPY ACTIVELY
C*           TRANSPIRING (PCATRN) INPUT DATA. PAIRED WITH VALUES OF
C*           PCT.
C*     TK1 = MINIMUM DAILY AIR TEMPERATURE EXPRESSED AS DEGREES K/100.0.
C*     TK2 = MAXIMUM DAILY AIR TEMPERATURE EXPRESSED AS DEGREES K/100.0.
C*    TMAX = MAXIMUM DAILY AIR TEMPERATURE IN DEGREES F.
C*    TMIN = MINIMUM DAILY AIR TEMPERATURE IN DEGREES F.
C*    TOFR = TOTAL OVERLAND FLOW RUNOFF FROM THE BEGINNING OF THE SEASON,
C*           INCHES.
C*  TOTSTR = TOTAL SOIL MOISTURE STORAGE CAPACITY IN THE TOP 4 SOIL
C*           LAYERS (INCHES). SET AT 80% OF SATURATION IN PRESENT PROGRAM
C*   TPAST = AVERAGE AIR TEMPERATURE FOR THE PREVIOUS 3 DAYS IN
C*           DEGREES F.
C*   TPINT = TOTAL DEPTH OF WATER IN INTERCEPTION STORAGE AT ANY TIME
C*           (INCHES).
C*      TR = AVERAGE DAILY AIR TEMPERATURE IN DEGREES R.
C*   TRILL = ACCUMULATED RILL EROSION SINCE LAST TILLAGE,T/HA.
C*    TRST = VOLUME OF RUNOFF SINCE LAST TILLAGE,INCHES.
C*   TRSTM = MAXIMUM VALUE OF RUNOFF WATER REQUIRED TO REDUCE THE PUDDLES
C*           CREATED BY TILLAGE TO ITS MINIMUM VALUE,INCHES.
C*  TSTART = TIME OF DAY (HOUR) WHEN RAINFALL FIRST OCCURRED.
C*   TSTOP = TIME OF DAY WHEN LAST RAINFALL HAS ENDED (HOUR).
C*  TYIELD = ACCUMULATED SEDIMENT YIELD FROM THE BEGINNING OF THE GROWING
C*           SEASON.T/HA.
C*       V = AVERAGE VELOCITY OF OVERLAND FLOW WATER,LT/SEC.
C*      VC = AVERAGE VELOCITY OF OVERLAND FLOW WATER,M/SEC.
C*  VISCOS = KINEMATIC VISCOSITY OF OVERLAND FLOW WATER,SQUARE CM/SEC.
C*  VOLDPR = DEPTH OF WATER ACTUALLY IN STORAGE IN SURFACE DEPRESSIONS
C*           AT ANY ONE TIME (INCHES).
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C*        W = TOTAL DAILY WIND TRAVEL IN MILES IN SUBROUTINE PEVAP.
C*    WIDTH = AVERAGE WIDTH OF THE WATERSHED,FEET.
C*     WIND = INPUT VALUE OF WIND MOVEMENT (MILES PER DAY) FOR EACH DAY.
C*       WP = WILTING POINT OF EACH SOIL LAYER EXPRESSED AS PERCENT
C*            VOLUME.
C*       YC = CRITICAL SHEAR STRESS OF OVERLAND FLOW,DIMMENSIONLESS.
C*     YEAR = ALPHANUMERIC VARIABLE NAME USED TO READ IN THE YEAR FOR
C*            PRINTOUT OF DATES.
C*     ZINF = ACCUMULATED INFILTRATION TO EACH SOIL LAYER DURING A DAY
C*            (INCHES).
C*    ZOUTF = ACCUMULATED OUTFLOW FROM EACH SOIL LAYER FOR EACH DAY AS
C*            UNSATURATED WATER MOVEMENT DUE TO MOISTURE POTENTIAL
C*            GRADIENTS.  A NEGATIVE VALUE OF THIS VARIABLE MEANS FLOW
C*            WAS INTO THE LAYER.
C*    ZTRAN = ACCUMULATED DAILY TRANSPIRATION FROM EACH SOIL LAYER
C*            (INCHES).
C*
C*
C*     ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*     ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      COMMON/ABLOCK/ESOILM(365,15),WP(15),RESAT(15),ESAT(15),
     1SMET(16),PAD(6),ETRATE(16,6),FC(15),SHC(15),THICK(15)
      INTEGER DAYT,CARD
      REAL NRTDS(14),ALAI(12),DLAI(12),TJ(12),PCT(12)
      REAL*8 MONTH(12)
      REAL KI,KR,INTCPH,INTFAC
      DIMENSION ROOTS(14,10),IRT(10),PAN(365),EPCM(12),JTILL(5)
      DIMENSION MON(10),NDA(10),NYR(10),ANX(10,7),BNX(10,7),CNX(10,7),
     1TITLE(20),AEWP(15),SMTC(15),JOUT(20),SUMLAY(5),RS(365),TMAX(365),T
     2MIN(365),RHMAX(365),RHMIN(365),SAT(15),ZINF(14),COND(14),ZOUTF(14)
     3,ZTRAN(14),KDA(13),WIND(365),DELTP(800),PET(6),ATRANS(14)
      DATA  MONTH/'JANUARY ','FEBRUARY','MARCH   ','APRIL   ','MAY     '
     1,'JUNE    ','JULY    ','AUGUST  ','SEPTEMBR','OCTOBER ','NOVEMBER'
     2,'DECEMBER'/
      DATA KDA/0,31,59,90,120,151,181,212,243,273,304,334,365/
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   2 FORMAT(16F5.2)
   3 FORMAT(10X,10F7.3)
   4 FORMAT(A4,2I5)
   7 FORMAT(8F10.3)
   8 FORMAT(1H-//2X,I3,6X,A8,I3,',',A4)
   9 FORMAT(20I4)
  10 FORMAT(I3,2X,15F5.2)
  11 FORMAT(I3,F10.5)
  20 FORMAT(4X,3I3,7(F3.0,F2.0,F4.2))
  30 FORMAT(20A4)
  31 FORMAT(1H1,7X,20A4)
  32 FORMAT(11X,'TOTAL POTENTIAL STORAGE IN THE TOP TWO FEET = ',F5.2,
    1' INCHES')
  33 FORMAT(1H ,10X,'METEOROLOGICAL DATA FOR TODAY'/10X,'MAXIMUM AIR TE
    1MP. = ',F5.1,' DEG. F., MIN. = ',F4.1,' DEG. F.'/10X,'DAILY SOLAR
    2RADIATION = ',F6.1,' LANGLEYS'/10X,'MAXIMUM REL. HUMIDITY =',F5.1,
    3' PCT., MIN. RH.=',F5.1,' PCT.'/10X,'TOTAL DAILY WIND TRAVEL = ',
    4F7.2,' MILES')
  34 FORMAT(1H0,20X,'INITIAL SOIL MOISTURE DATA'//1X,'LAYER  THICK   SA
    1T    SHC    AEWP    SMTC      FC      WP     ESAT  RESAT  ESOILM'/7X,
    2'INCHES PERCENT CM/HR   CM',12X,'PCT.    PCT.  INCHES INCHES INCHES
    3'/14X,'BY VOL.',22X,'BY VOL BY VOL.'//(2X,I2,3X,F5.2,3X,F4.1,3X,F4
    4.2,2X,F5.2,2X,F5.2,1X,F6.2,2X,F6.2,1X,F5.2,2X,F5.2,3X,F5.2))
  35 FORMAT(10X,'PAN EVAPORATION FOR TODAY =',F7.3,' INCHES')
  36 FORMAT(8X,20A4)
  37 FORMAT(1H0,5X,'DRAIN TUBE IN LAYER',I3/5X,
    $'TILE FLOW RECESSION CONSTANT =',F7.4/)
  38 FORMAT(1H0,3X,'FIELD AREA =',F8.2,' ACRES.  AVERAGE FIELD SLOPE ='
    1,F8.4/4X,'SLOPE LENGTH =',F7.1,' FEET.  SURFACE ROUGHNESS COEFFICI
    2ENT =',2F7.3/4X,'TRSTM = ',F6.3,2X,'SMALLEST TIME INTERVAL USED =
    31/',I2,'TH  OF AN HOUR')
 381  FORMAT(' ',3X,'SURFACE  STORAGE=',2F7.3)
  39 FORMAT(11X,'WET SOIL INFILTRATION CAPACITY = ',F5.3,' IN./HR.')
  40 FORMAT(11X,'ASOIL = ',F7.3,5X,'PSOIL = ',F5.3,3X,'AMC = ',F7.3,
    1' PERCENT')
```

```
   41 FORMAT(1H0,40X,'PAD'/19X,6F8.3/12X,'SMET',23X,'ETRATE')
   42 FORMAT(11X,7F8.3)
   43 FORMAT(1H0,5X,'SOIL MOISTURE CONSIDERED 100 PERCENT USABLE BETWEEN
     1 100 AND 50 PERCENT OF AVAILABLE,'/
     2 6X,'AND LINEARLY DECREASING USABILITY BETWEEN 50 AND 0 PERCENT'/
     3 6X,'OF AVAILABLE'/)
   45 FORMAT(1H-,11X,'CURVE DATA FOR DENMEAD AND SHAW TYPE CURVES')
   46 FORMAT(1H0,11X,'DATA FOR INFILTRATION PARAMETERS')
   47 FORMAT(1H0,5X,'ASOILM=',F6.3,' AM=',F6.3,' PSFC=',F6.3,' PM=',
     1F6.3/5X,'CE1 = ',F6.3,'  CE2 = ',F6.3/)
 50   FORMAT(1H0,16X,'RUNOFF',5X,'TRANSPORT',4X,'TOTAL',6X,'SEDIMENT',5X
     1,'TOTAL'/8X,'TIME',5X,'RATE',7X,'CAPACITY',3X,'DETACHMENT',4X,'YIE
     2LD',5X,'SED.YIELD'/8X,'HR MI',4X,'C.F.S',8X,'T/HA',8X,'T/HA',6X,
     3'KG/HA.MIN',5X,'T/HA'/)
 51   FORMAT(' ',6X,2F3.0,3X,2(F7.3,5X),F7.3,4X,F9.3,4X,F7.3)
 53   FORMAT(1H0,3X,'KI=',F5.3,'KG.HR/N.M.M  KR=',F5.3,'KG.HR/N.M.M'/
     13X,'DIA=',F5.3,'CM VISCOS=',F5.3,'CM.CM/SEC  SG=',F6.3,'C1=',F6.3/
     13X,'C2=',F8.3,2X,'C3=',F6.3,2X,'RESIDU=',F6.3,'TONS/HA   RC=',F6.3
     1/3X,'RF1=',F6.3,2X,'TRILL=',F6.3,2X,'DF=',F5.3,2X,'FS=',F5.3/)
 301  FORMAT(5X,15F5.3)
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*
C*        INITIALIZING PART OF MAIN PROGRAM                          *
C*                                                                   *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
  100 READ(5,30,END=2000)TITLE
      WRITE(6,31)TITLE
      READ(5,30)TITLE
      DO86I=1,365
      DO85J=1,14
   85 ESOILM(I,J)=0.0
      RS(I)=0.0
      TMAX(I)=0.0
      TMIN(I)=0.0
      RHMAX(I)=0.0
```

```
      RHMIN(I)=0.0
      WIND(I)=0.0
      PAN(I)=0.0
   86 CONTINUE
      READ(5,9)NH,KEVAP,KSMA,KRHO
      READ(5,10)JIM,(THICK(JI),JI=1,JIM)
      JIM1=JIM-1
      READ(5,4)YEAR,JSTART,JSTOP
      JJ=JSTART-1
      READ(5,9)JOUT
      READ(5,9)JTILL
      READ(5,7)(ESOILM(JJ,JI),JI=1,JIM1)
C*   READ IN STARTING VALUES FOR SOIL MOISTURE.
C*   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                 *
C*          INITIALIZING INPUT FOR SUBROUTINE ET                   *
C*                                                                 *
C*   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      NC=6
      NPC=16
      DO88I=1,14
   88 ATRANS(I)=0.0
      EVAPTR=0.0
      AAET=0.0
      APET=0.0
      AAEVAP=0.0
      AATRAN=0.0
      AAINT=0.0
C*   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                 *
C*        INITIALIZING INPUT FOR SUBROUTINE REDIST                 *
C*                                                                 *
C*   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      ASTF=0.0
      READ(5,2)(SHC(I),I=1,JIM)
```

```
      READ(5,2)(FC(I),I=1,JIM)
      READ(5,2)(WP(I),I=1,JIM)
      READ(5,11)JTILE,TFRC
      READ(5,2)(SAT(I),I=1,JIM)
      SAT1=SAT(1)*THICK(1)/100.0
      READ(5,2)COEF
      DO90I=1,JIM
  90  RESAT(I)=COEF*SAT(I)*THICK(I)/100.0
      DO95I=1,JIM
      SMTC(I)=1.632/ALOG10(FC(I)/WP(I))
      AEWP(I)=350.0*(FC(I)/SAT(I))**SMTC(I)
   95 CONTINUE
      RESAT(JIM)=FC(JIM1)*THICK(JIM)/100.0
      ESOILM(JJ,JIM)=RESAT(JIM)
      TOTSTR=RESAT(1)+RESAT(2)+RESAT(3)+RESAT(4)
      SMASM=TOTSTR-ESOILM(JJ,1)-ESOILM(JJ,2)-ESOILM(JJ,3)-ESOILM(JJ,4)
      DO96JI=1,JIM
   96 ESAT(JI)=SAT(JI)*THICK(JI)*0.01
      SPERCO=0.0
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*         INITIALIZING INPUT TO SUBROUTINE PRECIP                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      TSTOP=0.0
      TSTART =0.0
      IERR=0
      IBIG=1
      CARD=I
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*   INITIALIZING INPUT TO SUBROUTINE INFILT                      *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      READ(5,7)FCINFL,ASOILM,AM,PSFC,PM,CE1,CE2
```

```
      FCS=FC(1)
      FCP=FC(1)
      DELTF=0.0
      SDELTF=0.0
      TESTIN=0.001
      VOLDPR=0.0
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*         INITIALIZING INPUT TO SUBROUTINE OFROUT                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      PEAI=0.0
      OFR=0.0
      TOFR=0.0
      READ(5,7)OFSS,OFMN1,OFMN2,TRSTM,PUDLE1,PUDLE2,OFSL,AREA
      READ(5,7)SRKE,TRST
C*   TRST = TOTAL RUNOFF SINCE TILLAGE, INCHES.
      SSRT=SQRT(OFSS)/OFSL
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*        INITIALIZING INPUT FOR SUBROUTINE SEDYLD                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      SYIELD=0.0
      TYIELD=0.0
      DEPOS=0.0
      TDEPOS=0.0
        DRTPH=0.0
      DITPH=0.0
      TDTPH=0.0
      RILLF=1.0
      READ(5,7)KI,KR,DIA,VISCOS,SG,TRILL,DF,FS
      READ(5,7)C1,C2,C3,RESIDU,RC,RF1,ALPHA
      OFSLM=OFSL/3.28
      SLFAC=2.96*(SIN(ATAN(OFSS)))**0.79+0.56
```

```
      RESFAC=EXP(-0.37*RESIDU)
      WIDTH=AREA/OFSL
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*         INITIALIZING INPUT TO SUBROUTINE INTCPT                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      DRI=0.0
      DDP=0.0
      TPINT=0.0
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*      INITIALIZING INPUT TO SUBROUTINE PLANT                    *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      READ(5,2)ALAI
      READ(5,2)DLAI
      READ(5,2)TJ
      READ(5,2)PCT
      READ(5,9)IRT
      DO105JR=1,10
  105 READ(5,2)(ROOTS(JI,JR),JI=1,JIM1)
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*          READ IN METEOROLOGICAL DATA FOR THE YEAR              *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      IF(KEVAP.EQ.1)GOTO110
C*  IF KEVAP = 1 READ IN PAN DATA.  IF NOT READ PENMAN DATA. ***
C*
      READ(5,3)(TMAX(JJ),JJ=1,365)
      READ(5,3)(TMIN(JJ),JJ=1,365)
      READ(5,3)(RHMAX(JJ),JJ=1,365)
      READ(5,3)(RHMIN(JJ),JJ=1,365)
      READ(5,3)(RS(JJ),JJ=1,365)
```

```
      READ(5,3)(WIND(JJ),JJ=1,365)
C*  END PENMAN DATA INPUT  SKIP TO READ PRECIP DATA NEXT.
      GOTO115
C*  READ IN PAN DATA AND COEFFICIENTS
 110  READ(5,301)(PAN(JJ),JJ=1,365)
C*  READ IN FIRST PRECIPITATION DATA CARD
  115 READ(5,20)MON(CARD),NDA(CARD),NYR(CARD),(ANX(CARD,N),BNX(CARD,N),
     1 CNX(CARD,N),N=1,7)
      I=MON(CARD)
      JJR=KDA(I)+NDA(CARD)
      JJR1=0
      JJ=JSTART-1
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*          PRINT OUT INPUT PARAMETERS FOR THE MODEL              *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      WRITE(6,36)TITLE
      WRITE(6,34)(JI,THICK(JI),SAT(JI),SHC(JI),AEWP(JI),SMTC(JI),FC(JI),
     1WP(JI),ESAT(JI),RESAT(JI),ESOILM(JJ,JI),JI=1,JIM)
      WRITE(6,32)TOTSTR
      WRITE(6,39)FCINFL
      IF(KSMA.EQ.1)GOTO122
      WRITE(6,45)
      WRITE(6,41)PAD
      WRITE(6,606)
      DO120I=1,NPC
      WRITE(6,42)SMET(I),(ETRATE(I,J),J=1,NC)
  120 CONTINUE
      WRITE(6,606)
      GOTO125
  122 WRITE(6,43)
  125 CONTINUE
      WRITE(6,46)
      WRITE(6,47)ASOILM,AM,PSFC,PM,CE1,CE2
```

```
      WRITE(6,38)AREA,OFSS,OFSL,OFMN1,OFMN2,TRSTM,NH
      WRITE(6,381)PUDLE1,PUDLE2
      WRITE(6,52)
   52 FORMAT('0','   PARAMETERS OF EROSION AND SEDIMENT YIELD SUBROUTINE
     1')
      WRITE(6,53)KI,KR,DIA,VISCOS,SG,C1,C2,C3,RESIDU,RC,RF1,TRILL,DF,FS
      IF(JTILE.EQ.0)GO TO 129
      WRITE(6,37)JTILE,TFRC
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*          BEGIN MAIN EXECUTION LOOP                             *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
  129 DO1000JJ=JSTART,JSTOP
C*  CHECK FOR REQUESTED DAILY OUTPUT DETAIL
      NOUT=0
      DO130LL=1,20
      IF(JJ.EQ.JOUT(LL))NOUT=1
  130 CONTINUE
      DO 140 LL=1,5
      IF(JJ.EQ.JTILL(LL))GOTO135
      GOTO140
  135 SRKE=0.0
      TRST=0.0
      TRILL=0.0
      RESIDU=0.0
      GOTO141
  140 CONTINUE
  141 CONTINUE
C*  INITIALIZE DAILY SUMMATION VALUES TO ZERO.
      SUMTRN=0.0
      ADTF=0.0
      ADET=0.0
      ADINT=0.0
      DDELTF=SDELTF
```

```
      DPERCO=SPERCO
      DAQEX=TOFR
      DAEVAP=AAEVAP
      DO150LL=1,JIM1
      ZINF(LL)=0.0
      ZOUTF(LL)=0.0
      ZTRAN(LL)=0.0
  150 CONTINUE
C*  SET INITIAL SOIL MOISTURE AT BEGINNING OF EACH DAY TO VALUE
C*  AT THE END OF THE PREVIOUS DAY.
      DO151JI=1,JIM1
  151 ESOILM(JJ,JI)=ESOILM(JJ-1,JI)
      IF(ESOILM(JJ,1).GE.SAT1)GO TO 158
      TDEPOS=TDEPOS*(1.0-EXP(-ALPHA*ESOILM(JJ,1)))
C*  UPDATE PLANT SYSTEM FUNCTIONS.
 158  CALL PLANT(JJ,NRTDS,PCATRN,CLAI,IRT,ROOTS,ALAI,DLAI,TJ,PCT,JIM1)
C*  UPDATE INFILTRATION EQUATION PARAMETERS, ADJUSTING FOR SOIL
C*  MOISTURE CONTENT OF THE TOP SOIL LAYER AND THE CROP LEAF
C*  AREA INDEX AT THE BEGINNING OF THE NEW DAY.
      AMC= ESOILM(JJ,1)*100.0/THICK(1)
      IF(CLAI.LE.3.0)GOTO159
      CLAIX=3.0
      GOTO160
  159 CLAIX=CLAI
  160 ASOIL=ASOILM*EXP(AM*(AMC-FCS))
       IF(ASOIL.GT.ASOILM)ASOIL=ASOILM
      ASOIL=ASOIL+0.5*CLAIX
      PSOIL=PSFC*(AMC/FCP)**PM
      DT=4.0
C*  DETERMINE MONTH AND DAY FROM JULIAN DAY NUMBER
      DO 198 I = 1 , 13
      IF(JJ.GT.KDA(I))GOTO198
      KMOT=I-1
      DAYT=JJ-KDA(I-1)
      GOTO199
```

```
  198 CONTINUE
  199 CONTINUE
C*   DETERMINE ESTIMATED POTENTIAL EVAPORATION FOR THE DAY FROM
C*   EITHER THE PENMAN EQUATION OR PAN EVAPORATION DATA AS
C*   PROVIDED IN THE INPUT DATA.
      IF(KEVAP.EQ.1)GOTO180
      TPAST    =(TMAX(JJ-3)+TMAX(JJ-2)+TMAX(JJ-1)+TMIN(JJ-3)+TMIN(JJ-2)
     1+TMIN(JJ-1))/6.0
C*   MINIMUM RELATIVE HUMIDITY WEIGHTED 3-TIMES IN ESTIMATION THE
C*   AVERAGE RELATIVE HUMIDITY FOR THE DAY.
      RH=(RHMAX(JJ)+3.*RHMIN(JJ))*0.25
      CALL PEVAP(JJ,TMAX(JJ),TMIN(JJ),CLAI,RH,RS(JJ),WIND(JJ),TPAST,
     1PE,PET)
      GOTO189
C*   IF PAN DATA IS USED CALL DIFFERENT FUNCTION FOR PET
 180  CALL PANEVP(PAN,JJ,PE,PET)
  189 CONTINUE
      IF(NOUT.NE.1.AND.JJR.NE.JJ)GOTO200
C*   IF DETAILED OUTPUT IS REQUESTED FOR THIS DAY, PRINT OUT WEATHER
C*   AND INPUT PARAMETER VALUES NEXT.
      WRITE(6,8)JJ,MONTH(KMOT),DAYT,YEAR
      IF(KEVAP.EQ.1)GOTO165
      WRITE(6,33)TMAX(JJ),TMIN(JJ),RS(JJ),RHMAX(JJ),RHMIN(JJ),WIND(JJ)
      GOTO168
  165 WRITE(6,35)PAN(JJ)
  168 CONTINUE
      WRITE(6,40)ASOIL,PSOIL,AMC
      WRITE(6,612)CLAI
      IF(JJR.NE.JJ)GOTO200
C*   IF RAINFALL OCCURS TODAY, NEXT READ THE REMAINING PRECIPITATION
C*   DATA CARDS FOR THIS DAY AND PROCESS THESE DATA FOR USE IN
C*   SUBROUTINE PRECIP.
  170 CARD=CARD+1
      READ(5,20)MON(CARD),NDA(CARD),NYR(CARD),(ANX(CARD,N),BNX(CARD,N),
     1 CNX(CARD,N),N=1,7)
```

```
      IF(MON(CARD).EQ.MON(1).AND.NDA(CARD).EQ.NDA(1))GOTO170
      CALL       PRECIP(KMOT,DAYT,YEAR,IBIG,NH,DELTP,IERR,TSTART,TSTOP,
     1 MON,NDA,NYR,ANX,BNX,CNX)
      IF(IERR.EQ.1)GOTO2000
      IF(KRHO.EQ.1)WRITE(6,50)
      JJR1=JJR
      I=MON(CARD)
      IF(I.EQ.0)GOTO190
      JJR=KDA(I)+NDA(CARD)
      IF(JJR.LE.JJR1)GOTO2000
      MON(1)=MON(CARD)
      NDA(1)=NDA(CARD)
      NYR(1)=NYR(CARD)
      DO175N=1,7
      ANX(1,N)=ANX(CARD,N)
      BNX(1,N)=BNX(CARD,N)
  175 CNX(1,N)=CNX(CARD,N)
      CARD=1
      GOTO200
  190 JJR=367
  200 CONTINUE
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*    BEGIN MAJOR CALCULATING LOOP NO. 2                          *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      DO599IT1=1,6
      IF(JJ.NE.JJR1)GOTO500
      TIME=DT*IT1
      IF(TIME.LE.TSTART.OR.TIME.GE.TSTOP+DT)GOTO500
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*    BEGIN MAJOR CALCULATING LOOP NO. 3                          *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
```

```
      DO499IT2=1,4
      DT=1.
      TIME=(IT1-1.)*4.+IT2*1.
      IF(TIME.LE.TSTART.OR.TIME.GE.TSTOP+DT)GOTO400
      IC=(TIME-1)*NH
      RSUM=0.0
      ICC=IC+1
      ICR=IC+NH-1
      DO 250 IR= ICC,ICR
      RSUM=RSUM+DELTP(IR)
  250 CONTINUE
      IF(RSUM.LE.0.0)GOTO400
      DT=1./NH
C*  IF HYDROGRAPH OUTPUT DETAIL IS NOT WANTED, SKIP TO BEGINNING
C*  OF THE NEXT LOOP.
      IF(KRHO.EQ.0)GOTO300
      TIME=TIME-1.0
      TM=0.0
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*    BEGIN MAJOR CALCULATING LOOP NO. 4                          *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
  300 DO399IT3=1,NH
      IC=IC+1
      INCI=1
      CALL INTCPT(CLAI,DELTP(IC),DPINT,TPINT,DDP,INCI,DT,DRI,PCC)
      CALL INFILT(ASOIL,PSOIL,TOTSTR,FCINFL,SMASM,DT,DDP,IC,
     1DELTF,VOLDPR,DRI,TESTIN,SDELTF,DINT,PEAI,SRKE,CE1,CE2)
      IRED=1
      CALL REDIST(IRED,DELTF,PERCO,SPERCO,JJ,TFRC,ADTF,VOLDPR,DT,COND,
     1ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC)
      CALL  OFROUT      (PEAI,VOLDPR,EQD,EQDF,OFR,TOFR,AREA,OFMN,
     1  NH,OFRF,OFRCFS,PUDLE,TRST,TRSTM,OFMN1,OFMN2,SSRT,PUDLE1,PUDLE2)
      CALL SEDYLD(DELTP(IC),DT,NH,SLFAC,C1,C2,C3,KI,KR,RF1,TRST,
```

```
     1TRSTM,OFR,OFRCFS,OFSS,OFSLM,RILLF,TRILL,WIDTH,FS,DIA,VISCOS,SG,
     1RESIDU,RESFAC,DRTPHC,DITPHC,TDEPOS,DEPOS,TDTPH,TCTPH,SYIELD,TYIELD
     1,SKGPHM,PUDLE,PUDLE1,PCC,RC,OFRCM,INTCPH,DITPH,DRTPH,TDTPHC,
     1EFFINT,VOLDPR,DF,AREA,OFSL)
      IF(KRHO.EQ.0)GOTO390
      IF(OFR.LE.0.0)GO TO 389
      WRITE(6,51)TIME,TM,OFRCFS,TCTPH,TDTPHC,SKGPHM,TYIELD
  389 TM=TM+60.0*DT
 390  CALL INTCPT(CLAI,DELTP(IC),DPINT,TPINT,DDP,INCI,DT,DRI,PCC)
  399 CONTINUE
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*                END MAJOR CALCULATING LOOP NO. 4                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      GOTO498
  400 CONTINUE
      CALL INFILT(ASOIL,PSOIL,TOTSTR,FCINFL,SMASM,DT,DDP,IC,
     1DELTF,VOLDPR,DRI,TESTIN,SDELTF,DINT,PEAI,SRKE,CE1,CE2)
      IRED=1
      CALL REDIST(IRED,DELTF,PERCO,SPERCO,JJ,TFRC,ADTF,VOLDPR,DT,COND,
     1ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC)
  498 CONTINUE
      CALL REDIST(IRED,DELTF,PERCO,SPERCO,JJ,TFRC,ADTF,VOLDPR,DT,COND,
     1ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC)
  499 CONTINUE
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*                END MAJOR CALCULATING LOOP NO. 3                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      GOTO598
  500 CONTINUE
      CALL INFILT(ASOIL,PSOIL,TOTSTR,FCINFL,SMASM,DT,DDP,IC,
     1DELTF,VOLDPR,DRI,TESTIN,SDELTF,DINT,PEAI,SRKE,CE1,CE2)
```

```
      IRED=1
      CALL REDIST(IRED,DELTF,PERCO,SPERCO,JJ,TFRC,ADTF,VOLDPR,DT,COND,
     1ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC)
  598 DT=4.
      CALL ET(JJ,TPINT,PCATRN,NRTDS,ATRANS,EVAPTR,PET(IT1),AAET,APET,
     1AAEVAP,AAINT,CLAI,NPC,NC,DT,SUMTRN,AINT,AET,VOLDPR,JIM,SAT,
     2 SMTC,KSMA)
      ADET=ADET+AET
      ADINT=ADINT+AINT
      DO550LL=1,JIM1
      ZTRAN(LL)=ZTRAN(LL)+ATRANS(LL)
  550 CONTINUE
      SMASM=SMASM+EVAPTR
      IRED=2
      CALL REDIST(IRED,DELTF,PERCO,SPERCO,JJ,TFRC,ADTF,VOLDPR,DT,COND,
     1ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC)
  599 CONTINUE
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*           END MAJOR CALCULATING LOOP NO. 2                     *
C*           THIS ENDS CALCULATIONS FOR THIS DAY                  *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      DDELTF=SDELTF-DDELTF
      DPERCO=SPERCO-DPERCO
      DAQEX=TOFR-DAQEX
      AATRAN=AATRAN+SUMTRN
      DAEVAP=AAEVAP-DAEVAP
      ASTF = ASTF + ADTF
C*  IF DETAILED OUT IS NOT NEEDED FOR THIS DAY, SKIP THE NEXT
C*  PART AND TO GO OUTPUT OF SOIL MOISTURE SUMMARIES.
      IF(NOUT.NE.1.AND.JJ.NE.JJR1)GOTO699
C*  OUTPUT DETAILS OF DAILY MOISTURE BALANCE CALCULATIONS.
  612 FORMAT(11X    ,'CROP LEAF AREA INDEX (CLAI) = ',G11.3)
      WRITE(6,611)OFMN,JJ,DAQEX,TOFR
```

```
  611 FORMAT(6X,F6.3,2X,'RUNOFF FOR DAY ',I3,' =',F6.3 ,' IN.',
     1' SEASON TOTAL =',F6.3 ,' IN.')
  699 CONTINUE
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C*                                                                *
C*         OUTPUT SOIL MOISTURE SUMMARIES FOR THE DAY             *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
      JX=10
      IF(JIM1.LT.10)JX=JIM1
      SUM5=0.0
      DO700JI=1,JX
      SUM5=SUM5+ESOILM(JJ,JI)
  700 CONTINUE
      SUM9=SUM5
      IF (JX.GE.JIM1)GOTO702
      JX=JX+1
      DO701JI=JX,JIM1
      SUM9=SUM9+ESOILM(JJ,JI)
  701 CONTINUE
  702 IF(JIM1.LT.10)GOTO710
      DO650LL=1,5
      LX=2*LL
      SUMLAY(LL)=ESOILM(JJ,LX)+ESOILM(JJ,LX-1)
  650 CONTINUE
  710 WRITE(6,620)JJ,MONTH(KMOT),DAYT,YEAR,SUM5,SUM9
  620 FORMAT(1H0,3X,I3,3X,A8,I3,',',A4,3X,
     $'TOP ZONE SOIL MOISTURE =',F6.2,' IN.,  TOTAL =',F6.2)
      IF(JIM1.LT.10)GOTO720
      WRITE(6,616)SUMLAY
  616 FORMAT(11X,'TOP 5-FT INCREMENTS',5F7.2)
 720  WRITE(6,606)
  606 FORMAT(10X,'******************************************************
     1********')
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
```

```
C*                                                                *
C*               END MAJOR CALCULATING LOOP NO. 1                *
C*                                                                *
C*  ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
 1000 CONTINUE
C*  RETURN TO LOOK FOR NEW SET OF INPUT DATA TO PROCESS          *
      GOTO100
 2000 STOP
      END
      BLOCK DATA
      COMMON/ABLOCK/ESOILM(365,15),WP(15),RESAT(15),ESAT(15),
     1SMET(16),PAD(6),ETRATE(16,6),FC(15),SHC(15),THICK(15)
      DATA SMET/0.0,0.05,0.1,.15,.2,.25,.3,.35,.4,.45,.5,.6,.7,.8,.85,
     A1.0/
      DATA PAD/0.0,0.05,0.15,0.35,0.55,1.1/
      DATA ETRATE/32*1.,.36,.49,.62,.78,.89,.93,.96,.97,.98,.985,.99,
     A.995,4*1.,.14,.18,.23,.30,.39,.52,.65,.76,.84,.91,.94,.98,.985,
     B.995,2*1.,.05,.09,.13,.18,.24,.32,.4,.49,.58,.66,.73,.85,.95,.98,
     C.995,1.,16*0.0/
      END
      SUBROUTINE ET (J,TPINT,PCATRN,NRTDS,ATRANS,EVAPTR,PET,AAET,
     1APET,AAEVAP,AAINT,CLAI,NPC,NC,DT,
     2 SUMTRN,AINT,AET,VOLDPR,JIM,SAT,SMTC,KSMA)
      COMMON/ABLOCK/ESOILM(365,15),WP(15),RESAT(15),ESAT(15),
     1SMET(16),PAD(6),ETRATE(16,6),FC(15),SHC(15),THICK(15)
      DIMENSION SAT(15),SMTC(15)
      REAL NRTDS
      DIMENSION NRTDS(14),ATRANS(14)
      JIM1=JIM-1
      IF(PET.GT.TPINT)GOTO1
      PETC=0.0
      TPINT=TPINT-PET
      GOTO2
    1 PETC=PET-TPINT
      TPINT=0.0
```

```
  2 CONTINUE
    IF(CLAI.GT.3.0)GOTO10
    CLAIX=CLAI
    GOTO11
 10 CLAIX=3.0
 11 PEVAP=PETC*EXP(-0.4*CLAIX)
    TRANSP=PETC-PEVAP
    IF(PEVAP.GT.VOLDPR)GOTO22
    EVAPDP=PEVAP
    VOLDPR=VOLDPR-PEVAP
    PEVAP=0.0
    GOTO23
 22 EVAPDP=VOLDPR
    PEVAP=PEVAP-EVAPDP
    VOLDPR=0.0
 23 CONTINUE
    CSMP=ESOILM(J,1)*100.0/THICK(1)
    SR=CSMP/SAT(1)
    CON=SHC(1)*SR**(1.5*SMTC(1)+3.0)
    IF(SR.GT.0.9)CON=SHC(1)
    CON=CON*0.3937*DT
    IF(CON.GT.PEVAP)GOTO24
    AEVAP=CON
    GOTO25
 24 AEVAP=PEVAP
 25 UPEVAP=PEVAP-AEVAP
    IF(CLAI.LE.0.0)GOTO3
    IF(CLAI.GT.3.)GOTO4
    PCT=CLAI*33.33
    GOTO5
  3 PCT=0.0
    GOTO5
  4 PCT=100.0
  5 UPEVAP=UPEVAP*PCT*0.01
    PTRANS=TRANSP+UPEVAP
```

```
      PPTRAN=PCATRN*PTRANS
      PAD1=PET*24./DT
      AINT=PET-PETC+EVAPDP
      AET=AEVAP+AINT
      DO6JJ=1,JIM1
      AVSM=(ESOILM(J,JJ)*100.0/THICK(JJ)-WP(JJ))/(FC(JJ)-WP(JJ))
      IF(AVSM.GT.1.0)AVSM=1.0
      IF(AVSM.LE.0.)AVSM=0.0001
      IF(KSMA.EQ.1)GOTO50
      RETRAT=GINT2(SMET,ETRATE,PAD,PAD1,AVSM,NPC,NC)
      GOTO55
   50 RETRAT=2.0*AVSM
      IF(RETRAT.GT.1.0)RETRAT=1.0
   55 ATRANS(JJ)=RETRAT*PPTRAN*NRTDS(JJ)*0.01
      AET=AET+ATRANS(JJ)
    6 SUMTRN=SUMTRN+ATRANS(JJ)
      AAET=AAET+AET
      APET=APET+PET
      AAEVAP=AAEVAP+AEVAP +EVAPDP
      AAINT=AAINT+AINT
      EVAPTR=ATRANS(1)+ATRANS(2)+ATRANS(3)+ATRANS(4)+AEVAP
      DO7JJ=1,JIM1
    7 ESOILM(J,JJ)=ESOILM(J,JJ)-ATRANS(JJ)
      ESOILM(J,1)=ESOILM(J,1)-AEVAP
      RETURN
      END
       FUNCTION GINT(X,Y,N,Z,NS)
      DIMENSION X(N),Y(N)
      DO100I=1,N
      IF(Z.LT.X(1))GOTO160
      IF(Z.GT.X(I))GOTO101
      IF(Z.EQ.X(I))GOTO102
      DX=X(I)-X(I-1)
      DY=Y(I)-Y(I-1)
      IF(DY.EQ.0.0)GOTO102
```

```
      GINT=Y(I)-DY/DX*(X(I)-Z)
      GO TO 200
  102 GINT=Y(I)
      GOTO200
  101 IF(I.GE.N)GOTO150
  100 CONTINUE
  150 WRITE(6,10)Z,X(N),NS
   10 FORMAT(3X,'INPUT Z = ',G14.6,' MAXIMUM X = ',G14.6,' IN FUNCTION G
     1INT USING STATEMENT ',I5)
      GOTO190
  160 WRITE(6,20)Z,X(1),NS
   20 FORMAT(3X,'INPUT Z = ',G14.6,',MINIMUM X = ',G14.6,' IN FUNCTION G
     1INT USING STATEMENT ',I5)
  190 STOP
  200 RETURN
      END
       FUNCTION GINT2 (X,Y,Z,U,V,M,N)
      DIMENSION X(M),Y(M,N),Z(N)
      DO100I=1,N
      IF(U.GT.Z(I))GOTO100
      DO90J=1,M
      IF(V.GT.X(J))GOTO90
      DX=X(J)-X(J-1)
      DY=Y(J,I)-Y(J-1,I)
      YT=Y(J,I)-DY/DX*(X(J)-V)
      DY=Y(J,I-1)-Y(J-1,I-1)
      YB=Y(J,I-1)-DY/DX*(X(J)-V)
      DZ=Z(I)-Z(I-1)
      DY=YT-YB
      GINT2=YT-DY/DZ*(Z(I)-U)
      GOTO200
   90 CONTINUE
  100 CONTINUE
  200 CONTINUE
      RETURN
```

```
      END
      SUBROUTINE INFILT (AS,PSOIL,TOTSTR,FCINFL,SMASM,DT,DDP,IC,
     1DELTF,VOLDPR,DRI,TESTIN,SDELTF,DINT,PEAI,SRKE,CE1,CE2)
      DELTP=DDP+DRI
      DINT=DDP/DT
      IF(DINT.LE.0.0)GOTO5
      RKE=DDP*(0.06133+0.02216*ALOG10(DINT))
C*    RKE = RAINFALL KINETIC ENERGY DURING THE PERIOD IN JOULES/CM2
      IF(RKE.LT.0.0)RKE=0.0
      IF(VOLDPR.GT.0.5)RKE=0.0
      SRKE=SRKE+RKE
C*    SRKE = SEASONAL SUM OF RAINFALL KINETIC ENERGY ON THE FIELD.
    5 IF(SRKE.LE.0.0)GOTO7
      REF=CE1*SRKE**(-CE2)
C*    REF = RAINFALL ENERGY FACTOR AFFECTING INFILTRATION.
      IF(REF.GT.1.0)REF=1.0
      GOTO10
    7 REF=1.0
   10 ASOIL=AS*REF
      F1=TOTSTR-SMASM
      IF(F1.GT.TOTSTR)GOTO30
      F2=F1
      IF(DELTP)15,15,20
   15 IF(VOLDPR)65,65,20
   20 N=0
      F1FCTN=F1/DT+FCINFL+ASOIL/2.*((TOTSTR-F1)/TOTSTR)**PSOIL
      AP2T=ASOIL/2.*PSOIL/TOTSTR
      APT=ASOIL*PSOIL*(PSOIL-1.)/(2.*TOTSTR*TOTSTR)
   25 IF(TOTSTR-F2)30,30,35
   30 F2=F1+FCINFL*DT
      GOTO65
   35 SR=(TOTSTR-F2)/TOTSTR
   40 F2FCTN=F2/DT-ASOIL/2.*SR**PSOIL-F1FCTN
      IF(ABS(F2FCTN)-TESTIN)65,65,45
   45 FPFCTN=1./DT+AP2T*SR**(PSOIL-1.)
```

```
      FSFCTN=-APT*SR**(PSOIL-2.)
      F2=F2-F2FCTN/(FPFCTN-F2FCTN*FSFCTN/2./FPFCTN)
      N=N+1
      IF(N-7)60,60,50
   50 WRITE(6,55)IC
   55 FORMAT(1H0,'ITERATION LIMIT EXCEEDED DURING ',I3,'TH PERIOD')
      GOTO65
   60 GOTO25
   65 F3=F2-F1
      F4=DELTP+VOLDPR
      IF(F3-F4)70,75,80
   70 DELTF=F3
      DELTPE=DELTP-DELTF
      GOTO85
   75 DELTF=F3
      DELTPE=-VOLDPR
      GOTO85
   80 DELTF=DELTP+VOLDPR
      DELTPE=DELTP-DELTF
   85 PEAI=VOLDPR+DELTPE
      SMASM=SMASM-DELTF
      SDELTF=SDELTF+DELTF
      DDP=0.0
      DRI=0.0
      RETURN
      END
      SUBROUTINE INTCPT(CLAI,DELTP,DPINT,TPINT,DDP,INCI,DT,DRI,PCC)
C
      GO TO (5,30),INCI
    5 IF(CLAI.GT. 3.0)GOTO10
      PCC=CLAI*33.33
      GO TO 11
   10 PCC=100.0
   11 DDP=DELTP*(1.0-0.01*PCC)
      PIMAX=0.03*CLAI
```

```
      DPINT=DELTP-DDP
      TTPINT = TPINT + DPINT
      IF((PIMAX-TTPINT).GE.0.0)GOTO19
      DPINT = PIMAX-TPINT
      TPINT=PIMAX
      DDP=DELTP-DPINT
      GOTO20
   19 TPINT=TTPINT
   20 INCI=2
      RETURN
   30 CONTINUE
      PIMIN=0.015*CLAI
      IF(TPINT.LE.PIMIN)GOTO32
      DDRI=TPINT*(1.0-EXP(-1.0*DT))
      IF((TPINT-DDRI).GE.PIMIN)GOTO31
      DRI=DRI+TPINT-PIMIN
      TPINT=PIMIN
      GOTO32
   31 TPINT=TPINT-DDRI
      DRI=DRI+DDRI
   32 INCI=1
      RETURN
      END
      SUBROUTINE PEVAP(JJ,TMAX,TMIN,CLAI,RH,RS,W,TPAST,PE,PET)
      DIMENSION PET(6)
      X=JJ+18.0
      RSO=547.0+227.0*SIN(0.01721*X-1.5708)
      T=(TMAX+TMIN)*0.5
      TR=T+459.69
      B=ALOG(TR)
      BB=54.6329 - 12301.688/TR - 5.16925*B
      ES=68.944*EXP(BB)
      ED=0.01*RH*ES
      TK2=((TMAX-32.0)/1.8+273.16)*0.01
      TK1=((TMIN-32.0)/1.8+273.16)*0.01
```

```
      RBO=(0.98-(0.66+0.044*SQRT(ED)))*5.855*(TK2**4-TK1**4)
      IF(RS.GT.RSO) RS=RSO
      RB=(1.35*RS/RSO-0.35)*RBO
      IF(CLAI.GT.4.0)GOTO50
      ALBEDO=0.23-0.0175*CLAI
      GOTO52
   50 IF(TMIN.LT.32.0)GOTO51
      ALBEDO=0.16
      GOTO52
   51 ALBEDO=0.20
   52 RN=(1.0-ALBEDO)*RS-RB
      TC=(T-32.0)/1.8
      DOG=.672+.0428*TC+1.13*10.**(-3.)*TC*TC+1.66*10.**(-5.)
     A*TC*TC*TC+1.7*10.**(-7.)*TC**4.0
      G=5.0*(T-TPAST)
      PER=(DOG/(DOG+1.0)*(RN-G))*0.000673
      PEW=((1.0/(DOG+1.0))*15.36*(1.0+0.01*W)*(ES-ED))*0.000673
      PE=PER+PEW
      PDX=PE/24.
      PET(1)=PDX*0.576
      PET(2)=PDX*1.152
      PET(3)=PDX*6.96
      PET(4)=PDX*9.528
      PET(5)=PDX*4.68
      PET(6)=PDX*1.104
      RETURN
      END
C*
      SUBROUTINE PANEVP(PAN,JJ,PE,PET)
C* THIS SUBROUTINE DETERMINES THE POTENTIAL EVAPORATION FROM
C*  EVAPORATION PAN INPUT DATA.
      DIMENSION PAN(365),PET(6)
      PE=0.01+0.83*PAN(JJ)
      PDX=PE/24.0
      PET(1)=PDX*0.576
```

```
      PET(2)=PDX*1.152
      PET(3)=PDX*6.96
      PET(4) = PDX * 9.528
      PET(5) = PDX * 4.68
      PET(6) = PDX * 1.104
      RETURN
      END
      SUBROUTINE PLANT(JJ,NRTDS,PCATRN,CLAI,IRT,ROOTS,ALAI,DLAI,
     1 TJ,PCT,JIM1)
      REAL NRTDS(14)
      DIMENSION ALAI(12),DLAI(12),ROOTS(14,10),IRT(10),TJ(12),PCT(12)
C
      DO10J=1,9
      IF(JJ.GT.IRT(J))GOTO10
      DO9I=1,JIM1
    9 NRTDS(I)=ROOTS(I,J-1)
      GOTO13
   10 CONTINUE
   11 DO12I=1,JIM1
   12 NRTDS(I)=ROOTS(I,10)
   13 DJ=JJ
   31 PCATRN=GINT(TJ,PCT,12,DJ,31)
   32 CLAI=GINT(DLAI,ALAI,12,DJ,32)
      RETURN
      END
      SUBROUTINE PRECIP(KMOT,DAYT,YEAR,IBIG,NH,DELTP,IERR,TSTART,TSTOP
     1, MON,NDA,NYR,ANX,BNX,CNX)
       INTEGER CARD
      INTEGER DAYI,DAYT
      DIMENSION MON(10),NDA(10),NYR(10),ANX(10,7),BNX(10,7),CNX(10,7)
      DIMENSION A(7),B(7),C(7),DELTP(800),TIME(800),SUMP(800),CLOCK(8),
     1THC(8)
      CARD=0
      IF(IBIG.NE.1)CARD=1
      IF(IBIG.NE.1)GOTO89
```

```
      THC(1)=0.0
      CLOCK(1)=0.0
      THC(8)=0.0
      CLOCK(8)=0.0
      SUMO=0.0
      GOTO90
   89 IF(KMO.NE.KMOT.OR.DAYI.NE.DAYT)GOTO120
      IF(IBIG.NE.2)GOTO90
      IBIG=1
   90 IM=24*NH
      JCM=IM+1
      TNH=NH
      TIME(1)=0.0
      SUMP(1)=THC(8)
      DELTP(1)=0.0
      DO95I=2,JCM
      TI=I-1.
      TIME(I)=TI/TNH
      SUMP(I)=0.0
      DELTP(I)=0.0
   95 CONTINUE
      TSTART=0.0
      TSTOP=0.0
      I=1
   99 IF(I.GT.IM)GOTO400
      I=I+1
      GOTO(100,100,200,300),IBIG
  100 CONTINUE
      CARD=CARD+1
      KMO=MON(CARD)
      DAYI=NDA(CARD)
      KYR=NYR(CARD)
      DO98N=1,7
      A(N)=ANX(CARD,N)
      B(N)=BNX(CARD,N)
```

```
   98 C(N)=CNX(CARD,N)
C* IF DATA IS CODED FOR GAUGE ERROR OR SNOW, UNCODE DATA
      IF(C(1).LT.70.0)GOTO80
      DO60N=1,7
      IF(C(N).GE.70.0)C(N)=C(N)-70.0
      IF(C(N).GE.20.0)C(N)=C(N)-20.0
   60 CONTINUE
      WRITE(6,900)
  900 FORMAT(5X,'RAINGAUGE DATA CODED FOR ERROR OR SNOWFALL.')
   80 CONTINUE
      IF(KMO.NE.KMOT)GOTO101
      IF(DAYT.NE.DAYI)GOTO101
      GOTO102
  101 IF(IBIG.EQ.1)GOTO120
      IF(IBIG.EQ.2)GOTO140
  102 IF(ABS(A(1)-99.0).LT.0.000I)GOTO150
      GOTO200
  120 CONTINUE
      WRITE(6,660)KMOT,DAYT,YEAR,KMO,DAYI,KYR
  660 FORMAT(//'****ERROR****ERROR**DATE CHANGE ON INPUT PRECIPITATION
     UCARD.'/' WORKING DATE WAS ',I3,'/',I3,'/',A4,' AND INPUT CARD DATE
     2 WAS ',I3,'/',I3,'/',I3/)
      IERR=1
      RETURN
  130 E=C(3)
      F=C(1)/(C(2)-E)
  132 DO131JC=I,JCM
      SUMP(JC)=THC(8)+SUMO
  131 CONTINUE
      IBIG=2
      IF(KMO.EQ.0)IBIG=1
      CLOCK(1)=0.0
      THC(1)=0.0
      THC(8)=0.0
      SUMO=0.0
```

```
      GOTO600
  140 IF(ABS(A(1)-99.0).LT.0.0001)GOTO130
      IF(KMO.EQ.0)GOTO145
      IBIG=3
      GOTO305
  145 IBIG=1
      GOTO132
  150 E=C(3)
      F=C(1)/(C(2)-E)
      SUMP(I)=THC(8)+SUMO
      SUMO=THC(8)
      THC(1)=0.0
      CLOCK(1)=CLOCK(8)
      IF(IBIG.EQ.1)GOTO100
      IBIG=2
      GOTO99
  200 DO290N=1,7
      CLOCK(N+1)=A(N)+B(N)/60.
      IF(CLOCK(N+1).EQ.0.0)C(N)=E
      THC(N+1)=(C(N)-E)*F
  290 CONTINUE
  300 DO302JC=2,8
      IF(CLOCK(JC).LT.0.001)GOTO301
      IF(TIME(I).GT.CLOCK(JC))GOTO302
      IF(TIME(I).EQ.CLOCK(JC))GOTO312
      DX=CLOCK(JC)-CLOCK(JC-1)
      DY=THC(JC)-THC(JC-1)
      SUMP(I)=THC(JC)-DY/DX*(CLOCK(JC)-TIME(I))  +SUMO
  313 IBIG=4
      GOTO99
  312 SUMP(I)=THC(JC)+SUMO
      GOTO313
  301 IBIG=2
      CLOCK(8)=CLOCK(JC-1)
      THC(8)=THC(JC-1)
```

```
      GOTO100
  302 CONTINUE
      CLOCK(1)=CLOCK(8)
      THC(1)=THC(8)
      IBIG=2
      GOTO100
  305 CONTINUE
      IF(I.EQ.JCM)GOTO311
  306  CL = A(1)+B(1)/60.0+24.0
      THC1=(C(1)-E)*F
      DX=CL-CLOCK(8)
      DY=THC1-THC(8)
      DO310JC=I,JCM
      SUMP(JC)=THC1-DY/DX*(CL-TIME(JC))+SUMO
  310 CONTINUE
       GO TO 314
  311 IF(CLOCK(8).NE.24.0)GOTO306
  314  CLOCK(1)=0.0
      THC(1)=SUMP(JCM)-SUMO
      GOTO600
  400 CONTINUE
      IF(CLOCK(8).EQ.0.0)GOTO450
      GOTO599
  450 CLOCK(8)=24.0
      THC(8)=SUMP(JCM)-SUMO
  599 IBIG=2
      GOTO100
  600 CONTINUE
      DO610I=1,IM
      DELTP(I)=SUMP(I+1)-SUMP(I)
  610 CONTINUE
      SUMO=0.0
  680 DO681JC=1,IM
      IF(DELTP(JC).LE.0.0)GOTO681
      TSTART=TIME(JC)
```

```
      GOTO682
  681 CONTINUE
  682 CONTINUE
      DO683JC=1,IM
      JCC=JCM-JC
      IF(DELTP(JCC).LE.0.0)GOTO683
      TSTOP=TIME(JCC+1)
      GOTO700
  683 CONTINUE
  700 CONTINUE
      RAIN=0.0
      DO701JI=1,JCM
      RAIN=RAIN+DELTP(JI)
  701 CONTINUE
      WRITE(6,13)RAIN
   13 FORMAT(11X,'TOTAL RAINFALL TODAY = ',F8.3,' INCHES')
      WRITE(6,9)TSTART,TSTOP
    9 FORMAT(10X,'RAINFALL STARTED AT',G12.4,'HOURS AND ENDED AT',
     1G12.4,'HOURS')
      RETURN
      END
      SUBROUTINE REDIST (IRED,DELTF,PERCO,SPERCO,J,TFRC,ADTF,VOLDPR,
     1DT,COND,ZINF,ZOUTF,TOTSTR,SMASM,SAT,JTILE,JIM,AEWP,SMTC)
C*    THIS SUBROUTINE HAS UNDERGONE SUBSTANTIAL REVISION SINCE THE
C*    THESIS WAS WRITTEN TO ALLOW IT TO HANDLE DIFFERENT SOIL MOISTURE
C*    CHARACTERISTICS IN EACH LAYER AND TO ALLOW THE BUILDUP OF A
C*    WATER TABLE AND DISCHARGE OF WATER THROUGH A TILE DRAIN.
C*    THE WATER CHARACTERISTIC FUNCTION IS TAKEN AS A STRAIGHT LINE
C*    ON A LOG-LOG PLOT FOR ALL MOISTURE LEVELS BELOW 90% OF SATURATION
C*   THE SAME IS TRUE OF THE UNSATURATED HYDRAULIC CONDUCTIVITY FUNCTION.
C*   SEE ARTICLE BY G. S. CAMPBELL IN SOIL SCIENCE 117(6):311-314, JUNE 1
C*   ALSO ARTICLE BY R.K.GHOSH IN SOIL SCIENCE 124(2):122-124,1977
      COMMON/ABLOCK/ESOILM(365,15),WP(15),RESAT(15),ESAT(15),
     1 SMET(16),PAD(6),ETRATE(16,6),FC(15),SHC(15),THICK(15)
      DIMENSION COND(14),ZINF(14),ZOUTF(14),AINFIL(15),
```

```
     1 TENZ(15),SAT(15),AEWP(15),SMTC(15),UHC(15)
      PERCO=0.0
      TILEQ=0.0
      DO2KZZ=1,JIM
    2 AINFIL(KZZ)=0.0
      GO TO(3,45),IRED
    3 AINFIL(1)=DELTF
      JI=1
      JIM1=JIM-1
      IF(DELTF.EQ.0.0)GOTO40
      DO5JI=1,JIM1
      KB=JI
      ESOILM(J,JI)=ESOILM(J,JI)+AINFIL(JI)
      IF(ESOILM(J,JI).LE.RESAT(JI))GOTO10
      AINFIL(JI+1)=SHC(JI+1)*DT*0.3937
      EXT=ESOILM(J,JI)-RESAT(JI)
      IF(AINFIL(JI+1).GT.EXT)AINFIL(JI+1)=EXT
    5 ESOILM(J,JI)=ESOILM(J,JI)-AINFIL(JI+1)
   10 PERCO=AINFIL(JIM)
   15 EXTRA=ESOILM(J,KB)-ESAT(KB)
      IF(EXTRA.GT.0.0)GOTO20
      KB=KB-1
      IF(KB.EQ.0)GOTO35
      GOTO15
   20 ESOILM(J,KB)=ESAT(KB)
   25 KB=KB-1
      IF(KB.EQ.0)GOTO30
      ESOILM(J,KB)=ESOILM(J,KB)+EXTRA
      GOTO15
   30 VOLDPR=VOLDPR+EXTRA
   35 SMASM=TOTSTR-ESOILM(J,1)-ESOILM(J,2)-ESOILM(J,3)-ESOILM(J,4)
      DELTF=0.0
       SPERCO=SPERCO+PERCO
      DO 36 LL=1,JIM1
   36 ZINF(LL)=ZINF(LL)+AINFIL(LL)
```

```
   40 IRED=2
      RETURN
   45 CONTINUE
      JI=1
      JIM1=JIM - 1
      DO50KZZ=1,14
      COND(KZZ)=0.0
   50 CONTINUE
      DO 75 JI = 1,JIM
      IF(JI.EQ.JIM)GOTO55
      CSMP=ESOILM(J,JI)/THICK(JI)*100.0
      GO TO 60
   55 CSMP=RESAT(JIM)/THICK(JIM)*100.0
   60 SR=CSMP/SAT(JI)
      IF(SR.GT.0.9)GO TO 65
      TENZ(JI)=AEWP(JI)*SR**(-SMTC(JI))
      UHC(JI)=SHC(JI)*SR**(1.5*SMTC(JI)+3.0)
      GO TO 75
   65 IF(SR.GT.1.0)GOTO70
      TENZ(JI)=(10.0*SR-9.0)*AEWP(JI)*0.9**(-SMTC(JI))
      UHC(JI)=SHC(JI)
      GO TO 75
   70 TENZ(JI)=0.0
      UHC(JI)=SHC(JI)
   75 CONTINUE
      DO 80 JI = 1,JIM1
      TH2=THICK(JI)+THICK(JI+1)
      THM=TH2*1.27
C* TH2 = TOTAL THICKNESS OF ANY TWO ADJACENT LAYERS (INCHES)
C* THM = DISTANCE BETWEEN MIDPOINTS OF ANY TWO ADJACENT LAYERS (CM)
      GRAD=(TENZ(JI+1)-TENZ(JI)+THM)/THM
      CON=UHC(JI+1)
      IF(UHC(JI).LT.CON)CON=UHC(JI)
      COND(JI)=CON*GRAD*DT*0.3937
   80 CONTINUE
```

```
      JIM2=JIM-2
      DO95JI=1,JIM2
      IF(COND(JI).LT.0.0)GOTO85
      CONMAX=ESOILM(J,JI)*0.5
      IF(COND(JI).GT.CONMAX)COND(JI)=CONMAX
      GOTO90
   85 CONMAX=ESOILM(J,JI+1)*(-0.5)
      IF(COND(JI).LT.CONMAX)COND(JI)=CONMAX
   90 ESOILM(J,JI)=ESOILM(J,JI)-COND(JI)
      ESOILM(J,JI+1)=ESOILM(J,JI+1)+COND(JI)
   95 CONTINUE
      IF(COND(JIM1).LT.0.0)GOTO100
      CONMAX=ESOILM(J,JIM1)*0.5
      IF(COND(JIM1).GT.CONMAX)COND(JIM1)=CONMAX
  100 ESOILM(J,JIM1)=ESOILM(J,JIM1)-COND(JIM1)
      PERCO=PERCO+COND(JIM1)
      ZPERC=0.0
      DO105JI=1,JIM1
      IF(RESAT(JI).GE.ESOILM(J,JI))GOTO105
      ZPERC=SHC(JI+1)*DT*0.3937
      EXT=ESOILM(J,JI)-RESAT(JI)
      IF(ZPERC.GT.EXT)ZPERC=EXT
      ESOILM(J,JI)=ESOILM(J,JI)-ZPERC
      IF(JI.EQ.JIM1)GOTO104
      ESOILM(J,JI+1)=ESOILM(J,JI+1)+ZPERC
      AINFIL(JI+1)=AINFIL(JI+1)+ZPERC
      GO TO 105
  104 PERCO=PERCO+ZPERC
  105 CONTINUE
      IF(ZPERC.EQ.0.0)GOTO140
      KB=JIM1
  115 EXTRA=ESOILM(J,KB)-ESAT(KB)
      IF(EXTRA.GT.0.0)GOTO120
      KB=KB-1
      IF(KB.EQ.0)GOTO140
```

```
      GOTO115
  120 ESOILM(J,KB)=ESAT(KB)
      IF(KB.EQ.JTILE)GOTO130
  125 KB=KB-1
      IF(KB.EQ.0)GOTO135
      ESOILM(J,KB)=ESOILM(J,KB)+EXTRA
      GOTO115
  130 TILEQ=EXTRA*(-ALOG(TFRC**(DT/24.0)))
      EXTRA=EXTRA-TILEQ
      IF(EXTRA.GT.0.0)GOTO125
      TILEQ=TILEQ+EXTRA
      EXTRA=0.0
      KB=KB-1
      IF(KB.EQ.0)GOTO140
      GOTO115
  135 VOLDPR=VOLDPR+EXTRA
  140 SPERCO=SPERCO+PERCO
      ADTF=ADTF+TILEQ
      SMASM=TOTSTR-ESOILM(J,1)-ESOILM(J,2)-ESOILM(J,3)-ESOILM(J,4)
      DO145LL=1,JIM1
       ZINF(LL)=ZINF(LL)+AINFIL(LL)
       ZOUTF(LL)=ZOUTF(LL)+COND(LL)
  145 CONTINUE
       RETURN
       END
      SUBROUTINE OFROUT (PEAI,VOLDPR,EQD,EQDF,OFR,TOFR,AREA,OFMN,
     1  NH,OFRF,OFRCFS,PUDLE,TRST,TRSTM,OFMN1,OFMN2,SSRT,PUDLE1,PUDLE2)
C*  OVERLAND FLOW ROUTING FUNCTION AS DEVELOPED BY CRAWFORD AND
C*  LINSLEY IN THE STANFORD WATERSHED MODEL. TP-39.
C:
      QR=TRST/TRSTM
      OFMN=OFMN1-QR*(OFMN1-OFMN2)
      IF(OFMN.LT.OFMN2)OFMN=OFMN2
      OFRF=1020.0*SSRT/OFMN
      EQDF=0.00982*(OFMN/SSRT)**0.6
```

```
      PUDLE=PUDLE1-0.80*(QR*(PUDLE1-PUDLE2))
      IF(PUDLE.LT.PUDLE2)PUDLE=PUDLE2
      OFR=0.0
      OFRCFS=0.0
      SWS=VOLDPR+PEAI-PUDLE
      IF(SWS.LE.0.001)GOTO12
      IF((PEAI-VOLDPR).GT.0.0)GOTO10
      EQD=0.5*SWS
      GOTO11
   10 EQD=EQDF*((PEAI-VOLDPR)**0.6)
   11 IF(SWS.GT.(2.0*EQD))EQD=0.5*SWS
      OFR=(1.0/NH)*OFRF*((SWS*0.5)**1.67)*((1.0+0.6*(SWS/(2.0*EQD))
     $ **3.0)**1.67)
      IF(OFR.GT.(0.75*PEAI)) OFR = 0.75*PEAI
      OFRCFS=1.0083*AREA*OFR*NH
   12 TOFR=TOFR+OFR
      TRST=TRST+OFR
      VOLDPR=PEAI-OFR
      RETURN
      END
      SUBROUTINE SEDYLD(DELTP,DT,NH,SLFAC,C1,C2,C3,KI,KR,RF1,TRST,
     1TRSTM,OFR,OFRCFS.OFSS,OFSLM,RILLF,TRILL,WIDTH,FS,DIA,VISCOS,SG,
     1RESIDU,RESFAC,DRTPHC.DITPHC.TDEPOS,DEPOS,TDTPH,TCTPH,SYIELD,TYIELD
     1,SKGPHM,PUDLE,PUDLE1,PCC,RC,OFRCM,INTCPH,DITPH,DRTPH,TDTPHC,
     1EFFINT,VOLDPR,DF,AREA,OFSL)
      REAL KI,KR,INTCPH,INTFAC
      INTCPH=(DELTP*2.54)/DT
      INTFAC=1.0-0.70*(PCC/100.0)
      EFFINT=INTCPH*INTFAC
      DI=C1*KI*EFFINT**2.0*SLFAC
C     CALCULATE DETACHMENT BY RAINFALL IN TONS/HA
      DITPH=DI*(10.0/NH)
C     IF THERE IS ANY CROP RESIDUE  REDUCE DETACHMENT BY RAINEFALL
C     DUE TO CROP RESIDUE
      IF(RESIDU.GT.0.0)DITPH=DITPH*RESFAC
```

```
C     CALCULATE ROUGHNESS FACTOR
      RF=RF1+TRST/TRSTM*(1.0-RF1)
      IF(RF.GT.1.0)RF=1.0
      IF(VOLDPR.LE.0.0)DEPTHF=1.0
      IF(VOLDPR.GE.0.5)DEPTHF=0.0
      DEPTHF=EXP(-DF*VOLDPR)
C     REDUCE DETACHMENT BY RAINFALL DUE TO THE SURFACE ROUGHNESS
      DITPHC=DITPH*RF*DEPTHF
      OFRCM=OFR*2.54
      IF(OFRCM.GT.0.0)GO TO 10
      DR=0.0
      GO TO 30
C     CALCULATE THE POTENTIAL DETACHMENT BY RUNOFF
 10   IF(RESIDU.GT.0.0)GO TO 20
      DR=C2*KR*(9807. *(OFRCM/100.0)*OFSS)**C3
      GO TO 30
 20   WIDTH=AREA/OFSL
      OFRFT=OFR/12.0
      V=OFRCFS/(WIDTH*OFRFT)
      VC=V/3.28
      DR=C2*KR*(9807. *VC**2.0*FS/8.0*9.8)**C3
C     CALCULATE DETACHMENT BY RUNOFF IN TONS/HA
 30   DRTPH=DR*(10.0/NH)
      DRTPHC=DRTPH*RILLF
      TDTPHP=DRTPHC+DITPHC+TDEPOS
C     CALCULATE TRANSPORT CAPACITY TONS/HA USING YALIN EQUASION
      IF(OFRCM.LE.0.0)GO TO 40
      SHVEL=SQRT(980.0*OFRCM*OFSS)
      RN=SHVEL*DIA/VISCOS
      IF(RN.LE.0.0)GO TO 40
      IF(RN.LE.2.0)YC=0.114/RN**0.9
      IF(RN.GT.2.0.AND.RN.LE.4.0)YC=0.09/RN**0.585
      IF(RN.GT.4.0.AND.RN.LE.10.0)YC=0.056/RN**0.243
      IF(RN.GT.10.0.AND.RN.LE.30.0)YC=0.0265*RN**0.0815
      IF(RN.GT.30.0)YC=0.0181*RN**0.193
```

```
      Y=SHVEL**2.0/((SG-1.0)*980.0*DIA)
      A=2.45*SG**0.4*YC**0.5
      DELTA=Y/YC-1.0
      IF(Y.LE.YC)GO TO 40
      SIGMA=A*DELTA
      TC=0.800*DELTA*(1.0-(1.0/SIGMA)*ALOG(1.0+SIGMA))*1.0*DIA*SHVEL*SG
      GO TO 50
   40 TC=0.0
   50 TCTPH=(3600.0/NH)*TC/DFSLM
C     IF TRANSPORT CAPACITY IS LESS THAN TOTAL DETACHMENT  RILL EROSION
C     WILL BE LESS THAN ITS POTEMTIAL DEPENDING ON DIFFERENCE BETWEEN
C     TRANSPORT CAPACITY AND DETACHMENT BY RAINFALL
      IF(TCTPH.GE.TDTPHP)GO TO 80
      DRTPH=TCTPH-DITPHC
      IF(DRTPH.LE.0.0)GO TO 60
      DRTPHC=DRTPH*RILLF
      ARILL=DRTPHC
      GO TO 70
   60 ARILL=0.0
      DRTPHC=0.0
   70 TRILL=TRILL+ARILL
      SYIELD=TCTPH
      TDTPHC=DITPHC+DRTPHC+TDEPOS
      GO TO 90
C     IF TRANSPORT CAPACITY IS THE SAME OR GRETER THAN TOTAL DETACHMENT
C     RILL EROSION WILL BE THE SAME AS ITS POTENTIAL
   80 ARILL=DRTPHC
      TRILL=TRILL+ARILL
      TDTPHC=TDTPHP
      SYIELD=TDTPHC
   90 TDEPOS=TDTPHC-SYIELD
      IF(TDEPOS.LT.0.0)TDEPOS=0.0
      IF(PUDLE.GT.0.0)TDEPOS=TDEPOS*(1.0-PUDLE/PUDLE1)
      RILLF=EXP(-RC*TRILL)
      STPHM=SYIELD*NH/60.0
```

```
SKGPHM=STPHM*1000.0
TYIELD=TYIELD+SYIELD
RETURN
END
```

APPENDIX C:

PRINT OUT OF SAMPLE OUTPUT FOR COMPUTER MODEL

```
          TRIAL RUN NO. (    ) -   E.SHAHGHASEMI      RUN DATE = ( 3 / 5 /1980)
          GINGLES NE. WATERSHED - SURFACE PLANTED CORN - 1972 DATA

                            INITIAL SOIL MOISTURE DATA

LAYER  THICK   SAT    SHC    AEWP    SMTC      FC      WP     ESAT   RESAT  ESOILM
      INCHES PERCENT CM/HR    CM               PCT.    PCT.  INCHES INCHES INCHES
              BY VOL.                         BY VOL  BY VOL.

  1    6.00   53.0   0.50   34.85    3.42   27.00      9.00   3.18   2.54    0.95
  2    6.00   52.0   0.48   26.33    3.73   26.00      9.50   3.12   2.50    1.05
  3    6.00   50.0   0.46   30.48    3.73   26.00      9.50   3.00   2.40    0.90
  4    6.00   50.0   0.44   30.48    3.73   26.00      9.50   3.00   2.40    0.80
  5    6.00   50.0   0.40   30.48    3.73   26.00      9.50   3.00   2.40    0.75
  6    6.00   48.0   0.35   39.89    3.54   26.00      9.00   2.88   2.30    0.65
  7    6.00   46.0   0.30   37.16    3.68   25.00      9.00   2.76   2.21    0.40
  8    6.00   44.0   0.30   43.76    3.68   25.00      9.00   2.64   2.11    0.30
  9    6.00   44.0   0.30   34.32    3.83   24.00      9.00   2.64   2.11    0.10
 10    6.00   44.0   0.30   30.24    3.78   23.00      8.50   2.64   2.11    0.10
 11   12.00   45.0   0.30   27.78    3.78   23.00      8.50   5.40   2.76    2.76
          TOTAL POTENTIAL STORAGE IN THE TOP TWC FEET =  9.84 INCHES
          WET SOIL INFILTRATION CAPACITY = 0.140 IN./HR.
```

```
CURVE DATA FOR DENMEAD AND SHAW TYPE CURVES

                                  PAD
           0.0      0.050    0.150    0.350    0.550    1.100
SMET                         ETRATE
***************************************************************
    0.0    1.000    1.000    0.360    0.140    0.050    0.0
    0.050  1.000    1.000    0.490    0.180    0.090    0.0
    0.100  1.000    1.000    0.620    0.230    0.130    0.0
    0.150  1.000    1.000    0.780    0.300    0.180    0.0
    0.200  1.000    1.000    0.890    0.390    0.240    0.0
    0.250  1.000    1.000    0.930    0.520    0.320    0.0
    0.300  1.000    1.000    0.960    0.650    0.400    0.0
    0.350  1.000    1.000    0.970    0.760    0.490    0.0
    0.400  1.000    1.000    0.980    0.840    0.580    0.0
    0.450  1.000    1.000    0.985    0.910    0.660    0.0
    0.500  1.000    1.000    0.990    0.940    0.730    0.0
    0.600  1.000    1.000    0.995    0.980    0.850    0.0
    0.700  1.000    1.000    1.000    0.985    0.950    0.0
    0.800  1.000    1.000    1.000    0.995    0.980    0.0
    0.850  1.000    1.000    1.000    1.000    0.995    0.0
    1.000  1.000    1.000    1.000    1.000    1.000    0.0
***************************************************************
```

```
         DATA FOR INFILTRATION PARAMETERS

  ASOILM= 7.000 AM=-0.160 PSFC= 1.480 PM= 0.199
 CE1 =  0.125  CE2 =  1.250


 FIELD AREA =    2.21 ACRES.  AVERAGE FIELD SLOPE =  0.1500
 SLOPE LENGTH =  290.0 FEET.  SURFACE ROUGHNESS COEFFICIENT =  0.150  0.100
 TRSTM =  0.500  SMALLEST TIME INTERVAL USED = 1/30TH  OF AN HOUR
 SURFACE  STORAGE=  0.500  0.0

 PARAMETERS OF EROSION AND SEDIMENT YIELD SUBROUTINE


 KI=0.030KG.HR/N.M.M  KR=0.030KG.HR/N.M.M
DIA=0.015CM VISCOS=0.015CM.CM/SEC  SG= 2.000C1= 2.250
C2= 125.000  C3= 1.650  RESIDU= 0.0  TONS/HA   RC= 0.090
RF1= 0.750  TRILL=45.000  DF=0.0    FS=0.050
```

```
125       MAY        5,1972
        PAN EVAPORATION FOR TODAY =  0.120 INCHES
         ASOIL =    1.621     PSOIL = 1.568    AMC =   36.143 PERCENT
         CROP LEAF AREA INDEX (CLAI) =    0.000
         TOTAL RAINFALL TODAY =     1.329 INCHES
        RAINFALL STARTED AT    21.23    HOURS AND ENDED AT    24.00     HOURS

                  RUNOFF        TRANSPORT      TOTAL        SEDIMENT      TOTAL
       TIME       RATE          CAPACITY     DETACHMENT      YIELD      SED.YIELD
       HR MI      C.F.S           T/HA          T/HA       KG/HA.MIN      T/HA

      22.10.      0.139          0.000         0.502          0.000       0.368
      22.12.      0.182          0.000         0.213          0.000       0.368
      22.14.      0.227          0.000         0.111          0.000       0.368
      22.16.      0.272          0.000         0.075          0.052       0.368
      22.18.      0.316          0.002         0.063          0.971       0.370
      22.20.      0.359          0.006         0.058          2.912       0.376
      22.22.      0.721          0.116         0.545         58.026       0.492
      22.24.      2.111          1.498         1.785        749.212       1.991
      22.26.      4.469          6.232         6.300       3115.890       8.223
      22.28.      6.931         13.328         9.507       4753.426      17.729
      22.30.      7.455         15.098         4.478       2238.814      22.207
      22.32.      5.689          9.490         2.015       1007.602      24.222
      22.34.      3.957          5.031         0.971        485.478      25.193
      22.36.      2.462          2.059         0.437        218.589      25.630
      22.38.      1.759          1.020         0.273        136.649      25.904
      22.40.      1.298          0.521         0.146         73.175      26.050
      22.42.      0.950          0.248         0.097         48.273      26.146
      22.44.      0.740          0.126         0.072         35.995      26.218
      22.46.      0.604          0.066         0.058         29.182      26.277
      22.48.      0.512          0.036         0.026         17.856      26.313
      22.50.      0.416          0.014         0.011          7.050      26.327
      22.52.      0.320          0.002         0.011          1.120      26.329
      22.54.      0.252          0.000         0.020          0.000      26.329
      22.56.      0.202          0.000         0.031          0.000      26.329
      22.58.      0.164          0.000         0.042          0.000      26.329
      23. 0.      0.134          0.000         0.053          0.000      26.329
      23. 2.      0.111          0.000         0.064          0.000      26.329
      23. 4.      0.085          0.000         0.070          0.000      26.329
      23. 6.      0.051          0.000         0.072          0.000      26.329
      23. 8.      0.022          0.000         0.075          0.000      26.329
      23.10.      0.005          0.000         0.078          0.000      26.329
      0.100   RUNOFF FOR DAY 125 = 0.642 IN., SEASON TOTAL = 0.876 IN.

 125    MAY        5,1972   TOP ZONE SOIL MOISTURE = 10.51 IN.,   TOTAL = 10.51
          TOP 5-FT INCREMENTS    4.78    3.34    1.48    0.71    0.20
        ************************************************************************
```