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A MATHEMATICAL EROSION MODEL TO SIMULATE SOIL LOSSES IN AGRICULTURAL WATERSHEDS

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A mathematical erosion model to simulate soil losses in agricultural watersheds

by

Soon-kuk Kwun

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CHAPTER I. INTRODUCTION

The loss of soil by erosion induced by man's activity is a serious problem of increasing magnitude (Low 1978). The 1967 Conservation Needs Inventory conducted by the Soil Conservation Service, USDA, concluded that soil erosion is still the dominant problem and indicated that more than 60 percent of the crop land will need some control measures to reduce erosion losses to an acceptable minimum. Moreover, erosion problems will intensify as the demand for food increases (Pimentel et al. 1976).

Soil erosion has not only reduced the land available for food production but also has produced sediment which has become a major source of pollution in streams, reservoirs and lakes. Sediment carried by water runoff represents the dominant form of soil loss in the United States, delivering annually approximately 4 billion tons of sediment (NRCC 1974). Three billions tons of this total soil loss are estimated to be lost from agricultural and forest lands (Beasley 1972).

Sediment and erosion rate prediction from agricultural land are useful information, when planning facilities to control sediment losses and erosion damages on upland areas. In addition, estimation of the change in erosion rate of alternative land uses and watershed management systems requires that future methods for predicting sediment yield be very precise and easy to use.

Considerable progress has been made in the last decade in the development of techniques to estimate erosion and sediment yield from agricultural watersheds. Several types of prediction techniques are potentially available for this purpose. However, most of them have been directed towards determination of the quantity of soil delivered to a specific point, neglecting the components which contribute to the complex soil erosion processes within a watershed. The development of high speed digital computers has initiated a new research era in the field of soil erosion. The use of computers has provided a means for the rapid and intensive evaluation of complex soil erosion processes. The basis for the erosion model is the expression of the real system in terms of concise mathematical relationships.

Today, erosion modeling from agricultural watersheds is being rapidly developed to meet guidelines for the identification and evaluation of the characteristics and extent of agricultural non-point pollution such as sediment, nutrients and pesticides.

Objectives

The primary objective of this study is to develop a mathematical simulation model of soil erosion by water. The model must be comprehensive and acceptable for a wide range of conditions in agricultural watersheds and would be solved by a digital computer. The general objectives involved in this study are:

1. To develop a mathematical model to simulate soil erosion processes and to estimate total soil loss as well as sediment yield from an agricultural watershed.

2. To superimpose the mathematical erosion model on a working watershed model. The erosion model is designed to obtain most of its hydrologic impact data from the watershed model.
3. To evaluate the feasibility of the watershed and erosion model and to predict observed streamflow and sediment yield by application to a small test watershed.

CHAPTER II. LITERATURE REVIEW

More than 30 years ago, Ellison (1947) defined soil erosion as "a process of detachment and transportation of soil material by erosive agents." Detachment is the dislodging of soil particles from the soil mass by an erosive agent. Transportation is the entrainment and movement of detached soil particles from their original location. For erosion by water, the major erosive agents are raindrop impact and runoff water which flows over the soil surface.

The importance of erosion processes was recognized as early as the 1930's and 40's during which major progress in soil erosion research took place (Cook 1936, Ellison 1947). Although significant improvements regarding the concepts of soil erosion have been made in the past two decades, Ellison's definitions and approaches are still valid and are used.

A number of scientists have continued to develop methods for estimating soil erosion and sedimentation. Increased awareness of the need for pollution abatement has accelerated these efforts. Today, the Universal Soil Loss Equation (USLE) is widely used to predict soil-loss and sediment yield from upland areas (Wischmeier and Smith 1965). Although basic erosion principles were considered in the USLE development, its mathematical relationships were determined from statistical analysis of more than 10,000 plot-years of data. However, it is not reliable for predicting the soil loss from storms of a short duration basis which is essential for sediment yield prediction in streams, lakes and reservoirs.

More elaborate and flexible erosion prediction techniques are therefore needed for a wide range of meteorological and complex watershed conditions.

To help meet these needs, soil loss equations and models based on concepts and equations for basic erosion processes were developed in the late 1960's. Meyer and Wischmeier (1969) modeled the erosion process using ideas from Ellison and recent fundamental concepts. Using simulation, they demonstrated the potential of such a model in understanding and predicting the behavior of soil erosion by water.

In this chapter, the fundamentals of the soil erosion process as well as factors affecting soil erosion will be reviewed. Current methods of modeling soil erosion in upland and channel phases are also briefly described.

Erosion and Sedimentation Process

The erosion process is divided into interrill erosion and rill erosion according to the source of the eroded sediment (Meyer et al. 1975a). Generally, runoff (overland flow) on soil surfaces tends to concentrate in small channels called rills (Foster 1971, Meyer et al. 1975). Erosion occurring in these rills is defined as rill erosion, while erosion occurring on the areas between the rills is defined as interrill erosion (Foster and Meyer 1975).

The removal of soil from the soil mass can be thought of as a two-step process, first detachment, then transport (Ellison 1947). Detachment by raindrops (soil splash) and water runoff (overland flow), is a process of breaking the soil aggregates loose and into small units. Based on the above definition, the mechanics of erosion are composed of four subprocesses; detachment by rainfall, transport by rainfall, detachment by runoff and transport by runoff (Meyer and Wischmeier 1969). Although not all of the subprocesses occur on all source areas simultaneously, each has its part in the total erosion process.

Interrill erosion

Interrill erosion is primarily due to soil particle detachment by raindrop impact and subsequent transport of the detached particles by shallow interrill sheet flow (Foster and Martin 1969, Meyer et al. 1975a, Young and Wiersma 1973). Generally, detachment in interrill areas by overland flow is neglected since the shear stress is small because of the small flow depths and flow rates which occur on interrill areas (Foster and Meyer 1975). Consequently, raindrop impact is a dominant factor in the detachment of soil particles on interrill areas.

The rate of particle detachment by raindrop impact is time dependent even for a constant rainfall intensity (Moldenhauer and Koswara 1968). However, since the rainfall pattern is not consistent, the time effect must generally be ignored until further research defines the relationships (Foster 1978).

Soil particle detachment by rainfall impact has been shown to be dependent on several rainfall characteristics. The size of the drop and its velocity both contribute to the total detachment and thus to interrill erosion. Laws (1940) observed a 1,200 percent increase in the erosion rate when he increased the drop size from 1 to 5 mm. He concluded that the erosion rate increase was due to the greater kinetic energy of the drops. Ellison (1944) varied the size of water drops and raindrop velocities at various intensities and found that the resulting detachment was proportional to the velocity to the 4.33 power, the diameter to the 1.07 power and the intensity to the 0.65 power.

Ekern (1951) showed that soil splash was proportional to the kinetic energy when the amount of applied water is constant. Mihara (1951) also reported soil splash to be directly proportional to the kinetic energy. Free (1952, 1960) related soil splash to the 0.90 power of kinetic energy for sand and to the 1.46 power for natural soils.

Since rainfall intensity seemed to be related to the drop diameter and the associated terminal velocity, investigators attempted to express the energy of natural rainfall as a single valued function of rainfall intensity. Wischmeier and Smith (1958) used the data of Laws and Parsons (1943) to develop such a single valued function.

$$Ke = 206 + 87.3 \, \mathrm{Log}_{10} \, I \tag{2.1}$$

where Ke = kinetic energy per unit depth of rainfall (joules/m^2/cm)

I = rainfall intensity (cm/hr)

Rogers et al. (1967) found Wischmeier and Smith's equation to be a good approximation of the average kinetic energy - rainfall intensity relationship. However, other investigators such as Hudson (1971), Mihara (1951) and Morin et al. (1967) have shown that not all rainstorms confirm this relationship.

More recently, Bubenzer and Jones (1971) tested four different soil types having diverse physical characteristics. Rainfall intensity and kinetic energy were found to be the best indicators of soil detachment. By multiple regression they derived an equation of the following form:

$$SS = a(I)^{s}(KE)^{t} \qquad (2.2)$$

where SS = the amount of soil splash

I = rainfall intensity

KE = kinetic energy

a = constant

s,t = constant exponents

Ghadiri and Payne (1977) considered the actual breakdown of clods rather than the amount of splash and found that the breakdown was closely related to the product of raindrop diameter and drop velocity squared, which have the same dimensions as kinetic energy per unit area.

Since both the soil erosion rate and kinetic energy are a function of rainfall intensity, the soil detachment by raindrops can be expressed as a single function of the rainfall intensity. Laboratory experiments using soil and simulated rain of uniform size also suggest that soil detachment is proportional to rainfall intensity squared (Meyer and Wischmeier 1969, Bubenzer and Jones 1971, Moldenhauer and Long 1964, Foster and Meyer 1975). This relationship has been used successfully in several erosion models (David and Beer 1975, Smith 1977, Curtis 1976, Beasley 1977).

The transport capacity of interrill erosion is a function of several factors that include runoff rate, slope steepness, roughness of the surface, transportability of detached soil particles and the effect of raindrop impact (Meyer et al. 1975a). Raindrop splash significantly increases the transport capacity of interrill flow. Interrill flow without raindrop splash is therefore able to transport only a small load (Podmore and Merva 1969). On the other hand, Foster and Meyer (1975) suggested that direct splash of detached particles through the air to the rill is minor compared to soil transported by sheet flow. However, the relationship between the increase in transport capacity of sheet flow due to raindrop splash and the rainfall parameters is not known. Furthermore, a meaningful interrill transport capacity relationship is not yet available. However, a general relationship is suggested by Foster (1978) as follows;

$$T_{ci} = A\ (\tau - \tau_c)^{1.5} \tag{2.3}$$

where T_{ci} = the transport capacity of flow on interrill areas

τ = shear stress

τ_c = critical shear stress

A = a constant

Rill erosion

Overland flow occurs when rainfall intensity exceeds the soil infiltration rate. The erosiveness of runoff depends on its velocity of flow which increases with increased land slope, the depth of overland flow and the degree of concentration to rill (Meyer and Monke 1965).

Rill erosion begins when the eroding capacity of the flow at some point exceeds the ability of the soil particle to resist detachment by flow. Once rilling begins, the concentrated flow tends to enhance the detachment capability and rilling progresses (Meyer et al. 1975a).

An interrelationship between detachment by runoff and sediment load in rills has been proposed by Foster and Meyer (1972a).

$$\frac{D_r}{D_{rc}} + \frac{G}{T_c} = 1 \qquad (2.4)$$

where D_{rc} = rill detachment capacity (mass/unit area/unit time)

D_r = rill detachment rate (mass/unit area/unit time)

G = sediment load in flow (mass/unit width/unit time)

T_c = transport capacity of flow (mass/unit width/unit time)

The detachment capacity of rill flow describes the rate per unit of total area at which rill flow can erode particles from the soil mass, at a given location and slope, if there is no sediment load. Since the flow does contain a sediment load, the detachment rate is normally less than the detachment capacity. (Foster and Meyer 1975).

Some researchers (Rowlison and Martin 1971) have neglected rill detachment from their consideration of the soil erosion process. However, Foster and Meyer (1975) insisted that since the flow shear stress on agricultural land often exceeded the critical shear stress reported in the literature (Graf 1971), rilling of an unprotected slope should be considered. Smerdon and Beasley (1961) reported that the critical shear stress in agricultural soils could be expressed as $\tau_c = 0.213/d_r^{0.63}$ (when d_r = dispersion ratio of soil).

The relationship of flow variables to detachment capacity has received little study. Partheniades (1965) found that the erosion rate was well-correlated to the increase of the average bed shear past a threshold value. He derived a detachment capacity equation based on the assumption that the bed shear stress varies as a normal distribution with time. A sediment transport equation by Yalin (1963) also expresses detachment, combined with use of an appropriate critical shear stress. If the bed shear stress is large compared to the critical shear stress, Foster and Meyer (1975) proposed that detachment capacity may be proportional to the 1.5 power of the shear stress.

For rill flow, transport capacity is required to transport the detached soil particle either in the interrill or rill area. Meyer and Wischmeier (1969) suggested an equation to describe transport capacity by overland flow,

$$T_c = a\, s^{5/3}\, q^{5/3} \qquad (2.5)$$

where T_c = transport capacity (mass/width/time)

s = sine of slope angle

q = discharge rate per unit width

a = coefficient dependent on soil and cover

Moldenhauer and Koswara (1968) observed the erosion process on natural soils during simulated rainstorms. They found that a large fraction of the transported soil moves by saltation and by rolling along the bottom of the stream.

Soil transportability in rill flow is largely dependent on soil particles that are detached from the soil mass. Most soil is detached and transported in the form of aggregates having larger diameters but lower densities than primary particles (Swanson and Dedrick 1967). These particles were found to be 0.2 mm in diameter and had a specific gravity of 2.0 (Long 1964).

With these observations, Foster and Meyer (1972c) concluded that detached particles moved primarily as bed load and thus the transport capacity of rill flow could be expressed by bed load formulae. Formulae used include those of Yalin (Foster and Meyer 1972c), the DuBoys (Young and Mutchler 1969, Foster and Huggins 1977), Meyer-Peter and Müller (Li 1977), Einstein (Li 1977, Barfield et al. 1977), Young(Smith 1977) and Bagnold (Donigian and Crawford 1976a).

Yalin's bed load equation (Yalin 1963) assumed that flow was turbulent with a laminar sublayer having a thickness not exceeding the size of the bed roughness. It was also assumed that all bed grains have the same shape and size and the motion was caused by saltation. In this equation, the existence of critical tractive force is accepted. Foster and Meyer (1972c) summarized Yalin's equation as:

$$P = \frac{W_s}{\gamma d V_*} = 0.635s \left(1 - \frac{1}{as} \ln (1 + as)\right) \tag{2.6}$$

$$s = \frac{Y}{Y_{cr}} - 1 \text{ (when } Y < Y_{cr},\ W_s = 0.0) \tag{2.7}$$

$$a = 2.45\ C_T^{0.4}\ Y_{cr}^{0.5} \tag{2.8}$$

$$Y = \frac{V_*^2}{(C_T - 1)\ gd} \tag{2.9}$$

$$V_* = (gRS)^{1/2} = (\tau/\rho)^{1/2} \tag{2.10}$$

$$Re = \frac{V_* d}{\mu} \tag{2.11}$$

where W_s = transport capacity (gm/sec/cm of width)

γ = unit weight of solids in fluid (gm/cm^3)

d = particle diameter (cm)

V_* = shear velocity

s = dimensionless excess of the lift force

Y = particle movement of y direction of flow

Y_{cr} = ordinate from the Shield's diagram (Figure 1)

C_T = particle specific gravity

g = acceleration due to gravity (cm/sec^3)

R = hydraulic radius (cm)

S = slope of energy gradeline

τ = shear stress acting on soil

ρ = mass density of water

μ = kinematic viscosity of the fluid (cm^2/sec)

Yalin's method was derived analytically for the discharge of solids in steady uniform flow for which the movement of material is confined to the bed. The only empirically derived factors are the constant 0.635 and the Shield's diagram under flat bed conditions.

Deposition

The deposition of eroded particles was examined as a subprocess separate from either detachment or transport capacity, although it is related to both. Spraberry and Bowie (1969) indicated that deposition on upland areas was the major factor explaining the discrepancy between soil loss prediction with an erosion equation, such as the USLE and

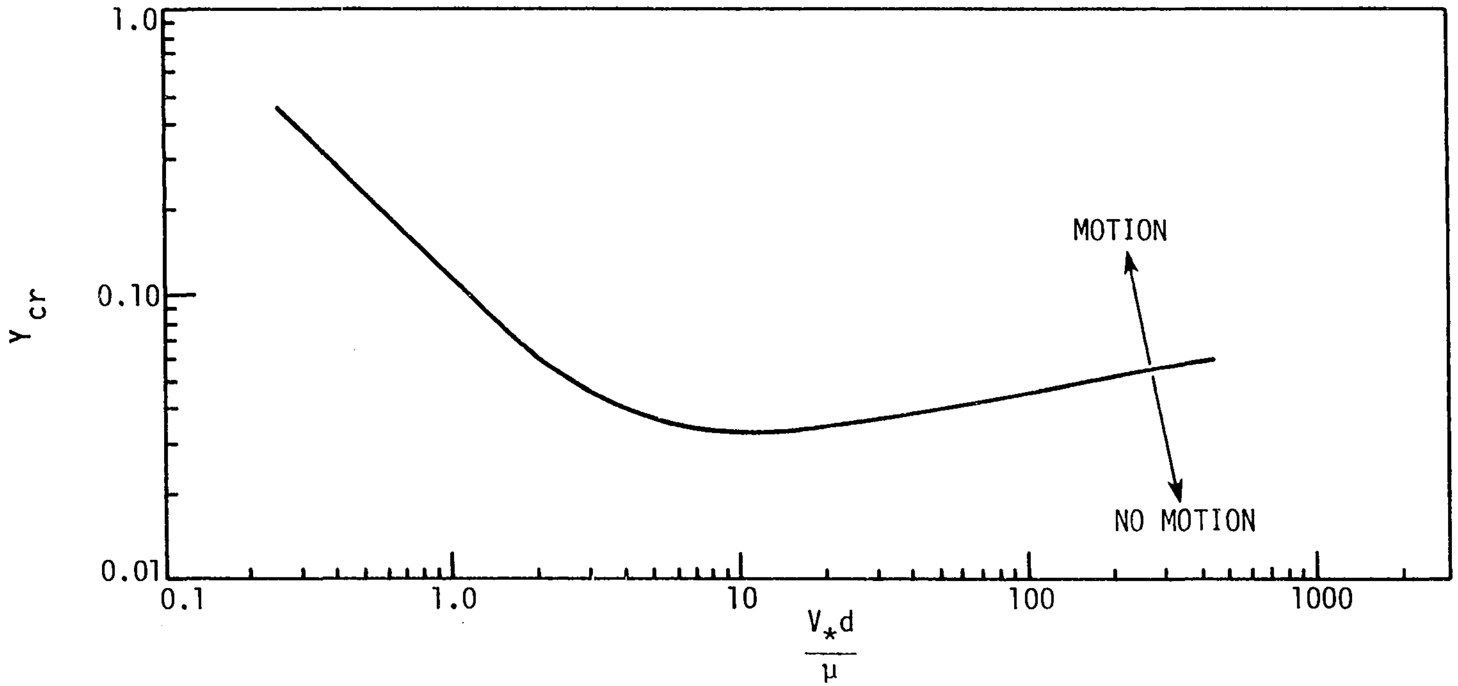


Figure 1. Shield's diagram; dimensionless critical shear stress vs Reynolds number

observed sediment yields. A delivery ratio concept has been used with these equations to account for the deposition.

Deposition may occur when the sediment load in the flow exceeds the flow's transport capacity (Meyer and Wischmeier 1969). This can happen when the transport capacity is reduced because of the reduction in the energy gradeline as flow reaches the bottom land or enters ponded water. Sediment deposition also depends on the size of delivered particles and the turbulence of the flowing water. Foster and Huggins (1977) described the deposition observed on an experimental concave slope with uniform size sediment and shallow overland flow. Flow through mulch or vegetation also has less transport capacity (Foster and Meyer 1972c) which may cause deposition.

Studies of the deposition as it relates to upland areas are relatively uncommon in the literature. Partheniades (1972) presented a summary of several basic studies in which he participated. However his results may not apply to erosion because of the different sediment sizes that he used.

Foster and Meyer (1975) introduced Einstein's equation (Einstein 1968) to approximate the rate of deposition based on the concept of detachment and limiting transport.

$$D_p = C_d (T_c - G) \tag{2.12}$$

where D_p = deposition rate

C_d = a coefficient which is a function of sediment fall velocity, water quality and depth of water

T_c = transport capacity

G = sediment load

This equation is simple and useful if the transport capacity and sediment load are reliably estimated.

Brenneman (1979) recently developed a model based on settle tank theory to predict deposition under the presence of cornstalks in single rills. For all other conditions constant, the model predicts less deposition on steeper slopes.

Channel erosion

Channel erosion, which includes both stream bed and stream bank erosion, can be a significant quantity under some circumstances. For channels in non-cohesive sediments, Lane's relationship (1955) is a useful tool for qualitative prediction of erosive channel conditions ($\sim$ indicates proportionality).

$$Q\ s \sim G_s\ d_s \tag{2.13}$$

where Q = stream discharge

s = longitudinal slope of stream channel

G_s = bed sediment discharge

d_s = particle diameter

Change in one variable will have a proportional effect on the others. This property is particularly useful when two of the variables are assumed to remain constant.

Several sediment discharge formulae (Lane and Borland 1951, Einstein 1950, Colby and Hembree 1955) can be used to obtain quantitative estimates of channel erosion and deposition. Other methods that consider the forces exerted in the channel boundaries and use a known sediment rating curve can also be used.

David and Beer (1975) discussed the factors related to channel erosion and formed an empirical statement.

$$C_s = f(Y, V, d_s, n, S, \gamma_d) \tag{2.14}$$

where C_s = channel bed and bank scouring

Y = flow depth in channel

S = slope steepness of channel

V = average velocity of flow

n = channel roughness coefficient

d_s = mean sediment diameter

γ_d = specific weight of sediment

They simplified the above relation to,

$$C_s = k1\ Q^{\alpha} \tag{2.15}$$

where C_s = channel erosion

Q = mean daily discharge

$k1, \alpha$ = coefficients related to watershed and stream flow characteristics

Because flow depth, velocity, channel shape and roughness coefficient are related to the discharge and the remaining terms are constant for a given stream, Equation (2.15) can be applied to different streams if reliable coefficients can be obtained. David and Beer (1975) found values of 0.15 for kl and 1.33 for α on an Iowa watershed.

Yoo (1979) proposed a similar equation but accounted for critical discharge based on the equation proposed by David and Beer (1975).

$$C_s = k2\ (Q - Q_c)^{\beta} \tag{2.16}$$

where Q_c = critical discharge

$k2, \beta$ = coefficients equivalent to kl and α in Equation (2.15).

This form of the equation may be an improvement on Equation (2.15) since the scouring power generated by a certain quantity of flowing water could be lower than the erosion resisting forces of the channel body. The maximum permissible velocity can be found in the literature (Fortier and Scobey 1926).

Effect of Soil, Vegetation and Land Management

Cook (1936) stated that three major factors that affect the process of water erosion are those due to soil, water and vegetation. The influence of water on soil erosion has been discussed in the previous sections. The soil and vegetation act as nature's intervener in the detachment and transportation of eroded particles. Early investigators (Cook 1936, Ellison 1947) considered the three factors in expressions of soil erodibility, potential erosivity and cover effectiveness.

Soil erodibility

Soil erodibility is expressed as an erodibility index based on field tests of the basic soil characteristics. Some soils are naturally more susceptible to erosion than others (Wischmeier and Mannering 1969). Soils also differ in their ease of detachment by raindrop impact relative to their ease of detachment by flow (Meyer et al. 1975a). The erodibility of deposited soil also depends on the type of sediment, on wetting and drying cycles and on compaction. When the soil is compacted, the moisture content and the cultivation practice are important since the soil surface conditions influence erodibility (Grissinger 1966).

Wischmeier and Smith (1965, 1978) developed a soil erodibility factor K in their Universal Soil Loss Equation from 23 major soils on which erosion studies have been conducted since 1930. The soil erodibility values for numerous other soil types have been approximated by comparison with those determined experimentally. Since the soil erodibility factor has been evaluated independently of the effects of the other factors, the K factor in the Universal Soil Loss Equation can be used as a relative term affecting soil erosion.

Olson and Wischmeier (1963) computed K values for many soils in 11 states by rearranging the Universal Soil Loss Equation and using data collected from a long term series of erosion experiments.

Since direct determination of K values is time consuming and expensive, considerable research has been performed on predicting soil erodibility from soil properties (Peele et al. 1945, Barnett and Rogers 1966, Wischmeier and Mannering 1969, Wischmeier et al. 1971, and Römkens et al. 1975, 1977). Wischmeier and Mannering (1969) presented the relationship of soil properties to the soil erodibility. They stated that the long time average soil losses may vary more than 30-fold due to basic soil differences. They presented a complicated mathematical equation based on 15 soil properties and their interactions.

Wischmeier et al. (1971) presented a new soil erodibility model based on five soil parameters, which translated into a simple nomograph. For soils containing less than 70 percent silt and very fine sand, the nomograph solves the equation for the soil erodibility factor, K.

$$100\ K = 2.1\ M^{1.14}\ (10^{-4})\ (12-a) + 3.25\ (b-2) + 2.5\ (c-3) \qquad (2.17)$$

where K = soil erodibility factor

M = (% silt + very fine sand) (100 - %c)

a = percent of organic matter

b = the soil structure used in soil classification

c = the profile permeability class

This procedure permits the determination of the soil erodibility factor for various soils, since it requires only five soil parameters that are available from routine laboratory determinations and standard soil profile descriptions.

Vegetal cover and land management

The best means of protection against soil erosion is vegetal cover. This affects both the infiltration rate and the susceptibility of the soil to erosion. Baver (1965) classified the major effects of vegetation on runoff and erosion as follows: the interception of rainfall by plants, the decrease in both velocity of runoff and the wetting action of water by the vegetative cover; the increased granulation of soil by roots; the increased soil porosity due to vegetative growth; plant transpiration of water leading to subsequent dehydration of the soil. Two of the most important effects of vegetative cover on soil erosion are the absorption or dissipation of raindrop impact and the reduction of both overland flow and tractive force with increased hydraulic roughness and reduced effective slope (Kisisel 1971, Meyer et al. 1975b).

Wischmeier (1975) created three categories for the effects of vegetation, plant residues and other materials: (1) above the soil surface, (2) at the soil surface and (3) within the soil surface. Above the soil, the vegetative canopy reduces the raindrop impact. Materials on the soil surface reduce the surface area exposed to direct raindrop impact, reduce flow velocity and increase the surface storage capacity. The effect within the soil is to improve soil structure and to increase the infiltration rate.

Baver (1938) showed that 12 to 55 percent of the total rainfall was intercepted by plant canopies and was prevented from falling directly on the land surface. Interception depends on both crop type and crop density. Wischmeier (1975) reported that if the canopy is close to the ground, water dripping off the leaves has much less energy than unhindered raindrops. Meyer et al. (1975b) indicated that the canopy which intercepted the rainfall immediately above the rill flow decreased rill erosion and in addition eliminated the interrill area. However, canopy seemed to have little effect on rill erosion.

Materials in contact with the soil surface are more effective than canopy in reducing erosion. Mulch protects a portion of the interrill area from direct raindrop impact and retards the runoff which causes an increase in the flow depth. The increased flow depth decreases detachment by cushioning the impact forces (Mutchler and Young 1975). Higher mulch rates protect the soil surface from sealing which results in a higher infiltration rate into the mulched surface than into a bare soil (Mannering and Meyer 1963). Mannering and Meyer showed, that on a five percent slope, straw mulch rates of 1/4 and 1/2 ton per acre reduced erosion from simulated rainstorms to 26% and 11%, respectively, of the erosion from an unmulched plot. Lattanzi et al. (1974) studied the effect of mulch rate on interrill erosion. His data showed no slope effect even though shallower flow and therefore less cushioning were expected on the steeper slopes.

In recent years more emphasis has been placed on relating soil erosion to the percentage of total surface that is covered by residue (Wischmeier 1973, Wischmeier 1975, Sloneker and Moldenhauer 1977, Laflen et al. 1978). From studies of uniformly distributed wheat straw, Wischmeier (1973) reported that if 50 percent of the surface was covered by crop residue, soil loss could be reduced to 32% of that lost with no mulch present. A surface cover of 75% would reduce soil loss to 16% of that with no mulch, and soil loss would virtually be eliminated by a 100% cover. Laflen et al. (1978) measured soil loss reduction from varying percent covers of corn residue. They found corn residues were more effective in controlling erosion than the wheat straw reported by Wischmeier (1973). Foster and Meyer (1972b) developed an equation which described the relationship between exposed soil and mulch rate.

$$\Delta = e^{-0.514M} \tag{2.18}$$

where Δ = portion of soil surface exposed

M = applied mulch rate (Mg/ha)

Another effect of surface material is to reduce rill erosion by reducing shear stresses exerted by the flow on the soil surface. Foster (1978) offered the relationship,

$$\tau = \gamma \, V_c \, f/8g \tag{2.19}$$

where τ = shear stress acting on the soil

γ = unit weight of the runoff

V_c = flow velocity with cover

f = friction factor

g = acceleration due to gravity

Foster and Meyer (1972b) also showed from the Darcy - Weisbach equation that,

$$\frac{\tau_c}{\tau} = \left(\frac{V_c}{V}\right)^2 \tag{2.20}$$

where τ_c = shear stress with cover

τ = shear stress without cover

V_c = flow velocity with cover

V = flow velocity without cover

It can be shown that if the soil loss is assumed proportional to $\tau^{1.5}$, then soil loss is also proportional to V^3. Consequently, the ratio of soil loss with cover to soil loss without cover is proportional to $\left(\frac{V_c}{V}\right)^3$.

Tillage is known to increase rill erosion more than it does interrill erosion. Wischmeier (1975) suggested that a soil that had not been tilled for six years was only 40% as erodible as it would have been immediately after its last tillage.

In the Universal Soil Loss Equation, the cropping management factor C, accounts for the crop grown, the tillage method, the crop residue treatment, the level of productivity and other cultural practice variables (Meyer 1971). Wischmeier (1975) presented the effect of plant vegetation and the mulch rate applied to a field as two factors which influence the crop and management factor C of the USLE.

Soil Loss Prediction Equations

There are several different methods one can use to compute the amount of erosion from upland areas. These were developed primarily to determine the amount of soil lost from the field, and do not express a realistic sediment yield without consideration of the processes of deposition and transportation.

Zingg (1940) experimentally obtained the following relationship which related the effects of slope and length of slope on soil loss:

$$E = C\ L^{1.6}S^{1.4} \tag{2.21}$$

where E = soil loss per unit width

C = a constant depending on the soil, infiltration, intensity and other variables

L = length of slope

S = percent slope steepness

A similar equation which includes more of the variables affecting the soil loss was developed by Musgrave (1947).

$$E = I \left(\frac{R}{100}\right) \left(\frac{S}{10}\right)^{1.35} \left(\frac{L}{72.6}\right)^{0.35} \left(\frac{P}{1.25}\right)^{1.75} \qquad (2.22)$$

where E = sheet and rill erosion

I = erosion from continuous crop from a given soil

R = cover factor

S = land slope in percent

L = length of slope

P = the maximum 30 minute rainfall amount, 2 year frequency

Equation (2.22) was later modified by Farnham et al. (1966) in the study of sediment yields in western Iowa as follows;

$$E = 0.59 \left\{\frac{KR}{100}\right\} P \left\{\frac{R}{100}\right\} \left\{\frac{S}{10}\right\}^{1.35} \left\{\frac{L}{72.6}\right\}^{0.35} \qquad (2.23)$$

where K = soil erodibility factor

R = rainfall factor

P = conservation and practice factor

S, L = same as defined in Equation (2.22)

Browning et al. (1947) developed the concept of predicting soil loss by use of erosion factors. This concept of using erosion factors was later used in the Universal Soil Loss Equation developed by Wischmeier and Smith (1958, 1965, 1978). The Universal Soil Loss Equation is:

$$A = R\ K\ LS\ C\ P \tag{2.24}$$

where A = average annual soil loss

R = rainfall factor

K = soil erodibility factor

LS = length and steepness of slope factor

C = cropping management factor

P = conservation practice factor

The Universal Soil Loss Equation is based on stochastic data and is a useful management tool. It is designed primarily for annual prediction of soil loss and may give large errors for single event rainstorms (Wischmeier 1976).

However, Foster et al. (1977) changed the R factor to:

$$R_m = R_{st} + 0.5\ a\ V_u\ \sigma_{pu}^{1/3} \tag{2.25}$$

where R_m = a modified erosivity factor to replace R when USLE is used to estimate single storm soil loss

R_{st} = EI for storm

E = total energy of a storm

I = the storm's maximum 30 minute intensity

a = a coefficient

V_u = volume of runoff for storm

σ_{pu} = peak runoff rate for storm

The slope length exponent n varies from storm to storm (Foster et al. 1977). The USLE was developed for plots of uniform steepness, soil and cover. The USLE is therefore, purely an erosion equation and it does not estimate deposition (Foster and Wischmeier 1974).

Meyer and Monke (1965) studied the effects of slope steepness, slope length, particle diameter and rainfall intensity on soil erosion by rainfall and overland flow using spherical glass beads. A multiple regression analysis of experimental data they obtained from trials when the slope steepness was 70% or greater gave the equation of best fit as;

$$e_r = C_S\ (S-S_c)^m,\ e_r = C_L\ (L-L_c)^n \text{ and}$$

$$e_r = C_D\ D^{-0.5} \tag{2.26}$$

where e_r = soil erosion by runoff

C_S, C_L, C_D = constant coefficients

L = slope length

L_c = critical slope length

S = slope steepness

S_c = critical slope steepness

m,n = exponential constants

D = sphere diameter

Other investigators (Meyer 1965, Meyer and Kramer 1968, Young and Mutchler 1969, Kilinc and Richardson 1973) have attempted to form a soil loss prediction equation which relates to the slope length and slope steepness factors.

Erosion-Sediment Yield Models

There are two approaches to modeling small watershed erosion-sediment yield processes; one is empirical and the other uses fundamental physical relationships. The fundamental model approach is based on theoretical concepts in erosion mechanics. The fundamental model provides more information on the variability of erosion and sediment load over both space and time during a storm than the empirical model. Foster (1978) recognized several advantages of fundamentally derived models over empirical equations;

(1) They are based on mathematical relationships and consequently can be more easily extrapolated.
(2) They more accurately represent the process they describe.
(3) They are more accurate for single storm events.
(4) They can consider more complex areas.
(5) They consider the deposition process directly.
(6) They consider both channel erosion and deposition.

The fundamental model is emphasized in current research programs although the empirical Universal Soil Loss Equation and modifications of it are still widely used. Meyer and Wischmeier (1969) proposed a mathematical erosion model to describe the process of soil erosion by water based on concepts first reported by Ellison (1947). Figure 2 shows the model flow chart which simulates the process of soil erosion by water. The four erosion subprocesses are evaluated at each successive slope length increment and the soil movement is routed downslope as illustrated.

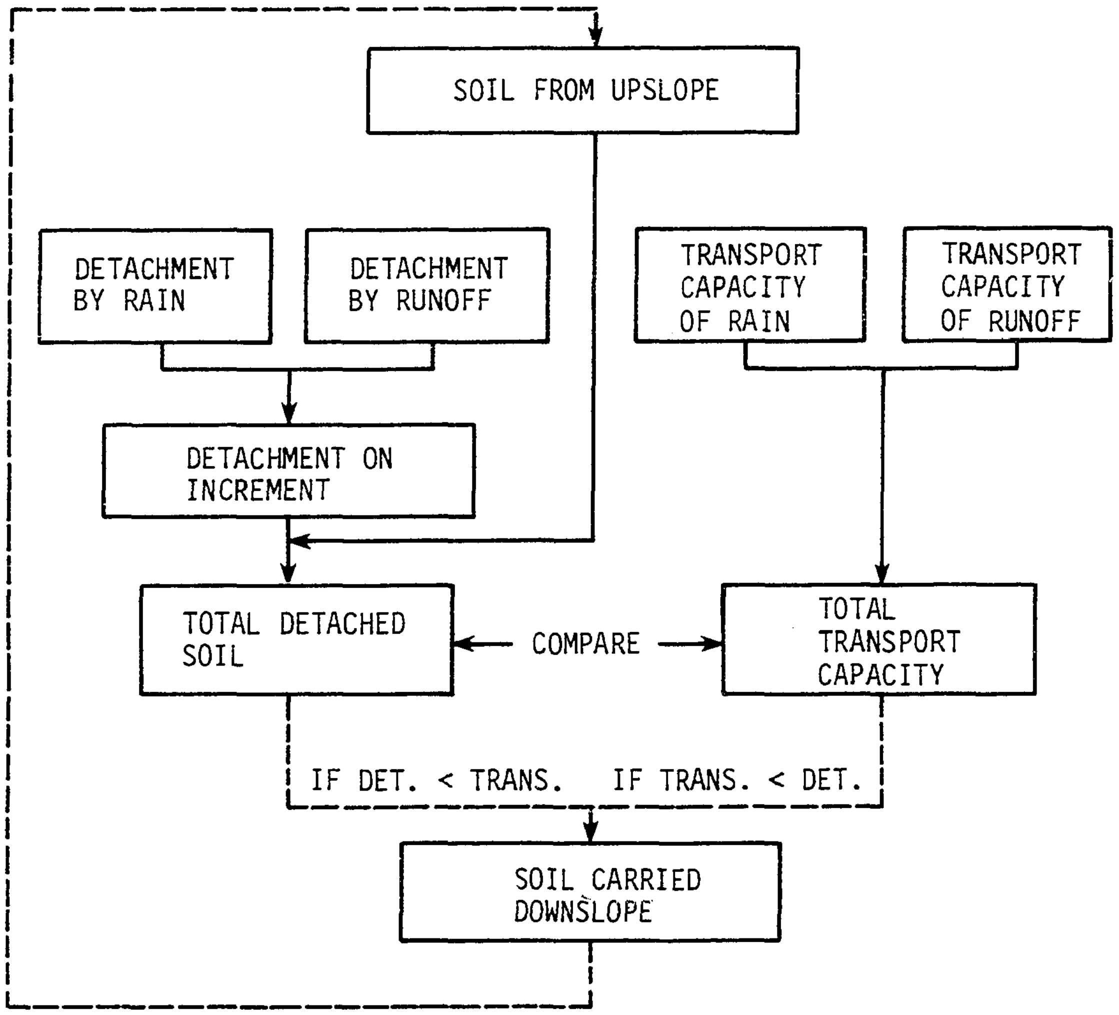


Figure 2. Flowchart of the model simulating the soil erosion process by water (Meyer and Wischmeier, 1969)

The study of Meyer and Wischmeier (1969) demonstrates two important concepts very relevant to erosion modeling:

1. Different processes are modeled separately which allows physical concepts to be used. The separate effects of these processes may be observed and varied independently.
2. The processes are separated into detachment and transport functions. These are then compared to determine whether sediment supply or sediment transport is limiting. Prediction of erosion or deposition at a point on the profile is therefore possible.

Negev (1967) developed a sediment model using a digital computer based on the Stanford Watershed Model by Crawford and Linsley (1966). The model calculates soil detachment by raindrop impact and places it in storage. Overland flow, calculated by Stanford Watershed Model, transports the material in storage and is used to compute rill and gully erosion. The total material from raindrop impact and gully erosion is then divided into stream interload and bed material load components using a sediment rating curve. Figure 3 depicts the erosion and sedimentation processes as conceived by the model.

Rowlison and Martin (1971) proposed a rational model which described slope erosion. This model is similar to that proposed earlier by Meyer and Wischmeier (1969). Both models consider the detachment and transport function of rainfall and runoff. Rowlison and Martin, however, qualitatively evaluated the effects of slope and the depth of water flow over the soil surface in the various erosion subprocesses during a

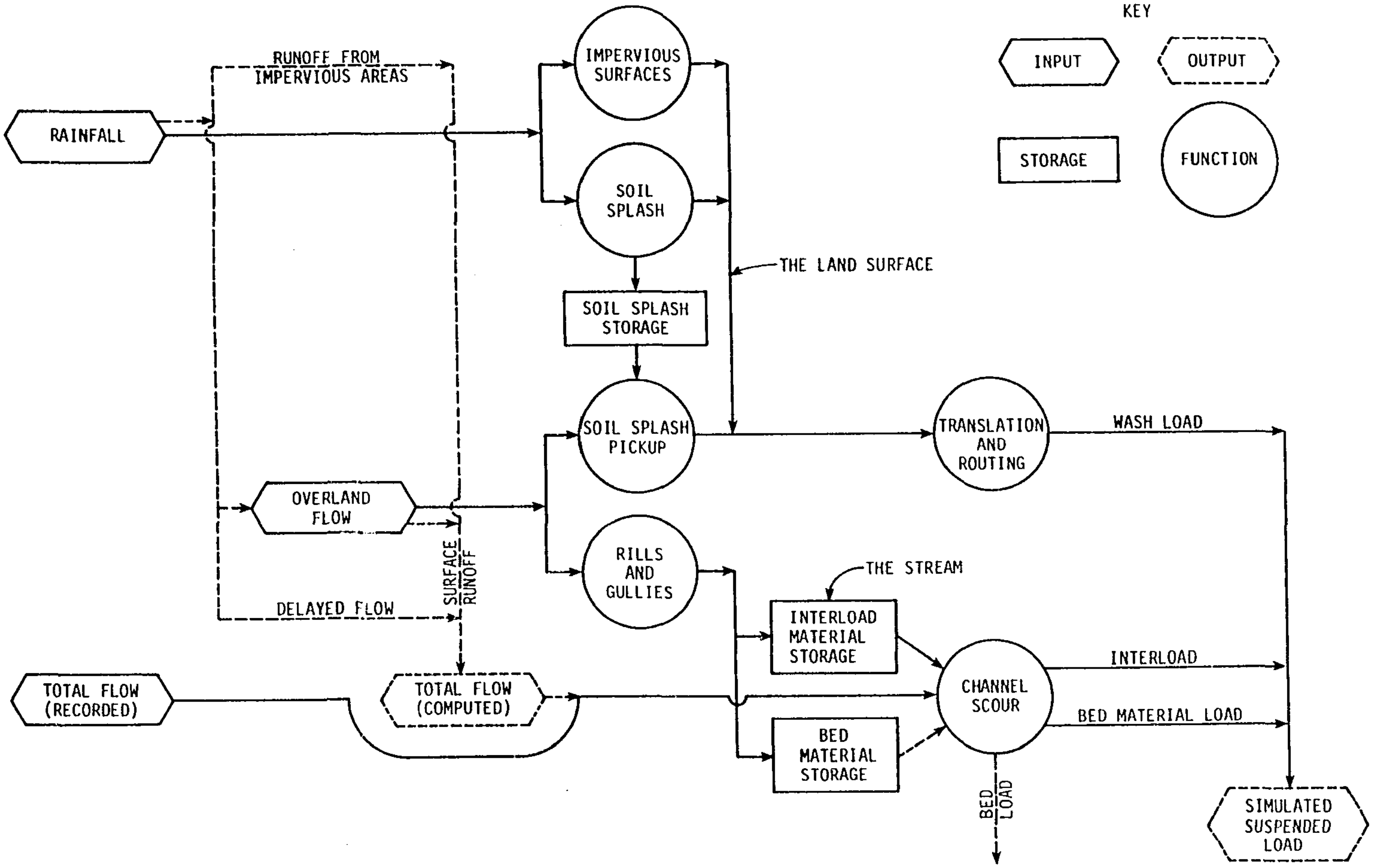


Figure 3. Flowchart of sediment model (Negev, 1967)

laboratory experiment. In the model it is assumed that the detachment of soil due to runoff is negligible since the shearing stresses exerted by the flowing water are usually small compared to the cohesive forces of most soils. The quantities of material detached and transported by both rainfall and runoff are functions of slope steepness, soil texture, surface roughness, soil moisture, crop or canopy cover and both rainfall and flow characteristics.

These basic concepts (Meyer and Wischmeier 1969, Rowlison and Martin 1971) have been combined into a model of soil erosion based on upland areas, by Foster and Meyer (1972a, 1975). Their model separates the source of sediment by flow conditions, that from concentrated runoff flowing in rills and that from regions of interrill erosion. Two equations, the continuity equation for mass transport and a sediment load flow detachment interrelationship, form the basis of the model. These equations, and the results from experimental evaluation of the factors affecting the amount of soil detached and transported, provide a means to study the effects of vegetation, mulches, slopes, etc., on the sediment yield.

David and Beer (1975) developed a similar model that incorporated the concepts of detachment and transport due to Meyer and Wischmeier (1969). It, however, embodies a concept of detachment storage and channel erosion and thus is designed for considerably larger watersheds. Figure 4 shows the component relationship in the model. Some of the relationship and concepts utilized by the model are explained below:

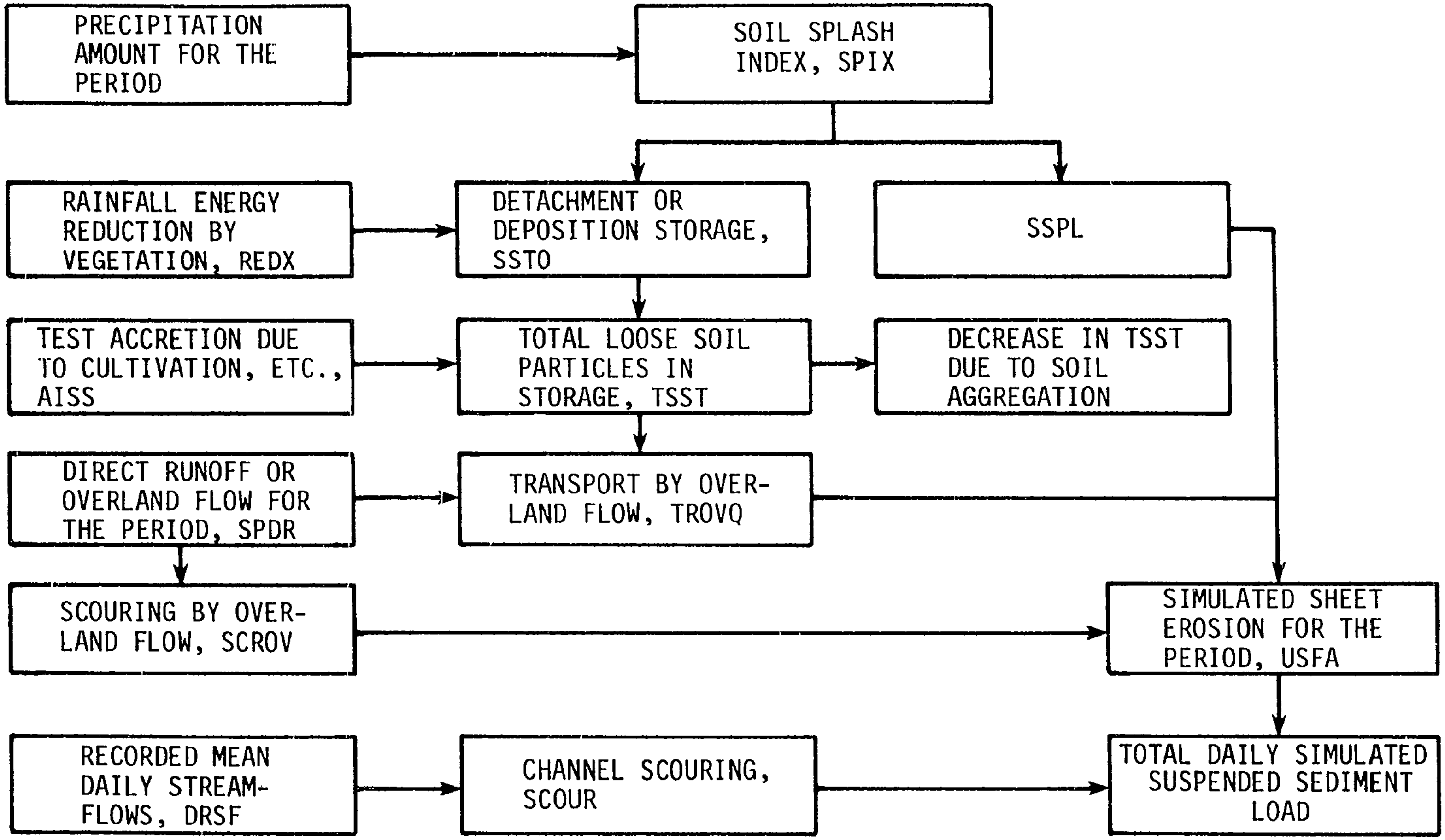


Figure 4. Schematic diagram of the sheet erosion model (David and Beer, 1975)

1. Detachment by rainfall

1) Soil detachment storage

$$TSST = SSTO \exp(-PEWR \; t) \tag{2.27}$$

$$SSTO = \beta 2 \; REDX \; SPIX \tag{2.28}$$

where TSST = total detachment storage

t = time

PEWR = constant depending on soil and climatic factor

SSTO = total detachment storage at the beginning of the time interval

β2 = soil and land factor

SPIX = 2.0 power of rainfall intensity

REDX = reduction of energy due to the depth of overland flow

SPDR = overland flow depth

2) Soil splash directly to stream

$$SSPL = A_{rd} \; OFSS \; SPLASH \tag{2.29}$$

where A_{rd} = area where the splash directly goes to stream

OFSS= overland flow surface slope

SPLASH = β2 SPIX

3) Soil particle picked up from impervious area

$$IMPU = KP \; FIMP \; SPLASH \tag{2.30}$$

where KP = empirical constant

FIMP = fraction of watershed by impervious

2. Scour by overland flow

$$SCROV = \beta 5 \quad SPDR^{\beta 6} \tag{2.31}$$

where $\beta 5$ = a constant representing soil characteristics and overland flow

$\beta 6$ = an exponent

3. Transport capacity

$$TROVQ = \beta 3 \quad SPDR^{\alpha 2} \tag{2.32}$$

where $\beta 3 = SL_F \quad OFSS^{\alpha}$

SL_F = soil and surface roughness factor

α = an exponent

$\alpha 2$ = an exponent

4. Channel scour

$$SCOUR = \beta 4 \quad DRSF^{\alpha 3} \tag{2.33}$$

where $\beta 4$ = constant depending on channel roughness coefficient, mean particle diameter and specific weight of sediment

$\alpha 3$ = an exponent

DRSF = recorded channel stream flow

5. Total erosion

$$TDSSL = SCOUR + USFA \tag{2.34}$$

$$USFA = ATROVQ + SCROV + SSPL + IMPU \tag{2.35}$$

where ATROVQ = TSST if TROVQ > TSST or TROVQ if TROVQ < TSST

David and Beer (1975) superimposed this erosion model on the flow components of the Kentucky Watershed Model. To fortify the model, they considered the erosion-sediment yield subprocesses and used hydrologic inputs for both rainfall and runoff to get the interaction effect.

However, the model included several lumped parameter values over the watershed, and requires accurate data for calibration. Consequently, transferability to ungaged areas and to land uses significantly different from those used during model calibration is limited.

Bennett (1974) discusses the mathematical concepts of sediment-yield modeling by dividing the phenomenon into an upland phase and a low land-channel phase. The upland phase relies on theory reported in the previous discussion and consists of stream channel transport. General problems of analytical solution and areas of greatest need in sediment modeling are thoroughly described.

Bruce et al. (1975) developed a mathematical model which described the rate and quantity of runoff water from separate rainfall events and the sediment and pesticides transported in a watershed. The runoff water is calculated by convolving an area characteristic and reliable state functions to produce a variable response function that is then convolved with a computed effective rain. Rill and interrill concepts were used conceptually in their sediment model. The sediment contribution from interrill erosion is a function of rainfall intensity and soil susceptibility to erosion. The rill is a function of water runoff and the rate of change of water runoff. The model fits a variety of complex size and land-use areas. However, the model is somewhat abstract, and difficult for the user to follow. It requires historical data for calibration.

Curtis (1976) used Meyer and Wischmeier's erosion relationships (1969) and a kinematic hydrologic model to simulate the erosion and sediment for an urban area. In this model, erosion simulation from an impervious area is emphasized and the channel processes are not included. This model can be classified as a distributed model since it is able to reflect interactions of spatial variations.

Smith (1977) described a dynamic simulation model that incorporates the differential equation for continuity and suspended sediment into a kinematic numerical model for the hydrologic response of the watershed surface. It included an advanced infiltration function that can accept complex rainfall patterns. The structure of the model enabled it to simulate the response from complex watershed shapes and to serve as a framework within which an alternative erosion and transport model could be compared.

Li et al. (1977) developed an erosion-sediment model based on equations for separate erosion and transport processes in overland flow and channel areas. These processes are driven by a kinematic overland flow model. The model is classified as a distributed or base event model which estimates erosion and sediment yield distribution in time and space.

The ANSWERS model developed by Beasley (1977) is also a distributed model. He used separate equations for detachment and transport of sediment in overland flow areas and used the watershed model developed by Huggins and Monke (1970) to obtain overland flow from rainfall. The model was designed to simulate the effects of hypothetical land use and management changes from several storms and was used for the purpose of water quality monitoring.

Yoo (1979) developed an erosion model to estimate upland and total soil loss from an agricultural watershed in the Pacific Northwest. This model is used in conjunction with the USDAHL-74 watershed hydrologic model. He concluded, after testing the model for different sizes of watersheds in the Polous area, that the model is sufficiently accurate to serve as an erosion simulation model for larger areas. The non-representative rainfall and temperature could be one of the reasons for poor simulations.

HYDROCOMP INTERNATIONAL developed a series of mathematical models for simulating the impact of nonpoint source pollutants on water quality by taking advantage of the Stanford Watershed Model as a watershed runoff model and Negev's model as an erosion-sediment model. The Pesticide Transport and Runoff (PTR) model (Crawford and Donigian 1973) was developed as a first attempt for this purpose. After including the snow-melt routine and a plant nutrient simulation model to the PTR model, they named their model the Agricultural Runoff Management (ARM) model (Donigian and Crawford 1976b, Donigian et al. 1977). Consequently, the ARM model is used to estimate the water, sediment, pesticide and nutrient impact in a stream, but does not simulate the channel process. The ARM model is therefore limited to small watersheds having uniform land use. To overcome this problem, Leytham and Johanson (1979) have recently included a channel process in the ARM model to simulate stream water quality and sediment movement in the channel. They renamed it the Watershed, Erosion and Sediment Transport (WEST) model. The WEST model is a comprehensive management model which includes several component models including an erosion and a sediment component to simulation stream water quality.

CHAPTER III. WATERSHED MODELING

To develop a physically based method for erosion prediction, a good method for determining the amount of surface runoff is essential. Present day hydrologic methods are oriented towards modeling the entire hydrologic cycle. These give better results than modeling only the point of interest. The development of watershed modeling based on mathematical relationships within a watershed hydrologic cycle is now well-established. Many different methods are in existence.

The term "watershed modeling" is often used for the simulation of streamflow from a watershed. This implies the use of digital computational methods to reproduce a historical event or to preview the future response of the physical system to a specific action.

One of the earliest classification of simulation models separates them into two broad categories: physical and mathematical. Physical models include analog technology and principles of similutude which are applied to a small scale model. In contrast, mathematical models rely on mathematical statements representing the real system. The mathematical models can be classified further as having a theoretical or empirical approaches. Empirical models can be said to be "representations of data" and theoretical models are said to be "logical structures similar to real world systems" (Woolhiser 1973). Mathematical models also can be stochastic or deterministic models. Stochastic models involve the use of statistical techniques and use the statistical properties of existing records and probability laws to generate future events. A model is deterministic if the initial conditions, boundary conditions and inputs are specified and the output is known with certainty.

Deterministic models, whether empirical or theoretical, are referred to a lumped parameter model if a model ignores spatial variations in parameter values throughout an entire system. Distributed parameter models account for the variations from point to point throughout the system.

Since small agricultural watersheds normally have very limited hydrologic and climatological data, a deterministic model with lumped parameters will be the primary concern of this study. Models of this type include the Stanford Watershed Model (Crawford and Linsley 1966), USDAHL74 Model (Holtan et al. 1975) and SCRAM model (Bailey 1975).

One of the earliest and most widely used deterministic lumped watershed models is the Stanford Watershed Model. The model is based on the following principles set out by Crawford and Linsley (Fleming 1975).

1. The model should represent the hydrologic regimes of a wide variety of streams and rivers.
2. It should be easily applied to different watersheds with existing hydrologic data.
3. The model should be physically relevant so that estimates of other useful data in addition to streamflow, such as overland flow or actual evapotranspiration, can be obtained.

The Stanford Watershed Model has been applied to many watersheds throughout the world. In addition, several modified versions of the model have been developed to meet the various conditions of different regions and for other purposes (James 1970, Shanholtz et al. 1972, Ross 1970, Crawford and Donigian 1973, Donigian and Crawford 1976b, Leytham and Johanson 1979). The FORTRAN version of the Stanford Watershed Model by James (1970) is commonly referred to the Kentucky Watershed Model (KWM). The KWM model is used to simulate the various hydrologic components for the soil erosion simulation in this study.

The Kentucky Watershed Model

A later version of the Stanford Watershed Model which began in 1959 (SWM IV) appeared in 1966 after sustained watershed modeling efforts at Stanford University. The model was considered a comprehensive model with broad flexibility of application to a wide variety of watershed regimes. In spite of its great potential, a number of factors have prevented its widespread use. One frequently mentioned problem is programming in SUBALGOL, a little used computer language. To overcome this limitation, and others, James (1970) at the University of Kentucky translated the Stanford Watershed Model IV into FORTRAN IV language and called his translated version the Kentucky Watershed Model (KWM). The difference between the two versions is to make the Kentucky Watershed Model applicable to the climate and geology of the humid eastern portion of the United States. Other modifications are in computational efficiency and the output format. The major components and their interactions are similar and are shown in Figure 5.

David (1972) modified the Kentucky Watershed Model for Iowa conditions. He added a snowmelt subroutine to the KWM model to account for

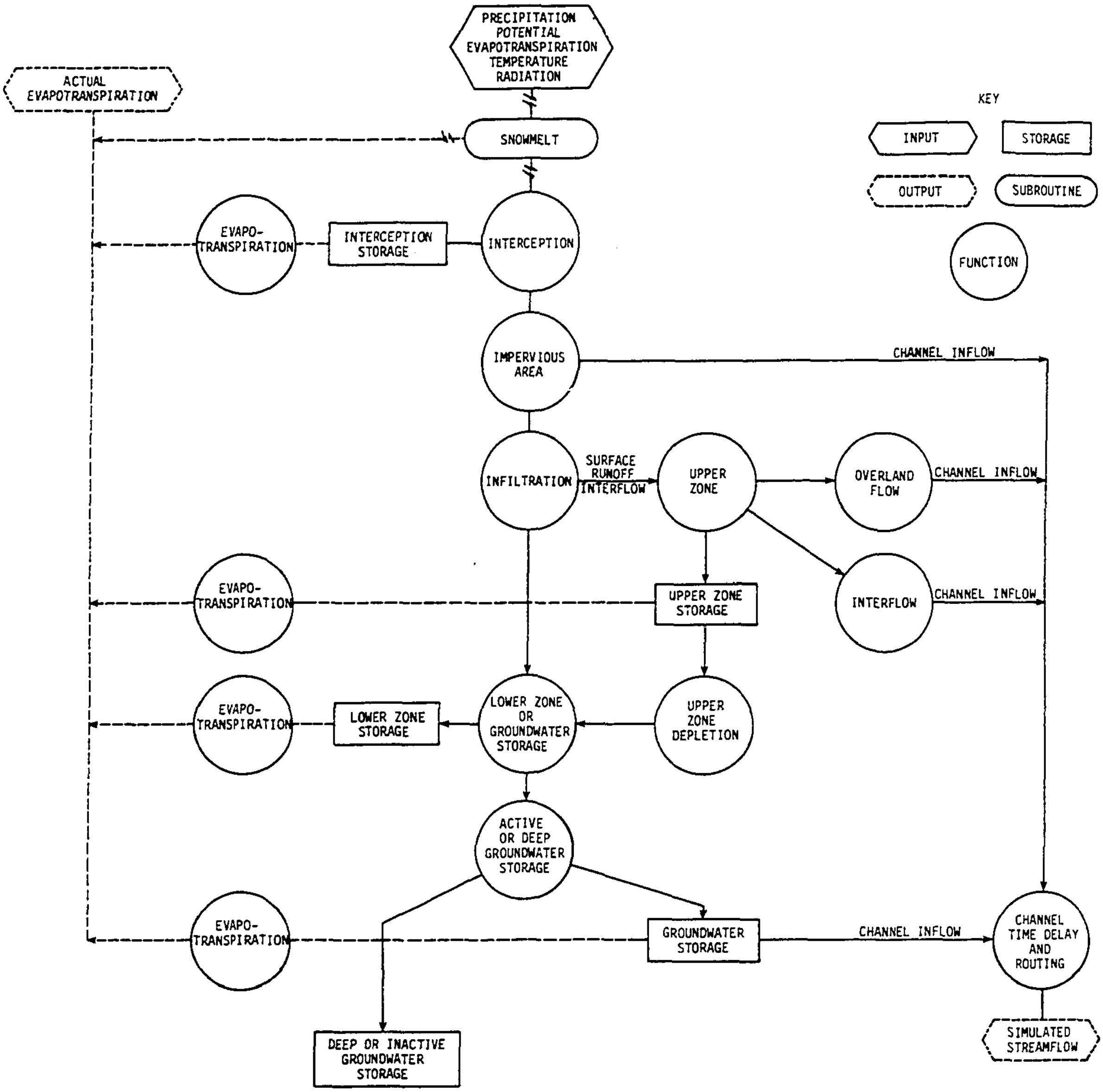


Figure 5. Flowchart of the Stanford Watershed Model IV (Crawford and Linsley, 1966)

snow which is an essential part of the hydrologic simulation in the midwestern United States. He also changed all the read statements to a convenient format, which were formerly written by a complicated subroutine in the KWM model.

The following is a brief summary of experience with the David modification of the KWM model. In the first section, a relatively detailed presentation of the model components is given followed by a discussion concerning the operation and parameter sensitivity of the KWM model.

Model description

The Kentucky Watershed Model is basically a soil-water balance process that can be expressed by:

$$SM_t = SM_{t-1} + P_t + (ML_g)_t - Q_t - PC_t - ET_t - (ML_l)_t \qquad (3.1)$$

where SM = soil moisture status

P = precipitation

ML = minor gains or loss

Q = discharge

PC = deep percolation

ET = evapotranspiration

t = time

t-1 = one time increment before time t

g,l = gain or loss

From continuity and water budget relationships, a general expression for the hydrologic system becomes,

$$\frac{\partial SM}{\partial t} = \frac{\partial (P + ML_g)}{\partial t} - \frac{\partial (Q + PC + ET + ML_l)}{\partial t} \qquad (3.2)$$

A solution to Equation (3.2) can be obtained by solving for the individual components over a preselected time increment t. Therefore, the model is made up of a sequence of computational routines for each process in the hydrologic cycle. In the model, a 15-minute loop contained most of the important hydrologic calculations. Preceding the loop, the model contains parameter input statements and initializing conditions. Following the loop, monthly and yearly summations of hydrologic values are computed with a printout statement for output values simulated by the model. A brief description of the 15 min loop within the KWM model follows:

Interception Precipitation is subjected to interception or retention on leaves, branches and stems of vegetation. Evaporation from these surfaces constitutes the first loss of water in the system. Interception during any single storm may be small and it may not be very important in a flood producing storm. However, the aggregate interception may have a significant effect on annual runoff.

In nature, interception is a function of the type and extent of vegetation and is dependent on the season of the year. In the KWM model, interception is modeled by defining an interception storage capacity, VINTMR as an input parameter. All precipitation is assumed to enter interception storage until it is filled to capacity. Water is removed from interception storage by evapotranspiration at the potential rate.

Impervious area Precipitation on an impervious area that is adjacent to or connected with a stream channel will contribute directly to surface runoff. An input parameter FIMP in the KWM model represents the impervious fraction of the total watershed area. Precipitation minus interception is multiplied by the impervious area fraction to determine the impervious area contribution to streamflow. However, the impervious area is usually a very small portion of the total area in an agricultural watershed.

Infiltration The process of infiltration is essential and basic to simulate the hydrologic cycle. Infiltration is the movement of water through the soil surface into the soil profile. Infiltration rates are often highly variable from point to point, and are assumed to be a linear cumulative distribution function in the KWM model shown as a line from the origin to the point CMIR in Figure 6.

Movement of water into the lower and groundwater storage zones is determined as a function of the moisture supply, PEBI, available for percolation. Steps to determine infiltration for a given PEBI in the model are:

1. The net infiltration is determined from the area labeled infiltration in Figure 6 .

   $\text{INFIL} = \text{PEBI}^2/2*\text{CMIR}$ when $\text{PEBI} < \text{CMIR}$ (3.3)

   $\text{INFIL} = \text{CMIR}/2$ when $\text{PEBI} > \text{CMIR}$ (3.4)

2. Some of the moisture supply contribution to an increase in the interflow detention during any time increment, WEIFS is assumed linearly proportional to infiltration and is calculated by the region indicated by the arrow in Figure 6.

   $\text{WEIFS} = \text{PEBI}^2/2*\text{CMIR}\ (1.0-1.0/\text{CIVM})$ when $\text{PEBI} < \text{CMIR}$ (3.5)

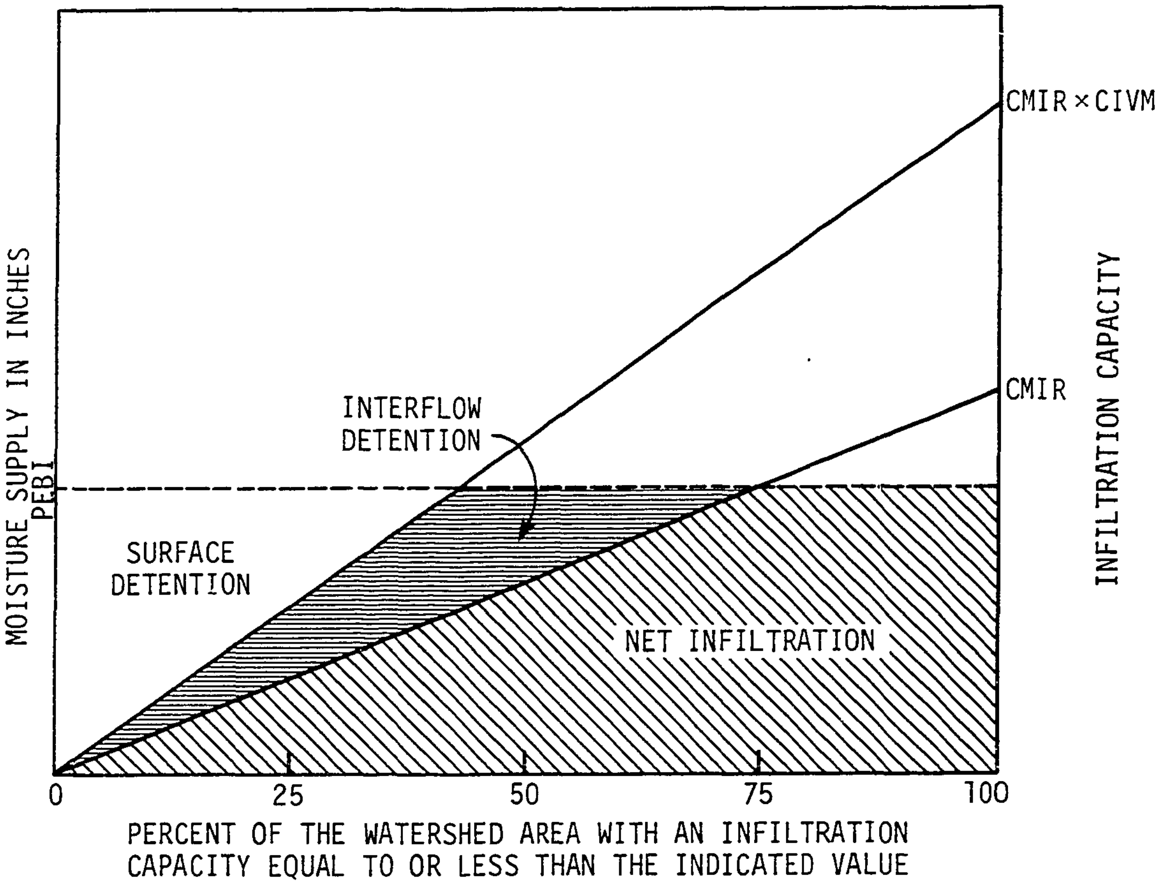


Figure 6. Cummulative frequency distribution of infiltration capacity showing infiltration volumes, interflow and surface detention (Crawford and Linsley, 1966)

$$\text{WEIFS} = \text{PEBI} - \text{CMIR}/2 - \text{PEBI}^2/2*\text{CMIR}*\text{CIVM} \text{ when } \quad (3.6)$$

$$\text{CMIR} < \text{PEBI} < \text{CMIR}*\text{CIVM}$$

$$\text{WEIFS} = \text{CMIR}/2\ (\text{CIVM} - 1.0) \text{ when PEBI} > \text{CMIR}*\text{CIVM} \quad (3.7)$$

3. Any remaining moisture supplied, D, in Figure 6, contributes to increasing the surface detention (PEAI) during the time increment. Equations used in the model for this triangular-shaped area are as follows:

$$\text{PEAI} = \text{PEBI}^2/2*\text{CMIR}*\text{CIVM} \text{ when PEBI} < \text{CMIR}*\text{CIVM} \quad (3.8)$$

$$\text{PEAI} = \text{CMIR}*\text{CIVM}/2 \text{ when PEBI} > \text{CMIR CIVM} \quad (3.9)$$

The quantity of net infiltration is controlled largely by the maximum infiltration capacity. This CMIR is a decay type function of lower zone storage ratio (LZSR) and input parameter SIAM and BMIR which should be determined by the calibration. The relationships among these parameters are highly empirical in nature and are expressed as follows:

$$\text{CMIR} = 0.25*\text{SIAM}*\text{BMIR}/2.0^{\text{EID}} \quad (3.10)$$

where $\text{EID} = 4.0*\text{LZSR}$ when $\text{LZSR} < 1.0$

$\text{EID} = 4.0 + 2.0(\text{LZSR} - 1.0)$ when $1.0 < \text{LZSR} < 2.0$

$\text{EID} = 6.0$ when $\text{LZSR} > 2.0$

$\text{LZSR} = \text{LZS}/\text{LZC}$

The parameter CIVM, on the other hand, significantly affects hydrograph shapes because the parameter controls the amount of water detained during the time increment.

$$\text{CIVM} = \text{BIVF}*2.0^{\text{LZSR}} \quad (3.11)$$

The parameter BIVF is an input value that fixes the level of interflow relative to the overland flow.

Water stored as overland flow surface detention will contribute to stream flow or enter the upper zone storage as depicted in Figure 5. That portion which enters the upper zone storage is called delayed infiltration and is a function of the upper zone storage ratio (UZSR). The percent retained by the upper zone is given by:

$$\text{FMR} = (1.0/1.0 + \text{UZRX})^{\text{UZRX}} \quad \text{when UZSR} < 1.0 \tag{3.12}$$

$$\text{FMR} = 1.0 - (1.0/1.0 + \text{UZRX})^{\text{UZRX}} \quad \text{when UZSR} > 1.0 \tag{3.13}$$

where UZRX = 2.0 (UZSR - 1.0) + 1.0

The lower storage zone receives water from the net infiltration and from percolation or delayed infiltration. The percentage of net infiltration that reaches groundwater storage depends on the lower zone storage ratio LZSR. If the ratio LZSR is less than 1.0, the percentage if found from,

$$\text{FMR} = 1 - \text{LZSR}\ (1.0/1.0 + \text{LZRX})^{\text{LZRX}} \tag{3.14}$$

If LZSR is greater than 1.0, the percentage is

$$\text{FMR} = (1.0/1.0 + \text{LZSX})^{\text{LZRX}} \tag{3.15}$$

In both equations, the variable LZRX is defined as

$$\text{LZRX} = 1.5(\text{LZSR} - 1.0) + 1.0 \tag{3.16}$$

When LZC nd LZS are equal, 50% of all the incoming moisture enters groundwater storage. The amount of water which percolates into the ground storage is,

$$\begin{aligned} \text{PGW} &= (1.0 - \text{FMR})*\text{PEAI}*(1.0 - \text{SUMWF})*\text{FPER} \\ \text{GWS} &= \text{GWS} + \text{PGW} \end{aligned} \tag{3.17}$$

The outflow from the groundwater storage, GWS, at any time is based on the commonly used linear semilogarithmic plot of base flow discharge versus time. In the modified form of the KWM model, the base flow equation is:

$$\begin{aligned} &\mathrm{GBS} = \mathrm{GWS}*\mathrm{BFRC}*(1.0 + \mathrm{BFNRL}*\mathrm{BFNX}) \\ &\mathrm{BFRL} = -\mathrm{ALOG}(\mathrm{BFRC})^{1/24} \\ &\mathrm{BFNRL} = -\mathrm{ALOG}(\mathrm{BFNLR})^{1/24} \end{aligned} \tag{3.18}$$

in which BFRC is the minimum of all the observed daily recession constants, where each constant is the ratio of the groundwater discharge ratio to the groundwater discharge rate 24 hr earlier. Thus, the recession constant BFRC is determined using t=1 day. In that equation, BFNX is the parameter which indicates the amount of water that percolates to the ground storage. The term BFNRL allows for changes that are known to exist in the groundwater recession rates as time passes. When BFNRL is zero, the groundwater recession follows the linear semilog relationship.

Overland flow The movement of water in surface or overland flow is an important land surface process. In the KWM model, overland flow is treated as a turbulent flow process. Since continuous surface detention is chosen as the parameter to be related to overland flow discharge, using the Manning equation, the relation between surface detention storage at equilibrium is found,

$$\mathrm{De} = 0.0008189(\mathrm{OFMN}*\mathrm{OFSL}/\mathrm{SQRT}(\mathrm{OFSS}))^{0.6}(\mathrm{PEAI} - \mathrm{OFUS})^{0.6} \tag{3.19}$$

where PEAI-OFUS = supply rate to overland flow

OFMN = Manning's roughness coefficient

OFSL = overland length

OFSS = overland slope

In the KWM model, an empirical expression relating outflow depth and detention storage which fits experimental data quite well is

$$y = (OFUS+PEAI/2)\ (1.0+0.6(OFUS+PEAI/2EQD)) \tag{3.20}$$

Substituting above equation into the Manning equation, the rate of discharge from overland flow in ft^3/sec/ft is

$$q = (1.486*OFSS^{0.5}/OFMN)(OFUS+PEAI/2)* \\ (1.0+0.6(OFUS+PEAI/2*EQD)) \tag{3.21}$$

During the recession, the ratio (OFUS+PEAI/2*EQD) is assumed to be one. The KWM model continuously solves a continuity equation. Following are algorithms related to overland flow in the KWM model.

$$EQDF = 0.00982*(OFMN*OFSL/OFSS^{0.5})^{0.6} \tag{3.22}$$

$$OFRF = 64200*OFSS^{\ 0.5}/OFMN*OFSL \tag{3.23}$$

If overland flow storage is increased during the time period,

$$EQD = EQDF(PEAI-OFUS)^{0.6} \tag{3.24}$$

which is equivalent to De, equilibrium depth. Otherwise,

$$EQD = OFUS+PEAI/2.0 \tag{3.25}$$

which is equivalent to the average overland depth.

Discharge from overland flow (OFR) in inch/hr/unit area is expressed as a product of OFR and a time interval.

$$OFR = 0.25*OFRF(OFUS+PEAI/2)^{5/3}*(1.0+ \\ 0.6(OFUS+PEAI/2*EQD)^{3})^{5/3} \tag{3.26}$$

By continuity equation.

$$\mathrm{OFUS=PEAI-OFR} \tag{3.27}$$

OFUS is the surface detention at the end of the current interval. The system of equations can be solved numerically with good accuracy if the time interval of the calculation is sufficiently small so that the value of discharge in any time interval remains a small fraction of volume of surface detention.

Evapotranspiration To estimate actual evapotranspiration from a watershed, there are two separate issues involved. Potential evapotranspiration must be selected and actual evapotranspiration is calculated as a function of the moisture condition and the potential evapotranspiration. In this model, however, potential evapotranspiration is assumed to be equal to lake evaporation estimated by the U.S. Weather Bureau Class A pan records.

When near surface storage is depleted, the concept of evapotranspiration opportunity is defined as the maximum quantity of water accessible for evapotranspiration in a time interval at a point in the watershed. It is a similar concept to infiltration capacity and would have a cumulative distribution. The cumulative evapotranspiration opportunity curve will be a function of watershed soil conditions and will give estimates of evapotranspiration, just as the cumulative infiltration capacity curve estimates net infiltration for any moisture supply.

Evapotranspiration occurs from interception and stream and lake surface at the potential rate. Evapotranspiration opportunity controls evapotranspiration from the lower zone storage where the surface detention storage is depleted. The quantity of water lost by evapotranspiration from the lower zone is given by the cross-hatched trapezoid of Figure 7.

The variable r is defined as the maximum water amount for evapotranspiration at a particular location during a prescribed time period.

$$r = ETLF*LZSR \qquad (LZSR=LZS/LZC) \tag{3.28}$$

When potential evapotranspiration (PET) is less than evapotranspiration opportunity (r), actual evapotranspiration from lower zone (SET) is

$$SET = PET-(PET^2/2*ETLF*LZSR) \tag{3.29}$$

When PET is greater than r,

$$SET = ETLF*LZSR/2.0 \tag{3.30}$$

ETLF is an input parameter that is a function of watershed covers.

Channel translation and routing The Kentucky Watershed Model utilizes a hydrologic watershed routing technique to translate the channel flow to the watershed neglecting the storage effect of the channel. To do this, the time-area method proposed by Clark (1943) is used by deriving a channel time delay histogram. The time ordinate of the time delay histogram is calculated from the equation from the time of concentration which is empirical in a watershed.

$$T_c = 0.0078\, L^{0.77}\, S^{-0.385} \tag{3.31}$$

where T_c = time of concentration (min)

L = mean horizontal length of flow along the stream (ft)

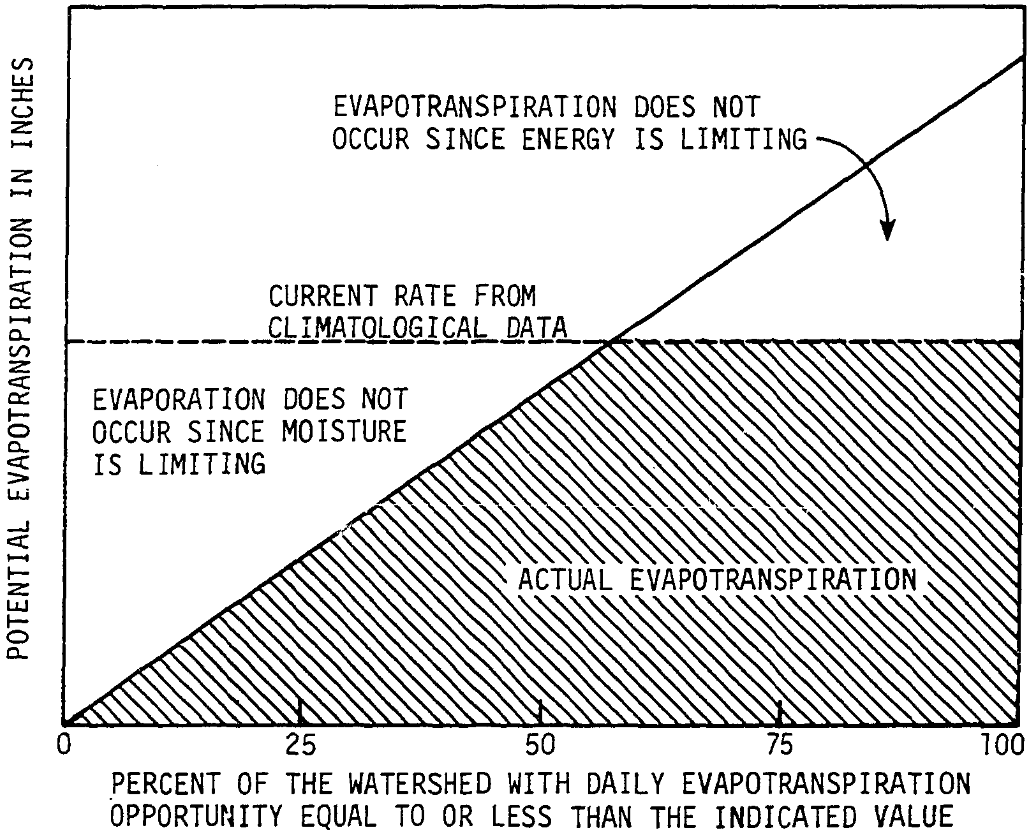


Figure 7. Cummulative frequency distribution of actual evapotranspiration over a watershed (Crawford and Linsley, 1966)

S = slope in feet per foot of the difference in elevation between outlet and the most remote point divided by length.

The volume of channel inflow in any time is multiplied by successive elements of the time-delay histogram to give a watershed outflow hydrograph. The equation is:

$$\mathrm{TRHF}=\mathrm{TRHF}+\mathrm{URHF}*\mathrm{CTRI}(\mathrm{KTRI}) \qquad (3.32)$$

where TRHF = the inflow in the current time interval

URHF = the channel inflow at the beginning of a time interval

CTRI = an element of the time-delay histogram.

The sum,

$$\mathrm{CTRI}(\mathrm{KTRI}) = 1.0 \qquad (3.33)$$

where KTRI = the total number of elements in the time delay histogram.

The outflow hydrograph produced by channel translation is routed through a storage system to simulate attenuation in the channel system. By the continuity equation, the outflow at the end of a time interval (RHF1),

$$\mathrm{RHF1} = \mathrm{TRHF}-\mathrm{SRX}*(\mathrm{TRHF}-\mathrm{RHFO}) \qquad (3.34)$$

SRX may be varied depending on the channel capacity (CHCAP)

$$\mathrm{SRX} = \mathrm{CSRX} \quad \text{when } \mathrm{TFCFS} < 0.5*\mathrm{CHCAP} \qquad (3.35)$$

$$\mathrm{SRX} = \mathrm{CSRX}+(\mathrm{FSRX}-\mathrm{CSRX})*(\mathrm{TFCFS}-0.5\mathrm{CHCAP}/1.5\mathrm{CHCAP})^3$$

$$\text{when } 0.5*\mathrm{CHCAP} < \mathrm{TFCFS} < 2.0*\mathrm{CHCAP} \qquad (3.36)$$

$$\mathrm{SRX} = \mathrm{FSRX} \quad \text{when } \mathrm{TFCFS} > 2.0*\mathrm{CHCAP} \qquad (3.37)$$

where TRHF = the average inflow during the time interval

RHFO = the outflow at the previous time interval

FSRX,CSRX = input parameters which can be obtained from the analysis of hydrographs and will be discussed in a later section.

Operation of the model

A computer listing of the Kentucky Watershed Model in conjunction with the superimposed erosion model is given in Appendix B. Appendix A itemizes the variable names used in the KWM model.

To operate this large computer model, input data and parameter evaluation must be clarified. In the model, the input data are composed of (1) control option, (2) watershed parameters, (3) recorded hydrologic flow data and (4) climatological data. Data collected by government agencies can be utilized for the recorded hydrologic flow and climatological data. Details of the input data will be discussed in a later chapter.

Control options Control options specify inputs and outputs for a particular run. The model is designed to use twenty control options, of which the first sixteen are working options and the last four are reserved for further program extensions. Each of the sixteen options are explained in Appendix C.

Watershed parameters The application of the KWM model to a watershed requires fitting or calibrating the parameters for a specific watershed. Some parameters are measured directly from topographic maps or are found by conventional hydrologic procedures. Other parameters are established by a trial and error method using computer runs.

There are 40 input parameters in the KWM model including those in the snowmelt subroutine. Fourteen parameters are difficult to assess because they are closely related to the variations of watershed characteristics. The parameters which may be obtained by calibration processes are listed. A more detailed discussion for the input parameters and the calibration process is given by David (1972), Liou (1970), and Ross (1970).

LZC - a soil profile moisture storage index (inch), approximately equal to the volume of water stored above the water table and below the ground surface. This parameter is a major runoff-volume parameter, inversely related to the basic yields, interflow and groundwater flow. The LZC depending on porosity and the specific yield of the soil, ranges from 2.0 to 20.0.

BMIR - an index that controls the rate of infiltration depending on the soil permeability and the volume of moisture that can be stored in the soil. This parameter moderately affects the runoff volume but it is believed that runoff is independent of BMIR in long terms.

BUZC - an index of the surface capacity to store water as interception and depression storage. This parameter normally ranges from 0.10 to 1.65. An estimate of BUZC can be made using LZC value as shown in Table 1.

Table 1. Estimation of upper zone storage capacity

Watershed	BUZC
Steep slope, limited vegetation and low depression storage	0.06 LZC
Moderate depression storage, slope and vegetation	0.08 LZC
High depression storage, soil fissures, flat slopes and heavy vegetation	0.14 LZC

These three parameters, LZC, BMIR and BUZC, will interact with each other in hydrologic responses and cannot be independent. Since these parameters relate to the occurrence of the overland flow, interactions are easily found by examining the ratio between the overland flow and total flow in a watershed.

SUZC - an index of soil-surface moisture storage capacity representing the additional moisture storage capacity available during warmer months due to vegetation. Its purpose is to adjust BUZC in order to account for seasonal changes in its value as a result of the effects of vegetation and cultivation practices. Depending on the soil type, the index ranges from 0.45 to 2.00

GFIE - an index of the effect of ground freezing on the infiltration capacity of the soil. It may be used to drastically reduce the infiltration capacity during the winter months when the soil surface is frozen.

SIAC - an index for the infiltration adjustment. This parameter simply allows a more rapid infiltration rate recovery during warmer seasons. This ranges from 0.1 to 4.0 which relates infiltration rates to evaporation rates.

ETLF - a soil evaporation parameter that controls the rate of evapotranspiration loss from the lower zone. This index is used to estimate the maximum rate of evapotranspiration. The maximum rate is estimated as the product of ETLF and the lower zone storage ratio. The parameter ranges from 0.2 to 0.9 depending on the type and extent of the vegetation. Since this parameter has a strong relationship to the condition of vegetation, it should not be constant during a year.

BIVF - an index controlling the time distribution and quantities of moisture entering interflow. It is used to define the variable CIVM. It controls the shape of the hydrographs by regulating the amount of moisture entering interflow. Increasing BIVF will reduce the storm peak and extend the hydrograph recession limbs. This index ranges from 0.55 to 4.5. For the values less than 0.55, they are assumed to be a constant value in order that CIVM is equal to 1.0.

BFRC - a daily baseflow recession constant. This constant controls the rate of discharge to the channel from the groundwater. A graphical technique of hydrograph analysis developed by Barnes (1940) is used to estimate this parameter.

$$\text{BFRC} = \frac{\text{groundwater discharge on any day}}{\text{groundwater discharge 24 hours earlier}}$$

BFNLR - a daily baseflow recession adjustment factor used to produce a simulated curvilinear baseflow recession. If BFNLR is 1.0, the baseflow recession for the hydrograph is linear.

IFRC - the interflow recession constant. Its value as well as those of BFRC and BFNLR may be estimated by trial and error. They may also be found by graphical analysis of a hydrograph similar to that used in determining the baseflow recession constant.

$$\text{IFRC} = \frac{\text{Interflow discharge on any day}}{\text{Interflow discharge 24 hours earlier}}$$

VINTMR - the maximum interception rate for a dry watershed. Crawford and Linsley (1966) (in SWM IV) suggest trial values of 0.10, 0.15 and 0.20 for grass lands, moderate forest covers and heavy forest covers, respectively.

CSRX - a stream routing index used to account for channel storage when flows are less than one half of the channel capacity. To simulate channel attenuation or storage, the outflow hydrograph produced by channel translating using the time area histogram is routed through a hypothetical storage system or reservoir. Since outflow is a function of storage, CSRX is estimated from the graphical analysis of a hydrograph.

FSRX - a stream flow routing parameter used to account for the channel as well as flood plain storage where stream flows are greater than twice the channel capacity. Where the flow is between one half and twice CHCAP, the model interpolates between CSRX and FSRX. When the average inflow in the routing equation (TRHF) is zero, the channel routing parameter becomes a recession constant for water in channel storage. The value of FSRX may be estimated using similar technique for CSRX.

Parameter Sensitivity Analysis

To fully evaluate and quantify the effects of parameter changes on simulation results, sensitivity analyses are performed for the KWM model. The sensitivity for the snowmelt and soil erosion parameters are not included in this analysis. The analysis involved a series of model runs on the Traer watershed in Iowa. Each run is performed while changing the value of a single parameter. Two model runs are performed for each parameter with the parameter value greater than and less than the calibrated value. Thus, the change in simulation results obtained from a change in parameter value indicates the sensitivity of the model to the specific parameter. Table 2 presents the parameter values chosen for the sensitivity analysis. Other input parameters for the simulation are shown in Table 3.

The parameters are analyzed on a water-year period, October 1975 to September 1976. The sensitivity results are displayed in terms of percent change versus the resulting percentage change in watershed responses. Thus, the slope indicates the relative sensitivity of the parameters, i.e., steeper slopes correspond to the more sensitive parameters. Figures 8 and 9 display the effect of changes in the parameters on the total runoff volume for one year period and the peak runoff for the April 24 storm, respectively.

Table 2. Parameter values for sensitivity analysis

Parameter	Baseline	Trial 1	Trial 2
VINTMR	0.10	0.15	0.05
BUZC	0.80	1.20	0.40
SUZC	2.50	3.75	1.25
LZC	9.10	13.65	4.55
ETLF	0.30	0.45	0.15
SIAC	4.00	6.00	2.00
BMIR	10.00	15.00	5.00
BIVF	0.50	1.00	0.00
OFMN	0.15	9.23	0.07
CSRX	0.975	1.00	0.950
BFRC	0.963	1.00	0.926

Lower zone storage capacity (LZC) and seasonal upper zone storage capacity (SUZC) have the greatest impact on total runoff volumes as well as peak runoff rate. This is generally true in most agricultural areas of the United States. For this reason, the SUZC and LZC parameters are most directly involved in the hydrologic calibration of a specific watershed. Although basic maximum infiltration rate (BMIR) and soil evaporation (ETLF) parameters do affect total runoff volume, their relative impact is less than what might be expected. Parameters, BUZC, VINTMR and OFMN have very little effect on runoff volume. This is generally accepted, especially

Table 3. Other parameters for the sensitivity analysis

Parameter	Value	Parameter	Value	Parameter	Value
NYSQ	2	PXCSA	0.05	GWS	0.10
NCTRI	27	RMPF	250.0	UZS	0.10
CTRI	27 values	RGPMB	1.0	LZS	3.0
DPSE	365 values	AREA	19.51	BFNX	0.025
BDDFSM	0.0008	FIMP	0.025	IFS	0.0
SPBFLW	0.05	FWTR	0.00	NDTUZ	75
SPTWCC	2.00	SUBWF	0.00	GFIE	5.0
SPM	1.40	GWETF	0.01	NDIM	315
ELDIF	0.00	OFSL	600.0	NDFM	91
XDNFS	0.18	CHCAP	350.00	DRSF	365 values
FFOR	0.005	OFSS	0.05	RICY	181 values
FFSI	0.1	IFRC	0.35	DMXT	181 values
MRNSM	0.15	FSRX	0.975	DMNT	181 values
DSMGH	0.0001	EXQPV	0.2		

for the watersheds which have little depression storage with flat topographical condition. Baseflow recession constant, BFRC and channel routing index, CSRX are generally thought to have a great effect on total runoff volume.

The effect of parameter changes on peak runoff are similar to the total runoff volume. Infiltration, soil moisture characteristics and

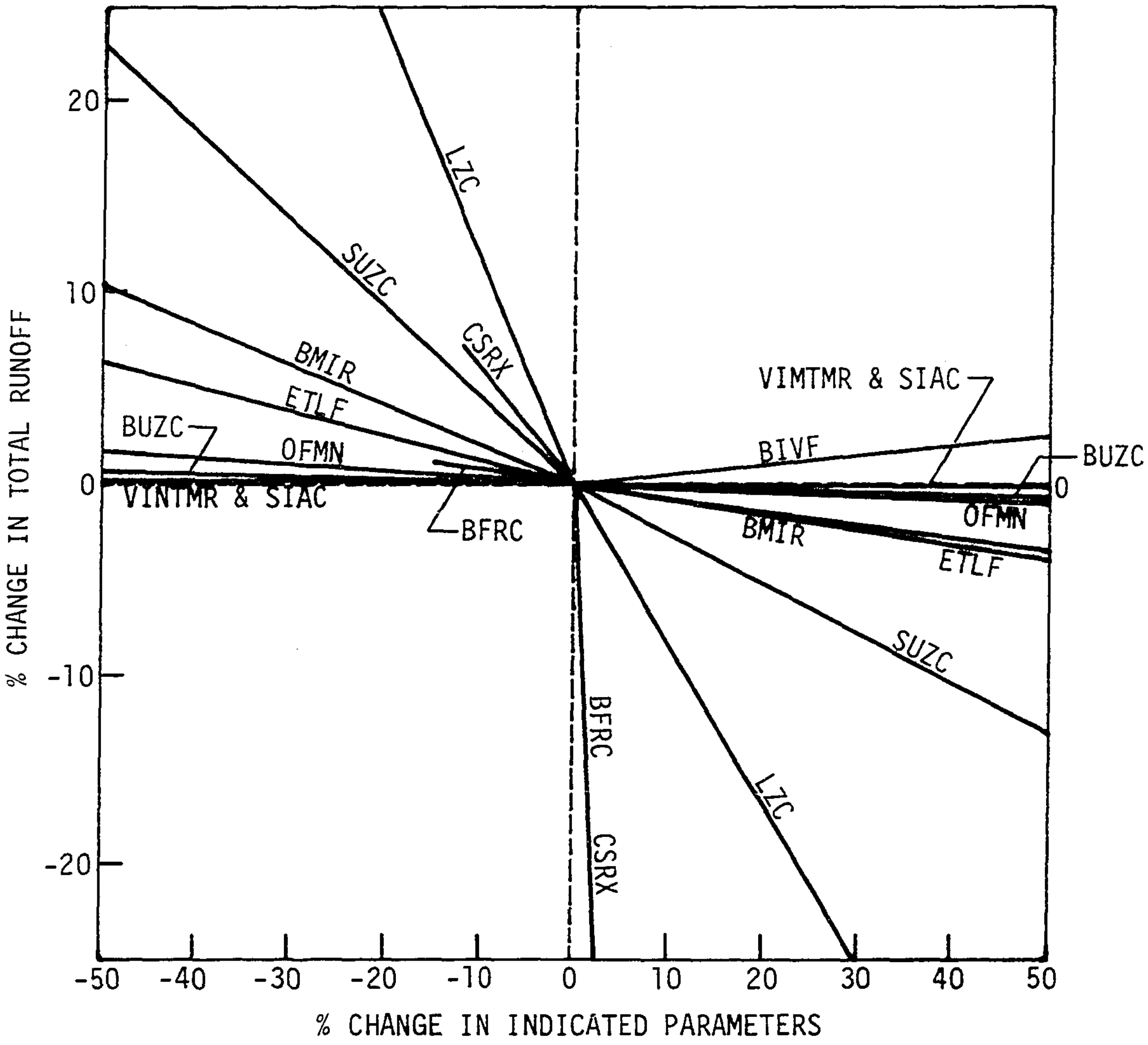


Figure 8. Watershed model parameter sensitivity - total runoff

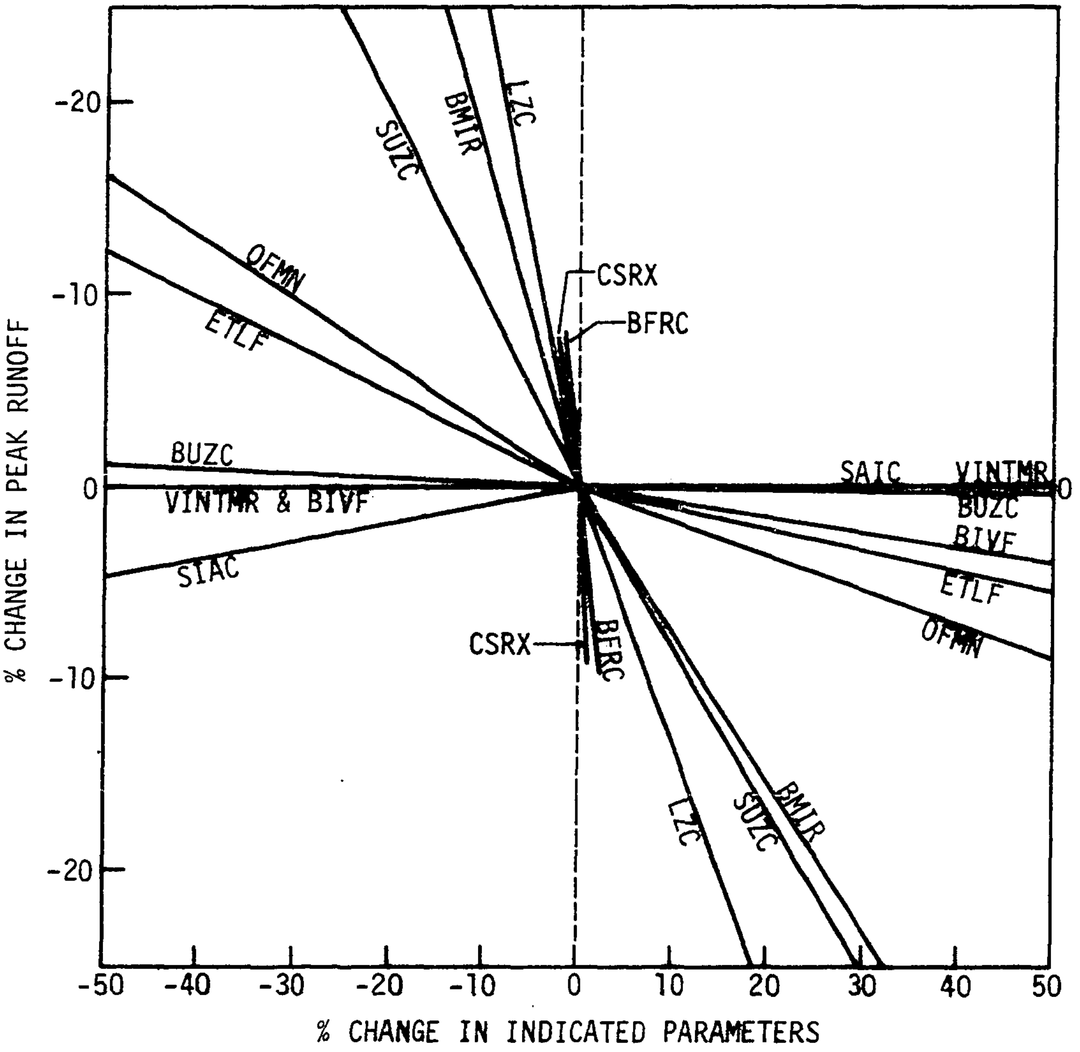


Figure 9. Watershed model parameter sensitivity - peak runoff

seasonal upper storage factor remain important. However, the rest of the parameters have little effect. The main reason for this is that the parameters OFMN, BUZC, ETLF, SIAC, and VINTMR are mostly associated with low flows; this trend may be acceptable.

Baseflow recession parameter and channel routing index have a significantly greater impact on peak runoff rate as compared to runoff volumes. An increase in LZC, BMIR, BFRC and CSRX will reduce peak runoff rate as well as total runoff volume and the impact of decreasing those parameters is reversed. Relative ranking of the parameter on the watershed responses is much the same in both Figures 8 and 9.

CHAPTER IV. EROSION MODEL DESIGN AND DEVELOPMENT

Several approaches can be used to determine soil erosion from an agricultural watershed. The choice of an approach depends on watershed size, available input data, the purpose of the result and the knowledge of the physical soil erosion process involved. Because of the complexity of the physical process governing soil erosion, mathematical modeling of watershed erosion has proved to be the most reliable way to estimate time dependent erosion and sediment yield.

Erosion modeling processes are often complex and difficult to understand, thus conceptual simplifications are made in the mathematical models. These simplifications and assumptions in erosion modeling may reduce the actual complexity of rainfall and runoff erosivity and transportability under natural conditions. Nonetheless, the model should provide an accurate simulation of the erosion process as it will be based upon sound, fundamental principles.

The erosion model in this study is deterministic. Accepted theories and empirical relationships which concern erosion and sediment movement processes in upland and channel phases are used. The model will have a structure to reduce the number of calibrated parameters by the use of measurable physical parameters. These will be obtained from the literature. Particularly, the Universal Soil Loss Equation and substitute to unknown calibrated parameters are concepts that will be used. Since data is usually limited on small agricultural watersheds, data requirement in the model should be minimal. The erosion model will use the data that would generally be available in most agricultural watersheds.

To accept additional data and newly adopted theories from future erosion and sedimentation research, the model must be capable of modification. Therefore, it should be capable of revision to change any components without any revision of the entire model.

With these several considerations, mathematical deterministic relationships from the literature are used as conceptual components of the erosion model. Empirical data from the literature will also be used where appropriate watershed data are not immediately available.

Basic Concepts

The basic governing process for the sediment movement by overland flow is expressed in the continuity equation for mass transport (Bennett 1974). Neglecting the dispersion of sediment within the flow and assuming a quasi-steady flow, simplify the continuity equation to (Foster and Meyer 1972a),

$$\frac{\partial G}{\partial x} = D_i + D_r \tag{4.1}$$

where G = sediment load

D_r = detachment rate by rill erosion

D_i = detachment rate by interrill erosion

An equation for the sediment load is obtained by integrating Equation (4.1) with respect to distance.

$$G = \int D_i \, dx + \int D_r \, dx = G_i + G_r \tag{4.2}$$

where G_i = interrill erosion contribution to total sediment load

G_r = rill erosion contribution to total sediment load

The erosion model is based on the concept of Equation (4.2) which divides the sheet erosion process into rill and interrill erosion according to the source of eroded sediment.

Interrill erosion is defined as the removal of eroded particles from the soil mass by rainfall impact. In view of the imperfect state of the theories and empirical relationships of eroded particle transportation in interrill areas, all eroded particles are conceptually assumed to be concentrated to rills either by rainfall splash or by overland flow transport.

Rill erosion is characterized as the detachment of soil particles by the erosive force of the overland flow. The sum of eroded particles from interrill and rill area is called detachment capacity, which is considered to be eroded soil mass available to transport to downslope by overland flow in rills. However, if the transport is less than the detachment capacity, the sediment movement in rills is limited to the transport capacity and deposition may occur simultaneously. Consequently, the dominant movement of sediment load is by overland flow in rills.

When the transport capacity is less than the detachment capacity, the actual rill erosion is adjusted using Equation (2.4) and Equation (4.3), a rearrangement of Equation (2.4) proposed by Foster and Meyer (1972a):

$$D_r = C_r\ (T_c - G) \tag{4.3}$$

where D_r = actual detachment capacity of overland flow

T_c = transport capacity of overland flow

C_r = a reaction rate coefficient

G = sediment load

In order to simplify the complex erosion processes, the following assumptions are made: (1) all eroded particles in interrill areas can move laterally to rills, (2) rills are assumed to be evenly distributed over the entire watershed except in impervious areas and non-agricultural sectors, (3) sediment load moves downslope through rills, (4) the deposition occurs when only interrill detachment is greater than the transport capacity and, (5) when rill transport capacity is limited, sediment load contribution from rill detachment is also limited and adjusted according to the first-order reaction equation.

The overall process of sheet erosion, therefore, can be divided into three major component parts: (1) the interrill erosion, (2) the rill erosion and, (3) the deposition processes. From the current soil erosion theory, mathematical expressions are developed for each component.

The total sheet erosion is then routed down to the stream using the area histogram method (Clark 1943). For streams, erosion due to channel bed and bank scour is also considered as a component. All components are then combined into a computer program to model the erosion sediment process from an agricultural watershed with the use of the watershed model (KWM model) for obtaining runoff from rainfall and the various hydrologic data.

Development of Components

Detachment of soil particles

The detachment of soil particles by water may be divided into two separate and distinct processes. The first process involves the dislodging of soil particles through the expenditure of the kinetic energy of impacting rain. Rainfall detachment is the major eroding force in interrill areas. The second detachment process occurs in the form of separation of particles from the soil mass by the shear stress and lift forces generated by the overland flow in rills.

The other factors affecting detachment of soil particles in interrill and rill areas are the susceptibility of the soil to detachment, the presence of material that reduces the magnitude of eroding forces and the magnitude of soil that makes it less susceptible to erosion.

Interrill erosion Interrill soil erosion for a storm is a function of the storm's energy. It is obvious that a storm's energy must be calculated from the inherent properties of rainfall such as raindrop size and mass, drop impact velocity and the depth of water over the soil surface. However, the state of art to account for the impact energy of the individual raindrop for a storm's energy has not been developed yet. Therefore, gross parameters like rainfall intensity must be used to express a storm's energy. Using results of Free (1960), Wischmeier and Smith (1958) and Foster and Meyer (1975) derived the relationship that interrill erosion is proportional to $I^{2.14}$ where I is the maximum 30 minute rainfall intensity of a storm. Other experiments (Bubenzer and Jones 1971 and Moldenhauer and Long 1964) using soils and simulated rainfall also suggest that interrill detachment is proportional to I^2.

The raindrops's energy, however, is not the actual force producing erosion because the energy is dissipated on the soil surface. Therefore, interrill erosion is influenced by soil type, soil steepness, cover and other factors which dissipate the rainfall's energy.

Soils, because of their inherent chemical, physical and mineralogical properties differ in their susceptibility to the interrill erosion. Soil properties known to affect erodibility are primarily the particle size distribution, the amount of and type of clay, and clod size after tillage (Foster and Huggins, 1977, Moldenhauer and Long 1964, Bubenzer and Jones 1971, Moldenhauer and Koswara 1968).

From the above considerations of the factors, the interrill erosion rate for any given time interval may be expressed by the following equation:

$$D_i = C1\ S_{DI}\ S_{LF}\ I^2\ \exp\ (-C2\ SPDR) \qquad (4.4)$$

where D_i = the amount of soil detached by rainfall during a specified time interval

S_{DI} = soil effect coefficient

S_{LF} = slope factor

C1 = correction factor for average rainfall intensity

C2 = exponent related to rainfall energy reduction due to overland flow depth

SPDR = the overland flow depth (cm)

I = rainfall intensity (cm/hr)

In Equation (4.4), rainfall intensity I is obviously the break point intensity or 30 minute maximum intensity. However, rainfall intensity in the model is derived from average hourly rainfall data. There must be some discrepancy between the two different definitions of rainfall intensity. In the erosion model, Cl represents the correction factor for computing average hourly rainfall intensity.

Foster (1976) used several of the factors of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965) to describe the coefficient S_{DI} and defined it as follows:

$$S_{DI} = K_{DI} C_{DI} \tag{4.5}$$

where C_{DI} = cropping and management factor from USLE

K_{DI} = erodibility of the soil from USLE

The cropping and management factor, C_{DI}, greatly affects the erosion and sediment for both interrill and rill erosion. The cropping and management factor, C_{DI}, can be divided into type I, II and III based on the definition of Wischmeier (1975). Type I is an above ground effect primarily from the crop canopy, type II is a soil surface cover effect including crop residue and grass roots which are exposed to soil surface, and type III is a subsurface effect from grass roots, tillage and incorporated residues which are not exposed on the soil surface.

Type I effect on soil erosion is reflected in dissipating the rainfall energy and type III effect in decreasing interrill erosion by retarding the flow's transport capacity in interrill areas. Type II effect, however, may be somewhat different from types I and III. Type II cover has the effect of dissipating raindrop energy due to covering of the soil surface and also retarding the removal of detached soil particles to rills.

The effect of canopy cover for dissipating raindrop's energy is described by modifying the rainfall intensity to be an effective rainfall intensity as,

$$I_{eff} = I \text{ CANO} \tag{4.6}$$

where I_{eff} = effective rainfall intensity

CANO = factor affecting dissipation of raindrop energy.

The canopy cover area does not reduce the exposed soil surface to erosion directly as the ratio of covered area to total area since some of the drops fall to the soil surface directly from the leaf top while others run down the stems. The drops falling from the crop canopy have less impact energy than the original raindrops because of shorter falling distance and modification of the mass of raindrops. Figure 10 shows the effect of crop canopy as it influences the crop factor of the USLE. It shows that the crop canopy effect on erosion, CANO, is a function of falling height and crop cover percentage. Although type II cover provides some means of dissipating the rain's energy, it is overlapped by the canopy cover. Therefore, it is assumed to be negligible in the model.

Because of different cover percentages and crop heights in different crops in the model, the CANO factor is considered for the different types of crops and calculated as the average value like a lumped parameter using an area weighted factor.

Soil surface cover including mulches, crop residue, gravel, and grass apparently reduces interrill flow velocity because cover generally

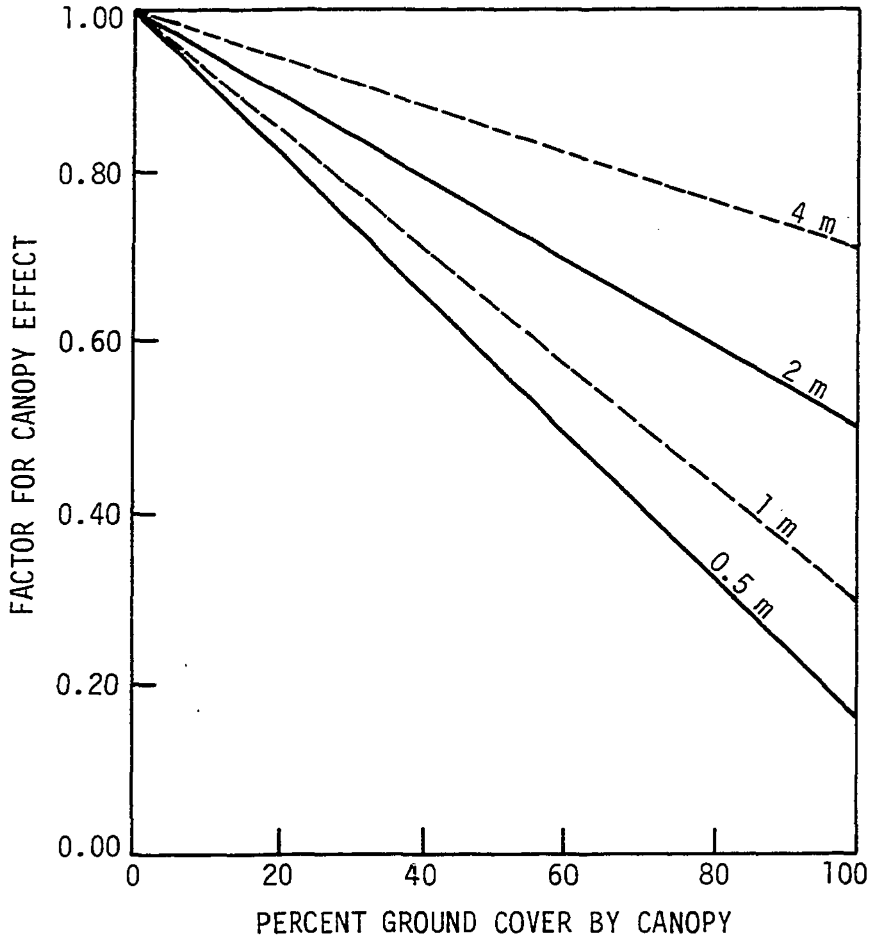


Figure 10. Influence of vegetative canopy on erosion (Wischmeier, 1973)

increases the hydraulic roughness of the flow surface. Foster (1978) using the data of Lattanzi et al. (1974) developed an equation to calculate the effect of soil surface cover on interrill areas:

$$\text{COVER} = \text{OPEN} \ \exp\left[0.21 - (Y_c/Y_b - 1.0)^{1.18}\right] \tag{4.7}$$

where COVER = management factor due to soil surface cover

OPEN = fraction of the soil surface left exposed by the cover

Y_c/Y_b = ratio of flow depth with cover to that without cover

Because the ratio Y_c/Y_b is difficult to properly evaluate, the exponential term in Equation (4.7) was dropped and linear terms added. Thus, surface cover subfactor in interrill areas, COVER, used in the model is,

$$\text{COVER} = 1.0 - 0.012\ (100.0 - \text{OPEN}) \quad \text{for OPEN} > 17\% \tag{4.8}$$

$$\text{COVER} = 0.0 \quad \text{for OPEN} < 17\%$$

Type III cropping and management factor represents the effect of subsurface crop residue, land use, and tillage. Most of type III factors may not be related to interrill erosion because interrill erosion is mainly associated with raindrops energy on the soil surface. Tillage is also assumed to have no effect on interrill erosion. Therefore, type III factor for cropping and management in interrill areas is negligible in this study.

Lattanzi et al. (1974) found that interrill erosion is influenced much less by slope steepness than is rill erosion or total erosion. Foster (1978) used data of Meyer et al. (1975a) and Lattanzi et al. (1974) to develop the following interrill slope factor,

$$S_{LF} = 2.96 (\sin \theta)^{0.79} + 0.56 \tag{4.9}$$

where θ = slope angle

Equation (4.9) uses a base slope of 9%. It is important to remember that the slope of interrill areas may not be the same as the average land slope. This is especially true of row sideslopes. A variable, slope length, did not appear in Equation (4.9) because interrill area is assumed to be independent of location on the slope when all other factors are the same.

Flowing water cushions the raindrop impact reducing the drop's hydrodynamic impact forces at the soil boundary, thus reducing detachment by raindrop impact. This concept of a reduction factor was developed by David and Beer (1975) and has been used successfully in models (Smith 1977 and Yoo 1979). In this study, the reduction of impact energy by the depth of water is expressed by a simple exponential decay function as shown in Equation (4.4).

When rain falls on snow covered or impervious areas, no eroded particles are detached by raindrop impact. The watershed model (KWM) model) includes a snowmelt subroutine which predicts the depth of snow at a specific time. Thus, information of snow cover is straightforward. However, erosion from impervious areas is treated as an independent component from interrill and rill erosion because of the different properties to accommodate the runoff and rainfall. This will be discussed in a later section.

With the previously discussed information, soil detachment capacity in interrill areas is expressed as follows:

$$D_i = C1\ K_{DI}\ COVER\ S_{LF}\ I_{eff}^2\ \exp\ (-C2\ SPDR) \qquad (4.10)$$

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

K_{DI} = soil erodibility factor for detachment by raindrop impact (kg hr/N m^2)

I_{eff} = effective rainfall intensity (cm/hr)

Other variables are the same as previously defined. Equation (4.10) will be the basic equation to evaluate soil detachment by rainfall impact in interrill areas. The variable obtained in this section will also be used later as surface protection effect against rill erosion.

Rill erosion Rill erosion is indicative of serious erosion with identifiable characteristics. Interrill erosion appears minimal because it removes soil particles in a uniform fashion. However, a soil susceptible to rill erosion is immediately obvious because flow concentrates in many small eroded channels (rills).

Erosion in a single rill is a function of flow hydraulics, especially shear stress. As discharge increases or as slope increases, rill erosion is expected to increase because shear stress increases. However, in the erosion model, erosion in many single rills is lumped together and described as gross rill erosion. As was suggested in the previous section, the rills are assumed to be uniformly distributed across the slope although physically the flow is concentrated in small channels.

The average shear stress on rills is approximated assuming the broad shallow condition of overland flow.

$$\tau = \gamma \ \text{SPDR OFSS} \tag{4.11}$$

where τ = average shear stress on rills (N/m^2)

γ = specific weight of water (N/m^3)

SPDR = depth of overland flow for the specific time interval from watershed model (m)

OFSS = overland flow surface slope

With the assumption that rill erosion is related to shear stress acting on rills by overland flow, the rill detachment equation will be obtained as,

$$D_r = a\,(\tau - \tau_{cr})^b \tag{4.12}$$

where D_r = rill detachment capacity

τ = the flow's shear stress

τ_{cr} = a critical shear stress

a = a constant

b = an exponent

Smerdon and Beasley (1961) used clay content to predict critical shear stress, τ_{cr}, expressed as

$$\tau_{cr} = 0.0503 \text{X} 10^{0.0193pc} \tag{4.13}$$

where τ_{cr} = critical tractive force (N/m^2)

pc = clay content of soil (%)

The exponent b in Equation (4.12) will be greater than, or equal to, one. Its value is equal to one under the idealized condition of flow of thin film. When flow is concentrated along well-defined rills such that the actual flow depth is greater than the average overland flow depth, its value will be greater than one. Foster (1978) suggested 1.10 as the b value when a critical shear stress is included in the equation as shown in Equation (4.13). A constant, a, may include the soil and crop factor.

With these assumptions, the soil detachment by rill flow is expressed as the following equation:

$$D_r = K_{DR} C_{DR} (\tau-\tau_{cr})^{1.10} \tag{4.14}$$

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

τ = average shear stress (N/m^2)

K_{DR} = soil erodibility factor for rill erosion (kg hr/N$\cdot$m^2)

C_{DR} = a cropping and management factor for rill erosion

Soil erodibility factor for rills, K_{DR}, is considered equal to the soil erodibility factor for interrill area and is defined in the soil erodibility nomograph (Wischmeier et al. 1971) using soil data on physical properties of the soil. Foster (1978) suggested that the K_{DR} factor be adjusted when the soil seems especially susceptible to rill erosion by increasing K_{DR} by 1/3 and conversely reducing K_{DR} by 1/3 if the soil does not seem susceptible to rilling.

A number of cropping management factors influence rill erosion and are treated in the C_{DR} factor within the framework of Wischmeier's (1975) type I, II and III effect. Type II (cover) effect is considered using the relationship between crop residual cover and cropping factor of the Universal Soil Loss Equation as shown in Figure 11. Since the crop residual cover, RESD, may be different in crops and cultivation method, weighted crop residual cover is used by accounting for the areas of crop cultivated and the cultivation method in use. Type III effect is significant in rill detachment. However, because of lack of information, only the tillage effect is considered. The reduction factor by cropping and management factor is

$$C_{DR} = \text{TILL RESD RULF} \tag{4.15}$$

where TILL = tillage effect

RESD = soil cover effect by crop residue

RULF = residual land use effect

Detachment capacity From Equation (4.2), detachment capacity from rill and interrill area is expressed as

$$\text{TDA} = \text{AID} + \text{ARD} \tag{4.16}$$

where TDA = detachment capacity for transport (t/ha)

AID = interrill detachment capacity (t/ha)

ARD = rill detachment capacity (t/ha)

The detachment capacity, TDA, is in effect "ficticious"; however, it is considered as a potential capacity due to interrill and rill detachment

Transport of eroded particles

As with detachment, several factors influence transport capacity by overland flow. In general, transport capacity is a function of a flow's

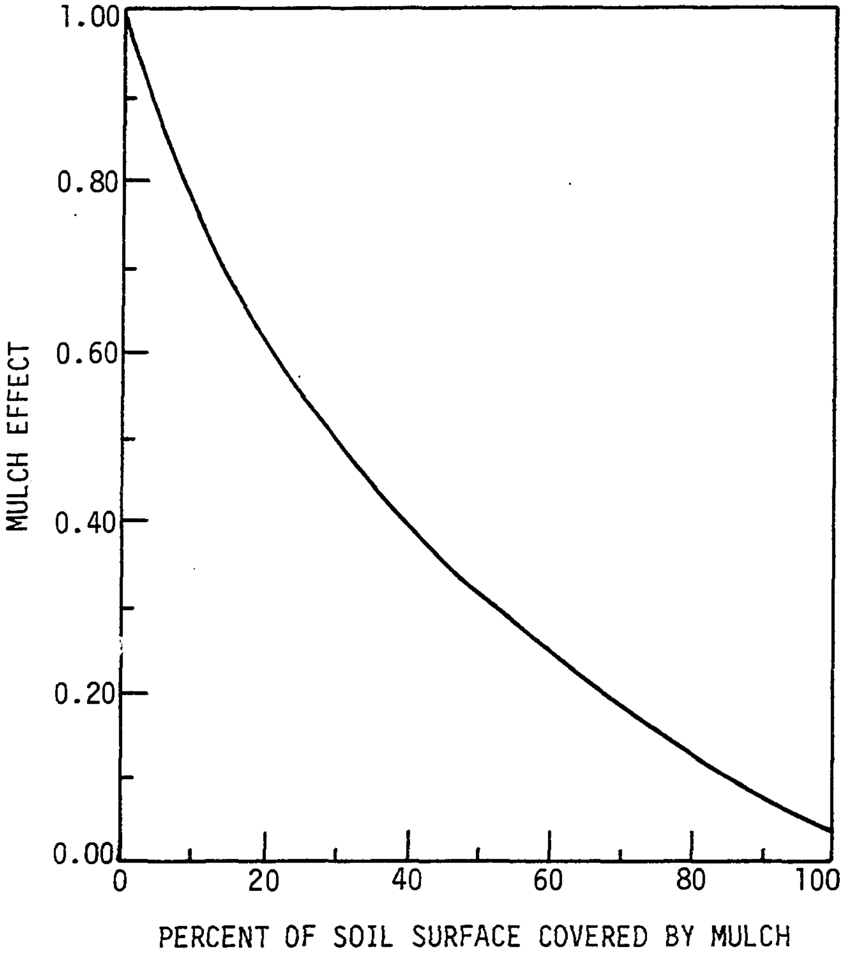


Figure 11. Effect of mulch on surface on cropping factor of the USLE (Wischmeier, 1973)

hydraulic forces including velocity, depth, discharge, stream power and shear stress of the flow and these factors are interrelated. However, shear stress is selected as a measure of a flow's hydraulic force in this study. The presence of media like grass and crop residue on the soil surface changes the flow's transport capacity. Particle size and density are assumed to be the major factors affecting the transportability of eroded particles.

A variety of relationships have been used in various erosion models to describe transport capacity by overland flow. These include the simple relationship like (David and Beer 1975),

$$T_s = K\ S^c\ D^d \qquad (4.17)$$

where T_s = transport capacity of overland flow

K = a constant related to soil and surface roughness

c,d = exponents

S = slope steepness

D = overland flow depth

Equation (4.17) is based on the turbulent flow equation considering that the transport capacity is related to flow velocity. The greatest problem with Equation (4.17) is transportability term, K. No data is available in the literature that allowed the selection of a value of this variable. Therefore, variable K must be obtained by calibration.

Foster and Meyer (1972c) proposed the use of the Yalin equation for transport capacity. This seems to be the most applicable because of its simplicity and assumptions used in its derivation. In this equation, transport of sediment particles by overland flow is assumed to be very similar to mechanics of bed load transport in channels. The sediment transport by bed load in overland areas is often observed in the field. The Yalin method (Yalin 1963) is illustrated by Equations (2.6) through (2.11).

Sediment in overland flow is apparently a mixture of particles having different size and densities. To describe more completely the transport capacity, the sediment load being transported is considered to be composed of several different types of particle sizes.

For each particle size i, a value of s (see Equation (2.6) through (2.11)) is determined. Yalin (1963) assumed, in derivation of the equation, the number of particles in transport to be equal to s. Thus the total transportability is

$$T = \sum_{i=1}^{N} s \tag{4.18}$$

where T = total transportability

N = number of particle size groups

s = dimensionless excess of the lift force

The number of transported particles of size i in a mixture, $(Ne)_i$ is taken as

$$(Ne)_i = N_i \frac{s_i}{T} \tag{4.19}$$

where N_i = number of particles transported in sediment of uniform type i for a s.

In the Yalin equation, the left side of Equation (2.6) is in proportion to the number of particles in transport. The left side of Equation (2.6) is set by P, thus $(Pe)_i$ would be

$$(Pe)_i = \frac{P_i \ s}{T} \tag{4.20}$$

where $(Pe)_i$ = the effective P from particle type in a mixture

P_i = P calculated from uniform particle size of type i

The sediment transport for each particle size is

$$W_{si} = \frac{s \ P_i}{T} \ \gamma_i \ d \ V_* \tag{4.21}$$

where W_{si} = transport capacity for particle size of type i

The total transport capacity for a particular slope and flow is determined as follows

$$W_s = \sum_{i=1}^{N} W_{si} \tag{4.22}$$

The indirect factors affecting transport capacity are surface cover, roughness and rainfall. As discussed earlier, crop residues, mulches, grass and other similar surface covers reduce the flow's shear stress acting on the soil surface. This reduces the flow's transport capacity by the same way it reduces the flow's detachment capacity. The cover factor for rill detachment, RESD, is directly used accounting for the crop residue effect on the transport capacity.

Roughness also reduces the flow's transport capacity. However, the roughness factor has already been used in the watershed model to calculate the overland flow depth. Overland flow depth is used to compute shear stress and shear velocity in Equation (2.10).

The effect of rainfall rate on rill flow transport capacity is not definitely known. Perhaps the rainfall effect is identified as interrill erosion. However, Foster and Huggins (1977) and Davis (1978) found that the effect of rainfall was negligible. Hence, it is disregarded in this study.

Deposition and storage of eroded particles

When eroded soil particles move along with rills, several factors must be considered to evaluate the sediment movement in rills. The basic concept of sediment moving and other related variables has been discussed in the earlier sections in Equations (4.1), (2.4) and (4.3). The mode of sediment movement in rills in the erosion model is followed by this basic concept.

If the transport capacity is less than the detachment capacity from interrill and rill erosion rate, the deposition may occur as follows:

$$\begin{aligned} &\text{if ATRF} < \text{TDA} \\ &\text{if AID} < \text{ATRF} < \text{TDA} \\ &\quad \text{DEPO} = 0.0 \\ &\quad \text{EROA} = \text{ATRF} = \text{AID} + (\text{ATRF} - \text{AID}) \end{aligned} \tag{4.23}$$

where ATRF = transport capacity

TDA = detachment capacity

DEPO = deposition

EROA = sediment load in rills

The term (AFRT-AID) represents the rill erosion contribution to the total erosion based on Equation (4.3).

$$\text{if AID} > \text{ATRF} \quad \text{DEPO} = \text{AID-ATRF} \quad \text{EROA} = \text{ATRF} \tag{4.24}$$

In this case, rill erosion will not occur. Instead, deposition occurs and this is also assumed to be uniformly distributed over the entire watershed. In either case, sediment load in rills is reduced to transport capacity. Rill erosion is reduced first. Interrill erosion is reduced only after the rill erosion rate reaches zero.

The previously deposited sediment is stored as a storage in the model. It is assumed that it is available for subsequent erosion if the incoming sediment supply decreases below the transport capacity or the transport capacity increases above the supply rate.

The detached particles in storage, however, will eventually form aggregates with soil mass by the cementation effect of clay particles and will no longer be available for overland flow pick up if left too long on the soil surface. Traffic and tillage may consolidate or break up the soil mass producing more fine particles which then hasten the consolidation process.

The rate at which sediment storage from aggregates occurs or the rate at which the storage decreases with time will depend on the soil properties, moisture content, climatic conditions and tillage operations. High values of soil aggregate formation may be expected during the spring and summer months when evaporation rates are high. The rate at which the total sediment storage decreases can be approximated by the decay type function

$$\mathrm{TNTDS} = \frac{\mathrm{TNTDS}_o}{\exp(\mathrm{PEWR}\ t)} \tag{4.25}$$

where TNTDS = total sediment storage at the end of the time interval (ton)

TNTDS_o = total sediment storage at the beginning of the time interval (ton)

PEWR = a constant depends on soil and climatic condition

t = time interval

However, accounting for sediment as storage is not straightforward. Most of the stored sediment in the depression which usually exists in cultivated fields will remain because interrill flow does not have the capacity to pick it up. Therefore, a large part of the previously stored sediment in depressions may not be available for transport, particularly in the initial stage of tillage operation. The constant PEWR must also be determined to account for this effect in addition to soil and climatic effects.

If the transport capacity exceeds the potential detachment capacity (TDA), the following three situations will occur:

if ATRF > TDA

1) when TNTDS > 0.00 and TNTDS > ATRF - TDA

$$\mathrm{DEPO} = \mathrm{TNTDS} - (\mathrm{ATRF} - \mathrm{TDA})$$

$$\mathrm{EROA} = \mathrm{ATRF} \tag{4.26}$$

2) when $TNTDS > 0.00$ and $TNTDS < ATRF - TDA$

$$DEPO = 0.0$$

$$EROA = TDA + TNTDS \tag{4.27}$$

3) when $TNTDS = 0.0$

$$DEPO = 0.0$$

$$EROA = TDA \tag{4.28}$$

When detachment capacity is less than the transport capacity, sediment load is at least the same as the detachment capacity or greater than TDA picking up sediment storage which occurred during the previous time interval.

Impervious areas

The amount of soil particles picked up from impervious areas may be taken as a factor affecting soil splash. In an agricultural watershed, this amount often contributes only a small portion to total erosion, but it may be conveniently approximated as

$$IMPU = KP\ FIMP\ SPIX \tag{4.29}$$

where IMPU = amount of sediment picked up from impervious area

KP = empirical constant

FIMP = fraction of the watershed being impervious

SPIX = 2.0 power of rainfall intensity

The erosion from impervious areas was not included as a part of detachment capacity because it does not, obviously, occur at rills. Hence, the erosion from impervious areas as expressed by Equation (4.29) is treated independently of Equation (4.23) through (4.28).

Channel erosion

Channel erosion would be significant during large floods. The channel flow can usually carry whatever cohesive particles are freely available or can be detached from cohesive banks or bed layers.

Clay and silt in the stream bed tends to bind bed material and prevent the formation of active layers of scouring. Therefore, channel bank and bed erosion are highly unpredictable and do not have consistent tendencies because of extremely complicated factors involved.

Channel erosion, in this study, is considered as an erosion component but gully erosion may be negligible because gully erosion contributions are relatively small in small agricultural watersheds.

Krone (1963) and Partheniades and Paaswell (1970) describe material properties of some factors which control cohesive material. David (1972) discussed the factors affecting channel bed and bank scouring and suggested an empirical equation.

$$\mathrm{SCOUR} = \mathrm{C3}\ \mathrm{DRSF}^{\mathrm{ALP3}} \tag{4.30}$$

where SCOUR = channel bed and bank scouring (t/day)

DRSF = daily recorded streamflow (ft^3/day)

ALP3 = an exponent

C3 = a constant

In Equation (4.30), DRSF is the mean daily discharge and hence the equation applies to a daily basin only. Constant C3 and exponent ALP3 are parameters to be determined through calibration.

Sheet erosion

For a specific period, the total amount of sheet erosion is the sum of the various erosion components. This total amount may be expressed by

$$USFA = (EROA(1.0-FIMP) + IMPU) \cdot OVCO \tag{4.31}$$

where USFA = unrouted total sheet erosion from the specified period

EROA = erosion contribution from interrill and rill erosion

IMPU = erosion from impervious areas

FIMP = fraction of impervious areas

OVCO = unit conversion for the watershed area

The daily synthesized suspended sediment load is computed as

$$TDSSL = SCOUR + DSSE \tag{4.32}$$

where TDSSL = total daily synthesized suspended sediment load (t)

DSSE = summation of USFA over the 24-hour period (t)

Operation of the Erosion Model

Model structure

The erosion model simulates sediment contributions to stream channels from an agricultural watershed. Channel sediment routing procedures are included and land use effect is considered. Thus, the model is applicable to watersheds with a variety of cropping and management practices. Although applicable watershed area will vary with climatic and topographic characteristics, watersheds greater than 50 to 70 km^2 are approaching the upper limits of applicability of the watershed and erosion model.

Figure 13 depicts the general structure and operation of the watershed and erosion model. The major component of the model is the Kentucky Watershed Model as a main computer program and the erosion model is executed as subroutines to the main program.

The erosion model is composed of two subroutines, EROS and CROP. The subroutine EROS simulates the erosion process of soil particle detachment by rainfall and overland flow and transport by overland flow. The subroutine CROP allows the user to specify seasonal variations on land cover and the occurrence and impact of tillage operations.

Program listing for the erosion model is given in Appendix B. The computer program, which includes both the watershed and the erosion model, has been run on an ITEL AS/6 computer system. For a year of data, the computer execution time is about 39.0 seconds.

Input and output

The basic data required for the erosion model are the hydrologic and meteorologic data as follows:

1. Mean daily recorded stream flow. This information is used to estimate the daily suspended sediment yield from channel bank and bed scouring. The principal sources of information for these data are the U.S. Geological Survey surface water records.
2. Daily recorded suspended sediment loads. These data are needed for statistical comparisons with the simulated suspended sediment which were drawn by the erosion model. The U.S. Geological Survey water quality records are available for information on suspended sediment loads in streams.

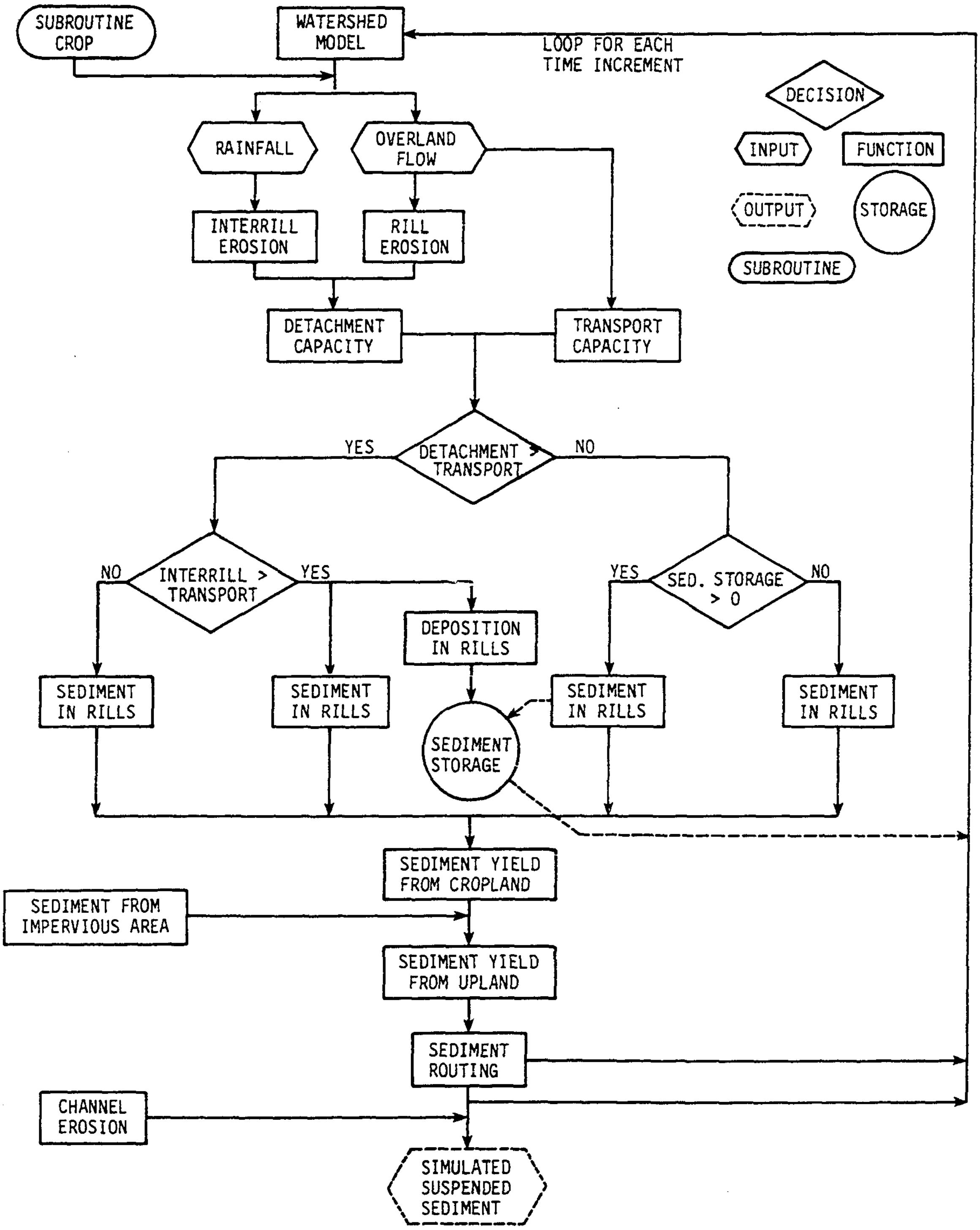


Figure 12. Flowchart of the erosion model

3. Hourly rainfalls and hourly or quarter-hourly overland flow. The overland flows are synthesized from the watershed model and put into the erosion model automatically within the model.
4. A group of constants and exponents representing watershed and hydrologic parameters.

Since the watershed and erosion model is a continuous simulation model, the period of record needed for each data series corresponds to the length of time for which simulation is performed.

The output from the model consists of the daily printouts of computed sheet erosion, channel erosion and suspended sediment loads. A sample of inputs is given in Appendix D.

Erosion model parameters

As mentioned in the previous section, the erosion model includes parameters that must be evaluated whenever the model is applied to a specific watershed. Since the model is designed to be applicable to a wide range of agricultural watersheds, the parameters provide the mechanism to adjust the simulation for the specific topographic, hydrologic, soil, and cropping and management conditions of the watershed. Most of the parameters, however, are easily evaluated from known watershed characteristics. Parameters that can not be precisely determined in this manner must be evaluated through calibration.

Calibration is the process of adjusting certain model parameters to improve agreement between recorded and simulated information. For the erosion model, observed stream flow and sediment data are usually required for accurate evaluation of certain model parameters. However, some of the calibrated parameters can be obtained from the literature or from laboratory analysis.

With the above viewpoint, there are three types of input parameters for the erosion simulation: parameters transferred from the watershed model, parameters which can be obtained through the calibration process, and known watershed and crop parameters. The parameters which are obtained from calibration processes and from other climatic and watershed characteristics are listed.

1. Parameters related to soil properties.

   ERKI - This parameter is related to the erodability or detachability of the specific soil type and land surface conditions by rainfall impact energy. In this study, ERKI is assumed to be directly related to the K factor in the Universal Soil Loss Equation (Wischmeier and Smith 1978). Therefore ERKI values can be obtained with techniques published in the literature or from soil scientists familiar with local soil conditions. A nomograph can be used for general estimation of the K value from soil properties.

   ERKR - ERKR is the erodability of a specific soil by the erosive force of overland flow in rills. This parameter is also taken from the K factor in the USLE. As a general guide, if a particular soil seems especially susceptible to rill erosion, ERKR might be increased by 1/3 from the USLE K value and conversely, if the soil is not susceptible to rilling.

The initial values of ERKI and ERKR will need to be checked through calibration trials.

PC - PC is the percentage of clay in the soil. This parameter can be directly obtained from the laboratory analysis of soil.

DIA, GF - DIA and GF are parameters which are related to sediment properties and used in the calculation of sediment transport capacity. DIA is a diameter of eroded particles and GF is specific gravity of an eroded particle. Since the eroded particles are composed of the different types of particles, several sizes of DIA and corresponding GF values can be used as input to the model. These parameters can be easily obtained from the analysis of sediment size distribution.

2. Cropping and tillage factors.

RULF - RULF is a residual land use factor. This includes effects of plant roots, long term residue incorporation by plowing, changes of soil properties, and other factors. For continuous tillage without crop production like on the USLE unit plot, the RULF factor value is 1.0. For continuous corn, it is estimated to vary from 0.82 (good production) and 0.86 (low production). For permanent pasture, use 0.25 to 0.40 as a RULF factor.

TILL - Till is a parameter that indicates the effect of tillage operation. Till is a somewhat complicated factor to evaluate; however, tentative values estimated by Foster (1978) are used in this study (Table 4).

Table 4. Consolidation effect after tillage on rill erosion

Time after Tillage	Factor		
	Conventional Seed Bed	Chisel Plowing and Disking	Turn Plowing
Immediately	1.0	0.80	0.60
1 year	0.60	0.55	0.45
2 years	0.40	0.38	0.32
3 years	0.30	0.28	0.25
5 years	0.22	0.22	0.22

ZONE(s) - ZONE is a fraction of area on which a specific crop is being cultivated

CZ(s) - CZ is a fraction of area on which a specific cultivating method is being used.

3. Parameters related directly to erosion.

C1 - C1 is the coefficient in the interrill erosion equation. This parameter is a correction factor for the average rainfall intensity.

C2 - C2 is a factor that reduces the rainfall energy due to water depth. It is a coefficient in the exponential function and relates to soil and rainfall intensity.

C3 - C3 is a constant coefficient which represents the properties of eroded particles due to channel bank and bed scouring.

PWER - PWER is a soil compaction factor that reduces the amount of detached soil particles available for transport from the sediment storage. The PWER parameter attempts to represent the natural aggregation and mutual attraction of soil particles and the compaction of the surface soil from which erosion occurs. Input data ALP1 and ALP2 represent climatic and soil condition to evaluate the PWER value. These values must be obtained from the calibration process.

ALP3 - ALP3 represents an exponent which is related to channel flow and is used in calculations of channel erosion.

CHAPTER V. THE EROSION MODEL TESTING AND EVALUATION - FOUR MILE CREEK WATERSHED NEAR TRAER, IOWA

As pointed out in Chapter IV, the Watershed and Erosion Model is actually composed of two models, the Kentucky Watershed Model and the erosion model, linked by superimposing the two models. The Kentucky Watershed Model has already been extensively tested and the results are presented by David and Beer (1975), James (1970), Huang and Gaynor (1977), and Magette et al. (1976). However there is also need of substantial testing of the Kentucky Watershed Model to verify the recent data collected by Iowa State University Weather Station at Four Mile Creek, Iowa. The main concern of model testing in this study has been to develop a reliable erosion model.

The Four Mile Creek Watershed was chosen for the erosion model testing in this study because comparatively good data are available for that watershed. A brief description of the watershed is given below.

Description of the Watershed

Four Mile Creek is located in northwest Tama County in east central Iowa, as shown in Figure 13. The watershed is approximately 50 sq. km in size and its centroid is located at latitude 42° 15', longitude 92° 41'.

The watershed is relatively long and narrow with Four Mile Creek flowing down a centrally located alluvial valley approximately 400 m wide. The land surface is relatively flat. These flat areas are located near the upstream end of the watershed.

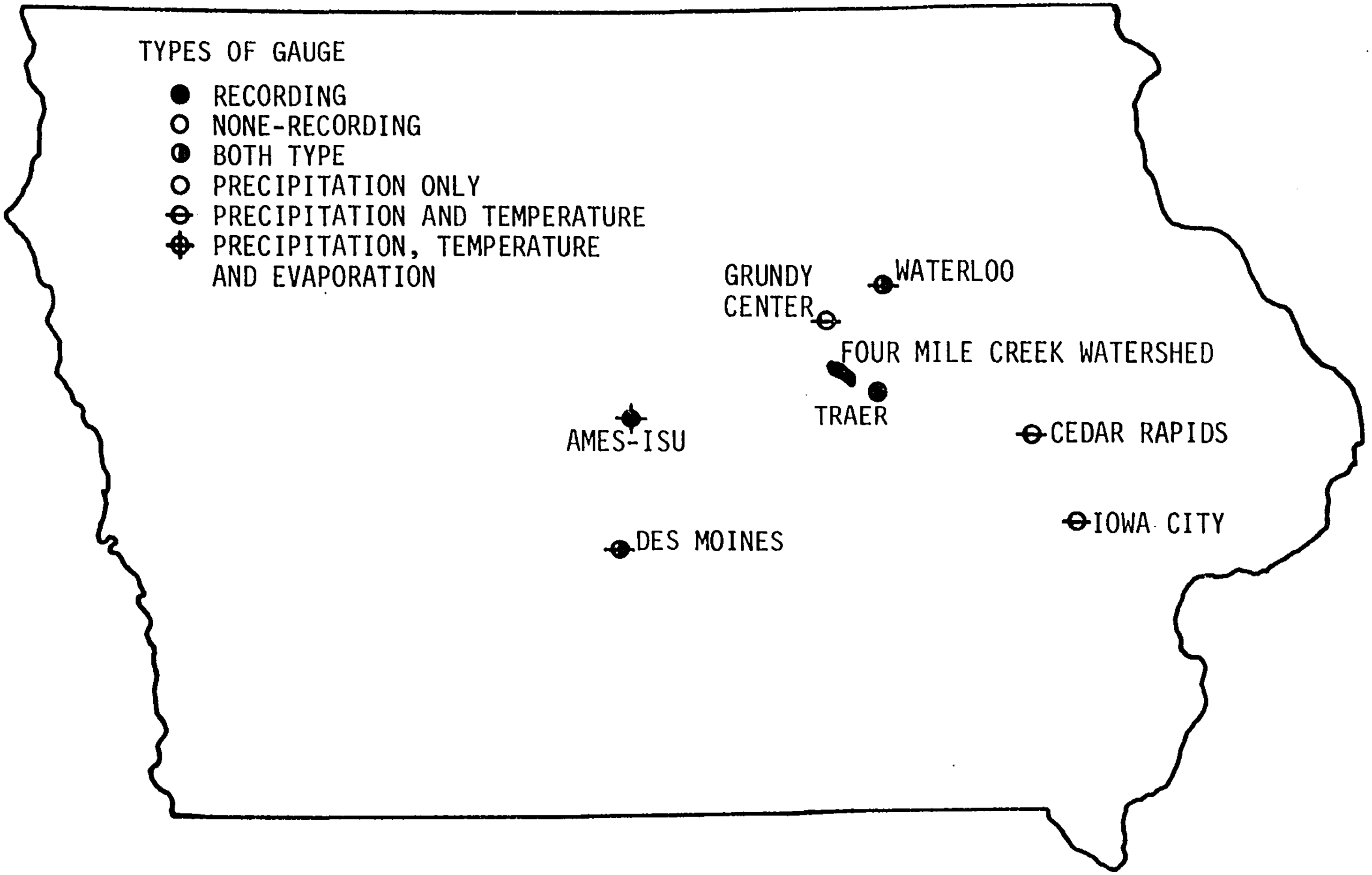


Figure 13. Location of Four Mile Creek watershed and various climatological data gage stations in Iowa

The soils of the area are principally loess derived silt loams. The loess varies in thickness from 1.3 m on the valley sides to over 10 m near the divides. The valley floor is alluvium. Approximately 4 m of clay and silt overlies 5 m of sand. The incised channel is about 2 m deep with a predominantly sandy bed.

The groundwater system in the watershed is quite complicated and has been investigated in detail by Kunkle (1968). Groundwater investigations show that leakage probably passes through the till to aquifers in the underlying limestone.

The Four Mile Creek Watershed is typical of the heavily cropped regions of Iowa in which drainage is well-developed. About 75% of the watershed is planted to corn and soybeans, 25% is in small grain, meadow and pasture. Crop rotation is practiced over much of the watershed. A typical cropping pattern is corn-corn-soybeans-meadow. However, on many level fields, only row crops are grown. The steep slopes are predominantly meadow or pasture.

Sediment yields in this area are about 150 t/km^2 for the 50 km^2 watershed. The average water yield is about 150 mm per year. The watershed has a humid region climate, subject to a wide variety of weather conditions typical of Iowa. The 30 year average temperature is 8.7°C and the 18 year mean annual precipitation is 823 mm.

At the present time most of the sediment supplied to Four Mile Creek comes from sheet erosion on slopes, headward erosion from tributaries and mass wasting of the banks of the mainstream. Some eroded sediment is trapped before it reaches the stream.

More detailed information for the Four Mile Creek Watershed can be obtained from reports by Kunkle (1968), Ruhe and Vreeken [1969), Vreeken (1972) and Aandahl and Simonson (1950).

The Agricultural Engineering Department at Iowa State University has collected hydrometerological data in the Four Mile Creek watershed since 1976. Hourly precipitation, streamflow, sediment and nutrient loss records, as well as climatic data, are available. Six recording raingages were installed to measure precipitation within the watershed. To obtain an average value from the six raingages, Thiessen polygons were used. Pan evaporation and incident solar radiation data on the watershed are also available. The maximum and minimum temperatures were not measured during the winter because the station was closed. Therefore, temperature data from Grundy Center, Iowa, approximately 15 km away from the test watershed, were used.

Flow discharge at the Traer gage station has been collected by the U.S. Geological Survey since 1962. Mean daily sediment load at the Traer gage is also available and has been collected since 1969. Figure 14 shows the gage stations from which various hydrometerological data were collected.

The watershed model utilizes the English system of measurement in the operational equations while the erosion model uses the metric unit. The watershed data must be transferred into metric units before they are used in the erosion model within the model. Simulation results, both in watershed and erosion model, will be reported in metric terms.

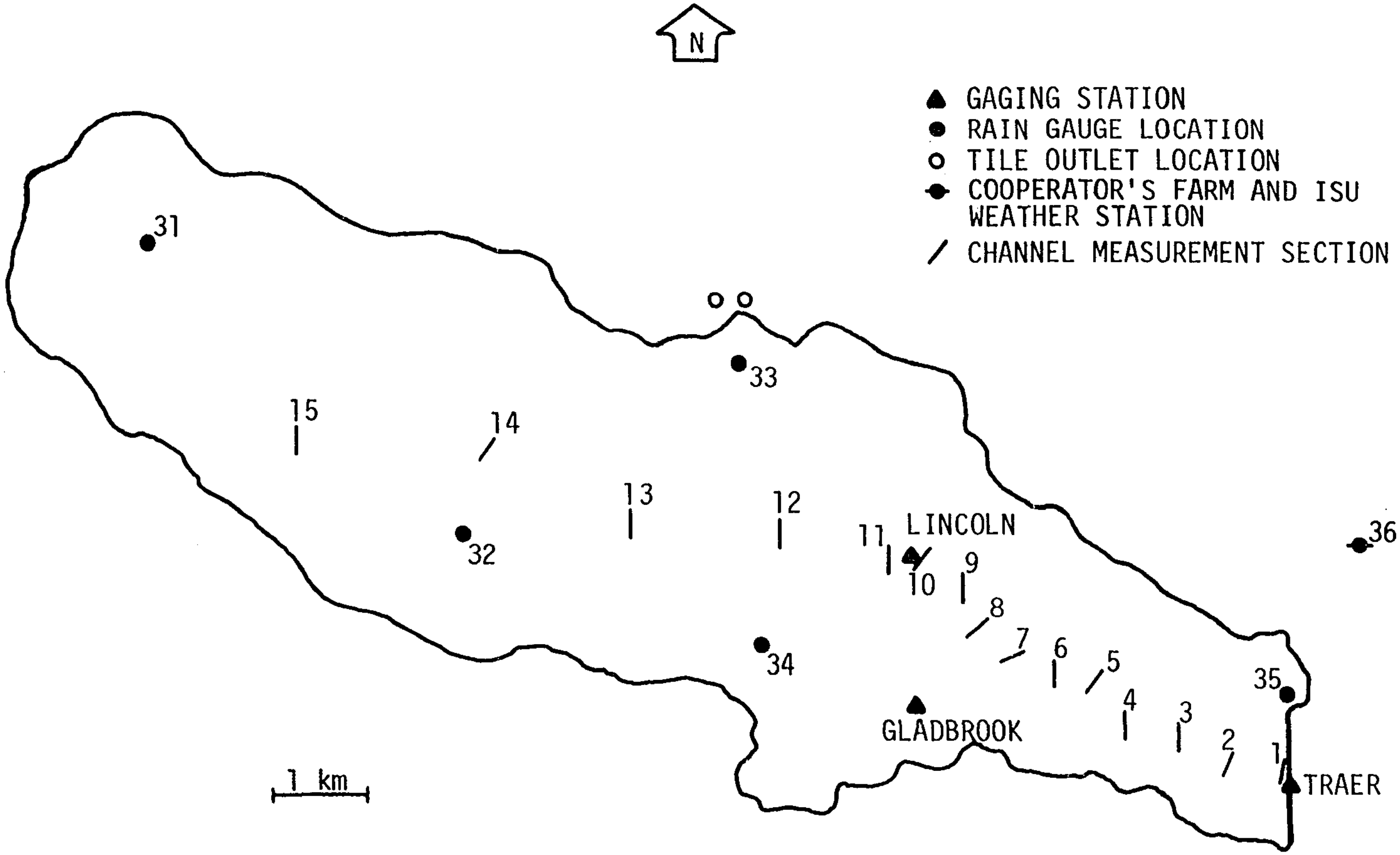


Figure 14. Four Mile Creek watershed instrumentation

Streamflow Simulation Results

To test and verify the Watershed and Erosion Model, the first step is the calibration of the Kentucky Watershed Model to allow reproduction of the hydrologic processes in the watershed. The erosion and the subsequent sediment transport is strongly dependent on the overland flow depth and flow velocity. The ability to adequately reproduce the hydrologic event, particularly the overland flow component, is most important for accurate simulation of erosion and sediment transport in the watershed.

The watershed model was calibrated using the 1976 and 1977 water years. The water years of 1970 and 1978 were used as test years for both the watershed and the erosion models.

The KWM model parameter values which were calibrated by David (1972) using the 1970 water year data for the Four Mile Creek Watershed showed a good simulation result. Since that time, the U.S. Geological Survey has revised the streamflow data for the 1970 water year and made some changes. In this study, the 1970 water year was used as a test year for the newly calibrated parameter values.

In general, the water year of 1976 was slightly below normal in terms of the water yield. The total precipitation was 651 mm for that year. The hydrometerological data such as hourly precipitation, daily pan evaporation, and incident solar radiation were measured within the watershed. The 1977 water year was very dry; therefore, the data may not be adequate to use for the purpose of parameter calibration. However, it was included because it provided a continuous simulation. Besides, it may show the KWM model is well-suited to extremely dry conditions. The 1978 water year was normal in terms of water yield as well as precipitation. The 1978 hydrometerological data which had been collected within the watershed were available. On the other hand, most of the data were measured outside of the watershed for the 1970 water year. Table 5 shows the data used for the calibration and test of the KWM model (see Figure 13 for the location of gage stations).

Table 5. Location of data collection stations

Simulation Year	1970	1976	1977	1978
Hourly precipitation	Traer	Four Mile Creek	Four Mile Creek	Four Mile Creek
Daily precipitation	Ames & Iowa City	Four Mile Creek	Four Mile Creek	Four Mile Creek
Daily min. & max. temperatures	Grundy Center	Grundy Center	Grundy Center	Grundy Center
Daily solar radiation	Ames	Ames	Ames & Four Mile Creek	Four Mile Creek
Recorded streamflow	Four Mile Creek	Four Mile Creek	Four Mile Creek	Four Mile Creek

Given the data available at the time of this study, the Four Mile Creek watershed has been treated as one homogenous segment for hydrologic calibration. The best estimates of the parameters for Four Mile Creek watershed are given in Table 6.

Table 6. Estimated watershed parameters for the Four Mile Creek watershed near Traer, Iowa

Parameter	Value	Parameter	Value	Parameter	Value
BDDFSM	0.0008	FIMP	0.025	CHCAP	350.0
SPBFLW	0.05	FWTR	0.00	OFSS	0.05
SPTWCC	2.00	VINTMR	0.10	DFMN	0.15
SPM	1.40	BUZC	0.80	OFMNIS	0.015
ELDIF	0.00	SUZC	2.50	IFRC	0.35
XNDFS	0.18	LZC	9.10	CSRX	0.975
FFOR	0.005	ETLF	0.30	FSRX	0.975
FFSI	0.10	SUBWF	0.00	EXQPV	0.20
MRNSM	0.15	GWETF	0.01	BFNLR	1.00
DSMGH	0.0001	SIAC	4.00	BFRC	0.963
PXCSA	0.05	BMTR	10.00	GFIE	5.0
RGPMB	1.00	BIVF	0.50	NDTUZ	75
AREA	19.51	OFSL	600.00		

In addition to the calibrated parameters, estimates must be made of the ratio of evapotranspiration to pan evaporation at various periods throughout the year. These ratios were estimated using the research results of Denmead and Shaw (1959), Stanley and Shaw (1978), and Shaw (1964). These ratios as shown in Table 7 were calculated using weighted area factor for three predominant crops, corn, soybeans and meadow in the Four Mile Creek watershed. Instead of being used as variable inputs into

Table 7. Ratio of evapotranspiration to pan evaporation throughout the water year

Period during the water year[a]	Ratio	Period during the water year	Ratio
From day 1 through 89	0.35	From day 212 through 242	0.80
From day 90 through 104	0.37	From day 243 through 257	0.72
From day 105 through 150	0.41	From day 258 through 272	0.56
From day 151 through 180	0.43	From day 273 through 288	0.41
From day 181 through 195	0.68	From day 289 through 366	0.35
From day 196 through 211	0.74		

[a] January 1 = day 1
December 31 = day 365
February 29 = day 366

the watershed model, they are constant within the watershed for the water year studied. Therefore, they must be modified if the watershed model is applied where the cropping pattern or climate are not the same as that for which the evapotranspiration ratio was estimated or even in the same watershed, if there is significant change in the cropping pattern.

A comparison of the recorded and simulated streamflow for the 1976 and 1977 calibration period are shown in Figures 15 through 16. Also, the comparison for the test water year of 1978 and 1970 is listed as shown in Figure 17 and 18. Total rainfall for each day is also shown since this is the primary factor affecting the streamflow occurrence. Table 8 shows the monthly and annual simulated and recorded streamflows for the water years of 1976, 1977 (years used in calibration), 1978 and 1970. The daily simulated and recorded streamflow values are tabulated in Appendix E.

A large number of criteria can be used for determining goodness-of-fit for the evaluation of model parameter values. In this study, statistical properties were used to determine the goodness-of-fit between simulation and recorded data.

For the 1976 calibrated period, the comparison of simulated and recorded flow showed very good agreement with acceptable correlation coefficients. The daily correlation coefficient was 0.85 and the monthly correlation coefficient was 0.93. For the low flows, the agreement was excellent but some discrepancies can be shown in the high streamflow period.

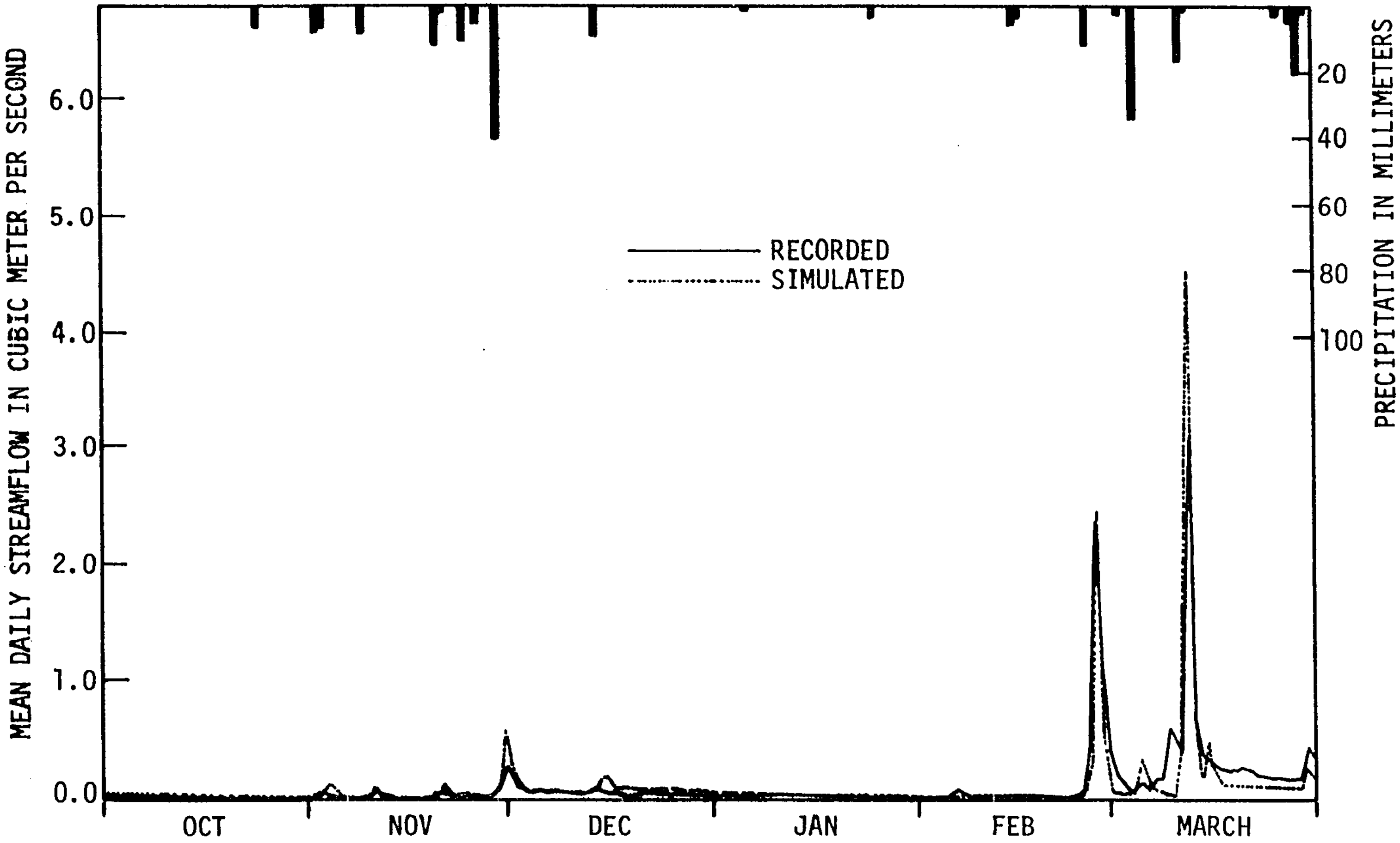
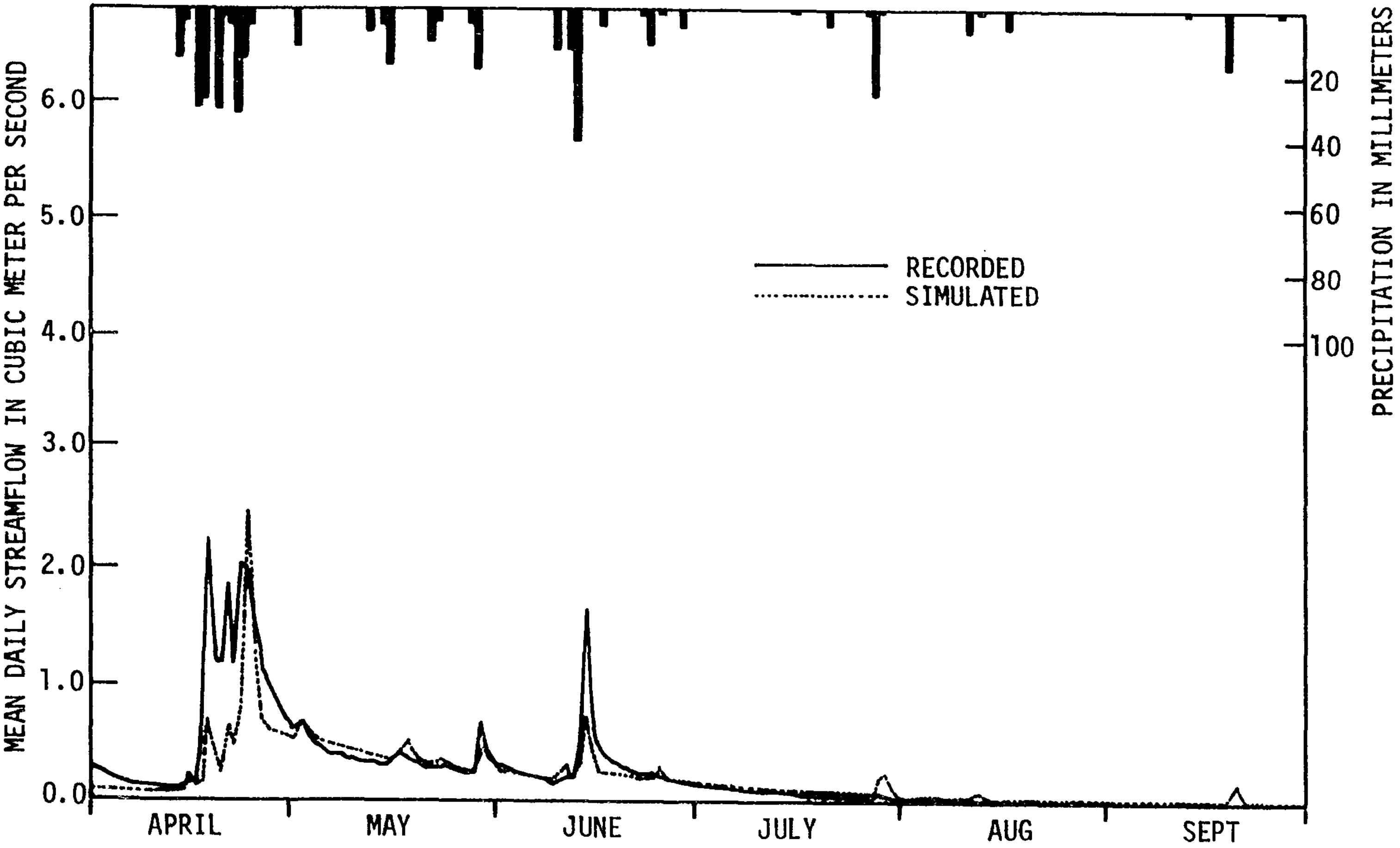


Figure 15. Mean daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1976 water year



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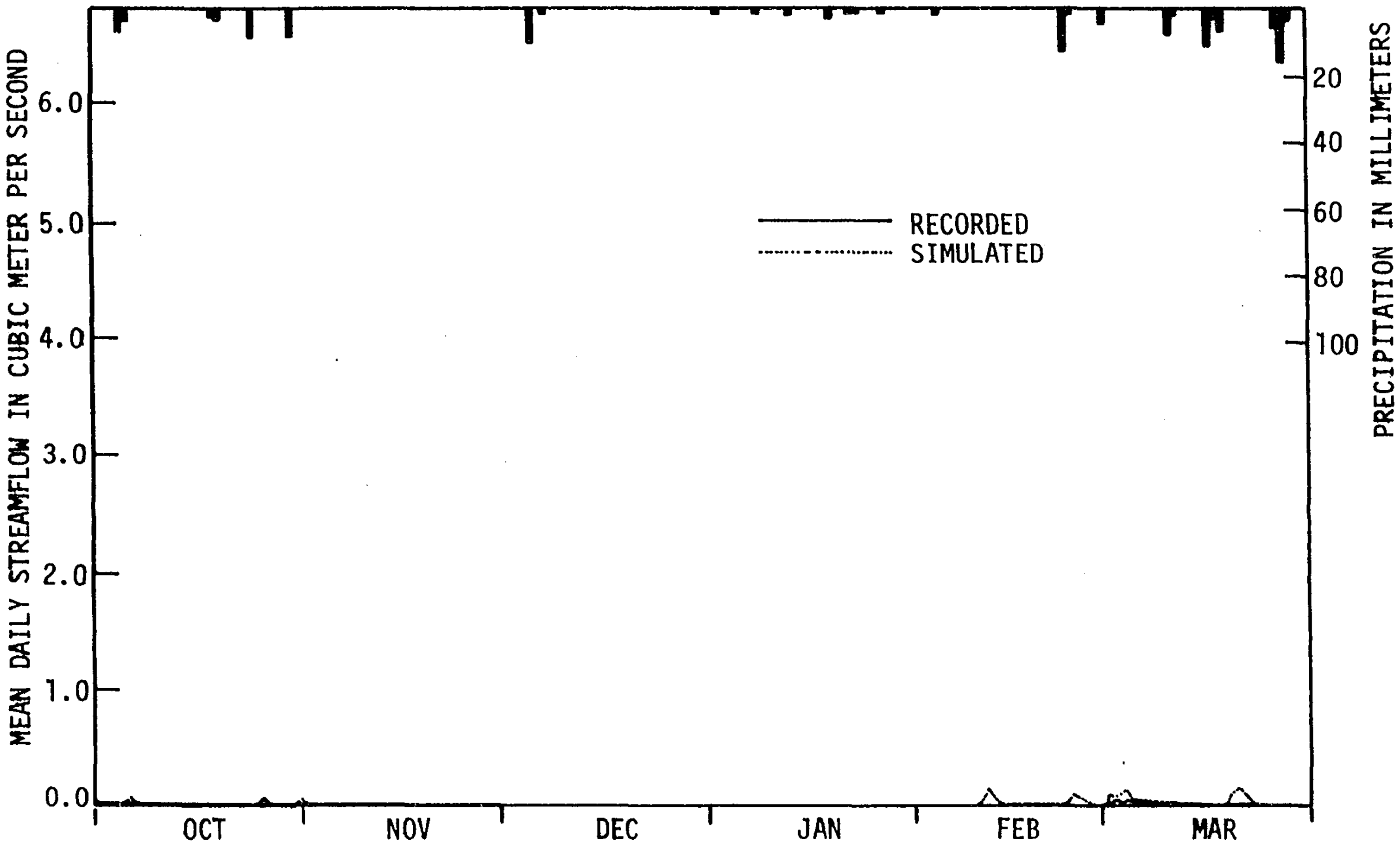
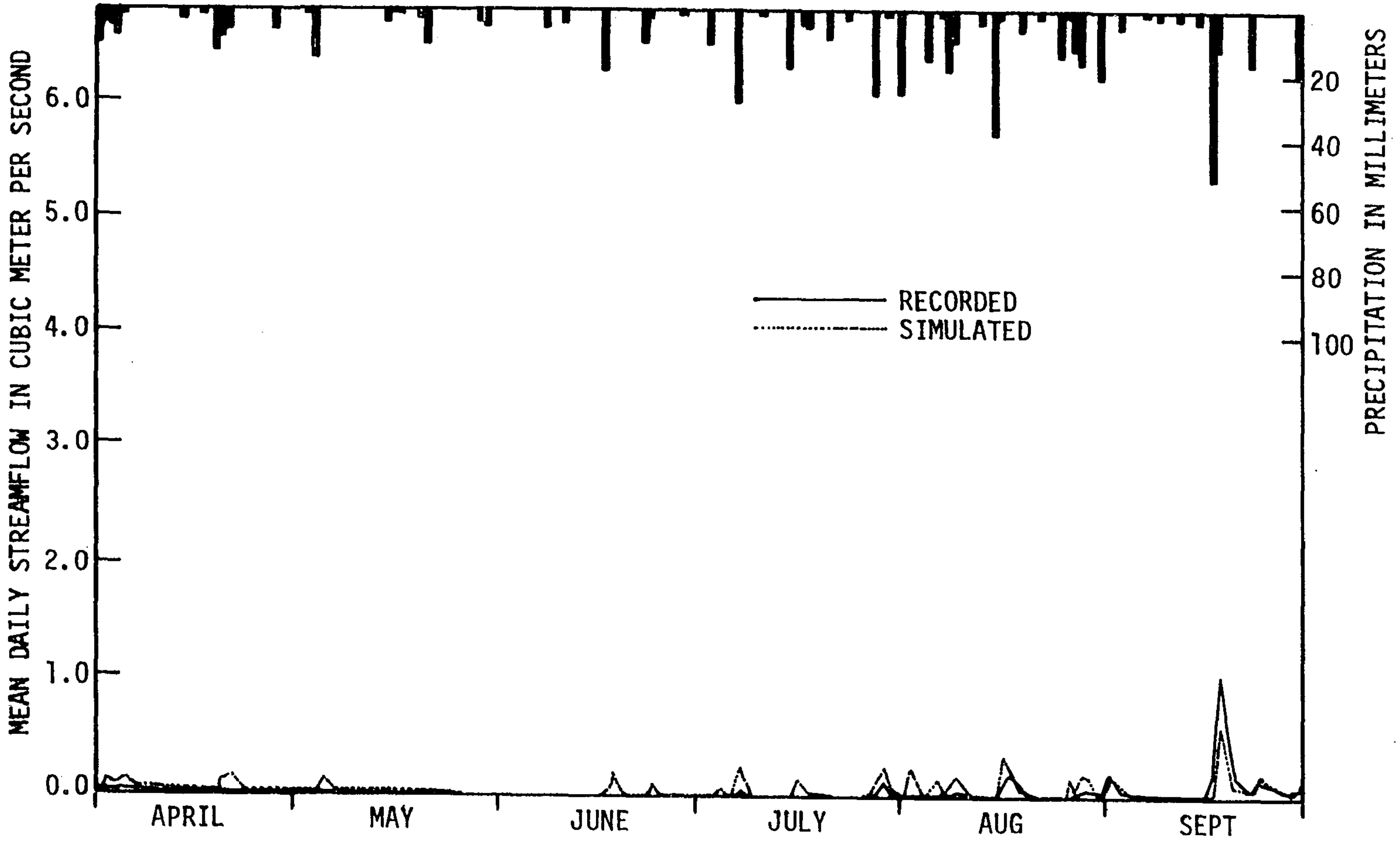


Figure 16. Mean daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1977 water year



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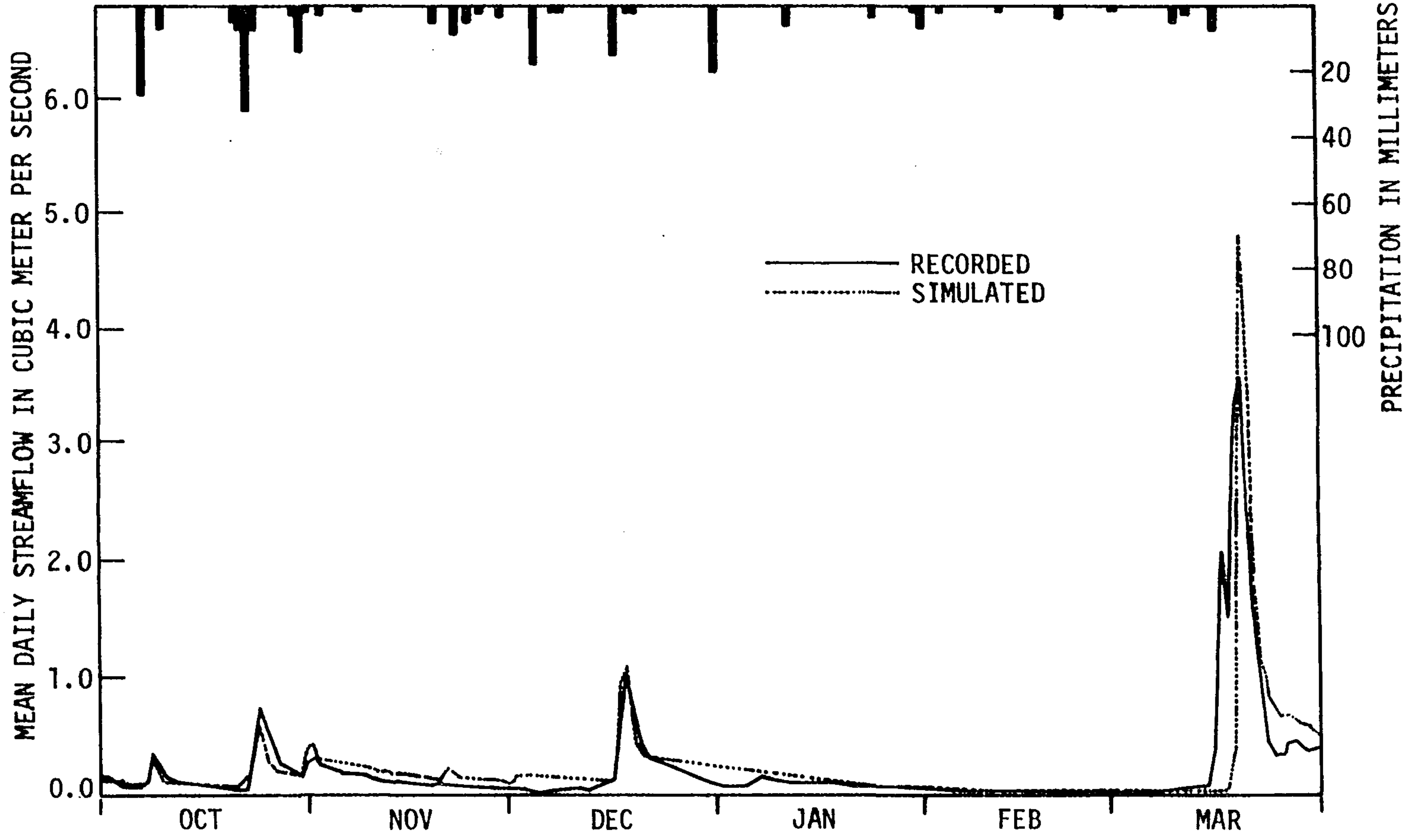
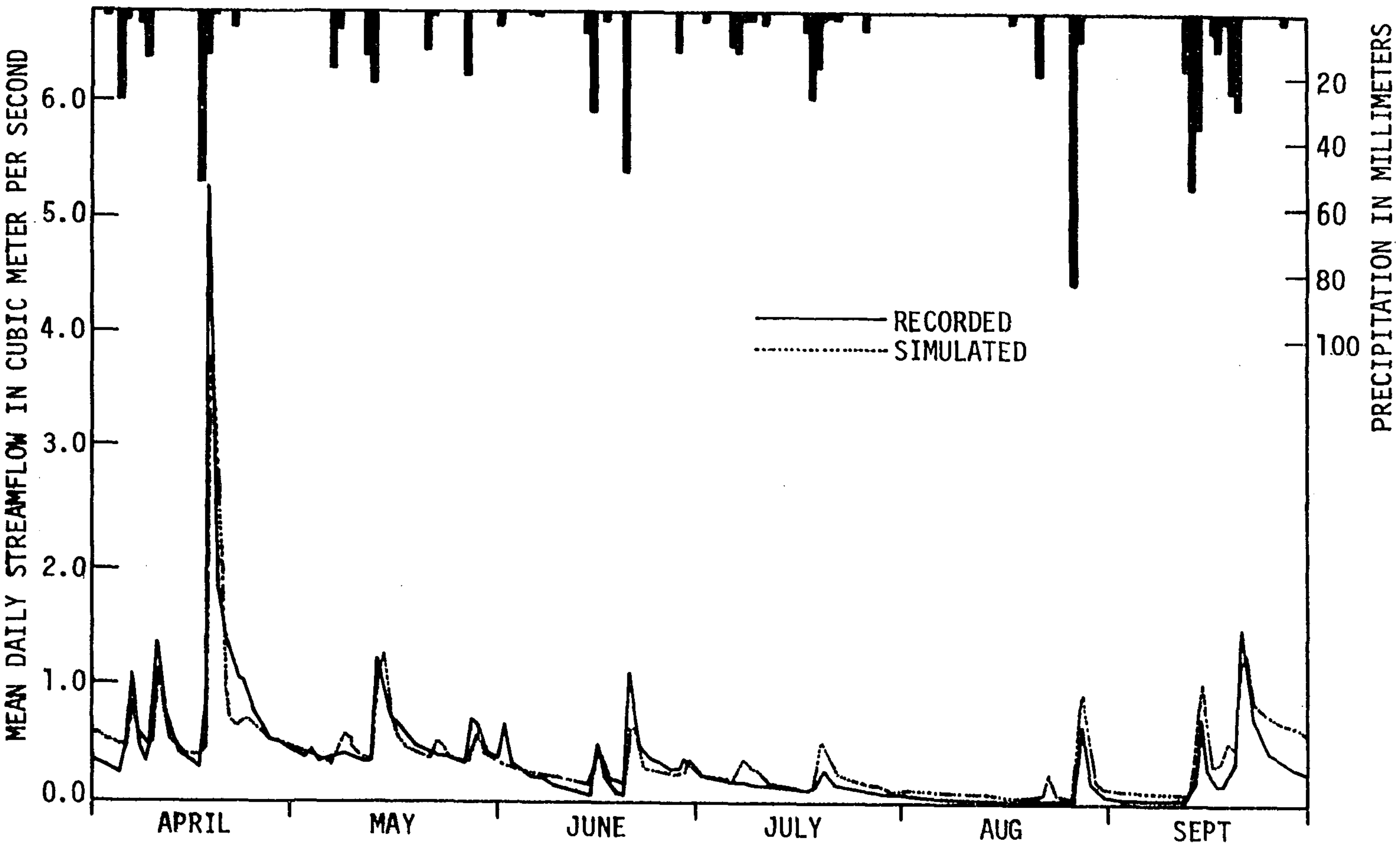


Figure 17. Mean daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1978 water year



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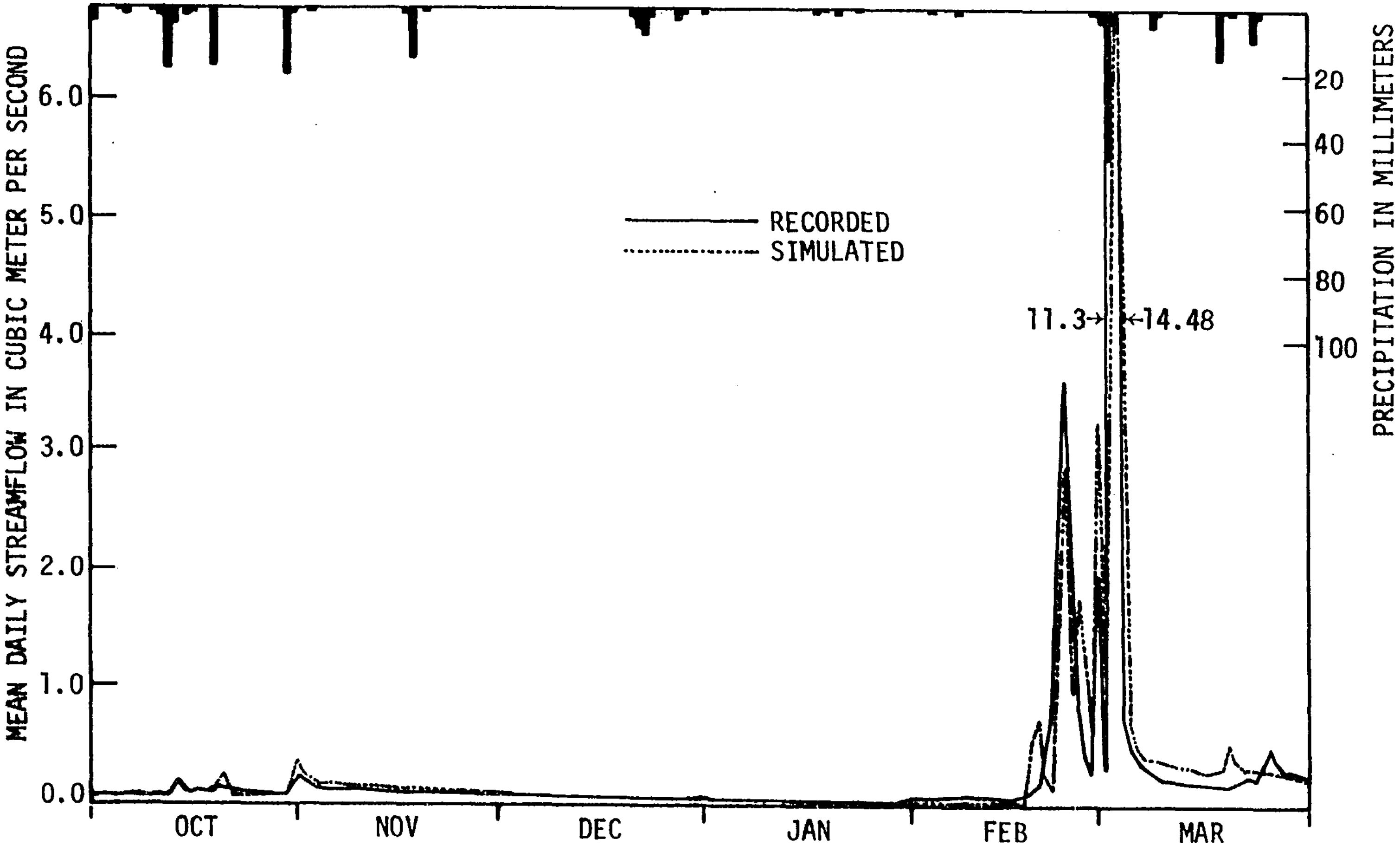


Figure 18. Mean daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

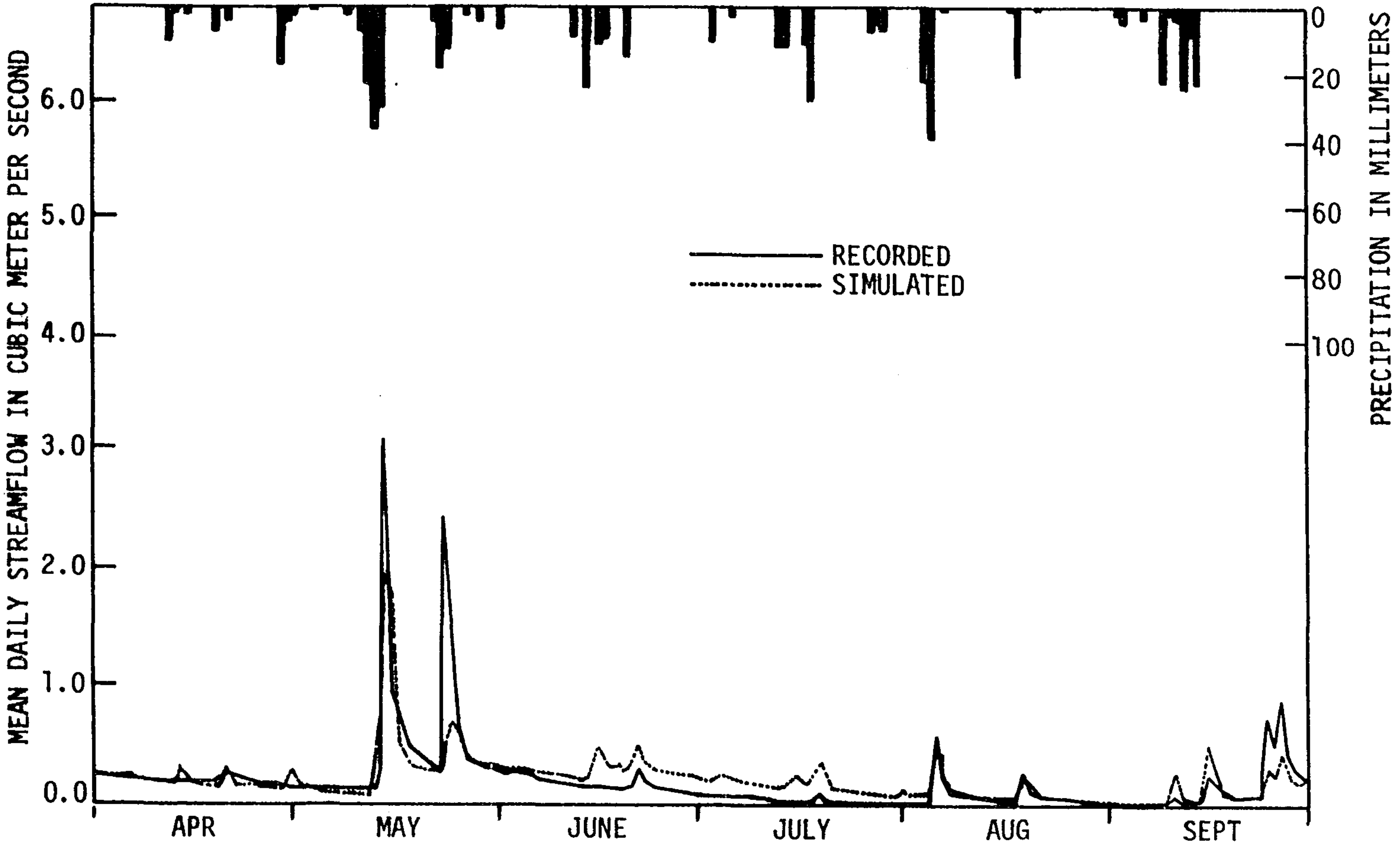


Figure 18. (continued)

Due to the extremely dry conditions in the 1976 water year, the daily correlation coefficient for the comparison of streamflows was lowered to 0.74. However, it indicated that the KWM model was capable of accommodating the dry condition.

A good fit during calibration does not necessarily mean good prediction. Hence, model verification with a set of data separate from that used in model calibration was needed. In this study, the calibrated parameters were applied to the water years of 1978 and 1970, during which data have been collected in different measuring stations.

As indicated earlier, since the data in the 1978 water year were collected within the watershed, as shown in Table 5, the agreement between recorded and simulated streamflow, as shown in Figure 17 was quite good, with a daily correlation coefficient of 0.83. However, for the 1970 water year, the correlation coefficient was dropped to 0.68. The principal reason for this is that the data used in the simulation may not represent the watershed. Particularly, the precipitation record at Traer is not always representative of the rainfall which falls on the watershed. The raingage is located 10 km from the centroid of the watershed. This result implies that the quality of precipitation data is very important for better streamflow simulation.

The agreement between recorded and simulated streamflow in the water years of 1976, 1977 and 1978 was satisfactory although better correlation was expected since improved data collected at the Four Mile creek weather station were used. Improvements could be made by the

Table 8. Monthly and annual recorded and simulated streamflows for the Four Mile Creek Watershed near Traer, Iowa.

Month	Water Year 1976 Streamflow, mm		Water Year 1977 Streamflow, mm		Water Year 1978 Streamflow, mm		Water Year 1970 Streamflow, mm	
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated
October	1.86	1.75	0.29	0.60	10.09	9.56	5.54	5.15
November	2.54	2.42	0.31	0.10	7.35	11.15	6.04	7.56
December	3.12	4.17	0.00	0.00	11.14	14.98	3.21	3.56
January	1.28	1.63	0.00	0.00	5.86	7.84	2.31	1.20
February	9.36	6.56	0.01	1.28	2.50	2.42	24.92	24.23
March	18.64	16.55	1.39	1.88	34.73	31.15	43.89	54.46
April	35.33	20.11	1.13	3.23	43.16	40.03	10.53	10.09
May	20.36	21.80	0.26	1.09	25.55	25.56	26.55	20.67
June	15.63	12.70	0.04	0.80	14.43	13.83	8.86	15.12
July	3.70	5.92	0.37	2.13	7.44	11.01	2.57	8.93
August	0.66	1.87	1.82	4.00	3.58	6.70	4.46	5.58
September	0.31	0.91	5.77	4.76	14.70	23.34	8.39	6.90
Total	112.79	96.39	11.39	19.87	180.53	197.57	147.27	163.45
Daily correlation coefficient	0.85		0.74		0.82		0.66	

improvement of snowmelt simulation. For both of the water years 1976 and 1978, the snowmelt simulation tends to overpredict the streamflow peaks. Also, there are 3 to 4 day discrepancies that indicate when the snowmelt started. The discrepancies affect the accuracy with which the process of snow accumulation and melts are simulated.

These results indicated the need for a more elaborate and comprehensive snowmelt subroutine. One of the limitations in accomplishing this task is the scarcity of climatological data such as detailed incident solar radiation, daily minimum and maximum temperatures, wind and humidity data within the watershed. If the solar radiation, temperature and wind data which are being collected by the Iowa State Weather Station at the Four Mile Creek are modified slightly, they will satisfy the above data requirement for the improvement of snowmelt subroutine in the KWM model. It is important that snow accumulation and melt be simulated as accurately as possible because snowmelt floods in the watershed are often large and account for a significant proportion of the total erosion and sediment yield. It was also thought that the KWM model might not handle correctly the occurrence and the effects of frozen ground conditions. This may have affected the occurrence of snowmelt as well as erosion.

The second problem encountered in the simulation of streamflow was the precipitation data used in the model. In this study hourly rainfall data were used to simulate the overland flow within the 15 minute loop in the KWM model, though the precipitation data were collected as a break point format from which the amount of precipitation was read from raingage chart for a time interval.

The distribution of precipitation in any given storm can vary significantly with time. The variation depends, to a large extent, on the type of storm. Summer thunderstorms have particularly large variations even within very short time intervals. The KWM model predicts the lesser overland flow and does not take into account the average effect of precipitation. The higher the intensity of precipitation, the greater the discrepancies between simulated and actual overland flow would be expected.

In the present state of the art, the sum of overland flow and base flow is compared with recorded streamflow. No direct method is available for evaluating accurately the amount of the overland flow in the model. This factor is even more critical when it comes to the simulation of erosion, which is simulated from the transportability of the overland flow.

The only way to obtain calibration results more suitable for the use of erosion simulation is to employ the break point data from the recording raingage chart. The break point rainfall data in the model would require more computer execution time when a very short time increment is used. However, adjustments can be made so that the short time interval should be used for large storms by modifying the KWM model structure. This work has not been attempted because it is beyond the scope of this study.

Even though several problems were encountered in the performance of the watershed model, general agreements between recorded and simulated stream flow data for the 4 years data were sufficient to show that the model can be used to simulate the soil erosion and sediment transport.

Results of Soil Erosion Simulation

The erosion model was calibrated by trial and error using the 1976 water year data. As described in Chapter IV, most parameters in the erosion model can be obtained from the literature or from the result of laboratory analysis. Even though the parameter values were taken from other sources of information, these should be checked with the recorded data through computer runs. After each run, the simulated daily sediment discharge was plotted against the recorded mean daily sediment discharge obtained at the Traer gaging station. These plots were used to decide the parameter values to be altered for the next run so as to improve the calibration. The final set of parameter values obtained by the calibration process are given in Table 9.

Table 9. Calibrated erosion model parameters for the Four Mile Creek Watershed near Traer, Iowa

Parameter	Value	Parameter	Value
ERKI	0.026	C3	0.15
PC	3.0	KP	0.018
RULF	0.82	ALP1	0.035
TILL	0.53	ALP2	0.100
ERKR	0.046	ALP3	1.330
CL	0.66	KDAY1	70
C2	0.50	KDAY2	360

In addition to the erosion parameters, estimates must be made of the particle size distribution of sediments which are being moved over the land surface. This was estimated from the research result of Kimes (1979) for the sediment size distribution analysis in the Four Mile Creek Watershed. From the particle size distribution curves, 5 representative sizes and the corresponding densities were selected as shown in Table 10.

Table 10. Sediment particle characteristics

Particle Group	Mean Diameter, mμ	Specific Gravity
I	32.0	1.80
II	13.0	2.00
III	7.0	2.65
IV	3.5	2.65
V	1.4	2.60

The recorded and simulated suspended sediment loads were compared to evaluate the accuracy of the simulation. Figures 19 through 21 are a series of mean daily recorded and simulated sediment loads versus time for the water years of 1976, 1978, and 1970. The sediment yield in 1977 was very small due to the small precipitation and could not be shown graphically, thus negating the possibility of comparison.

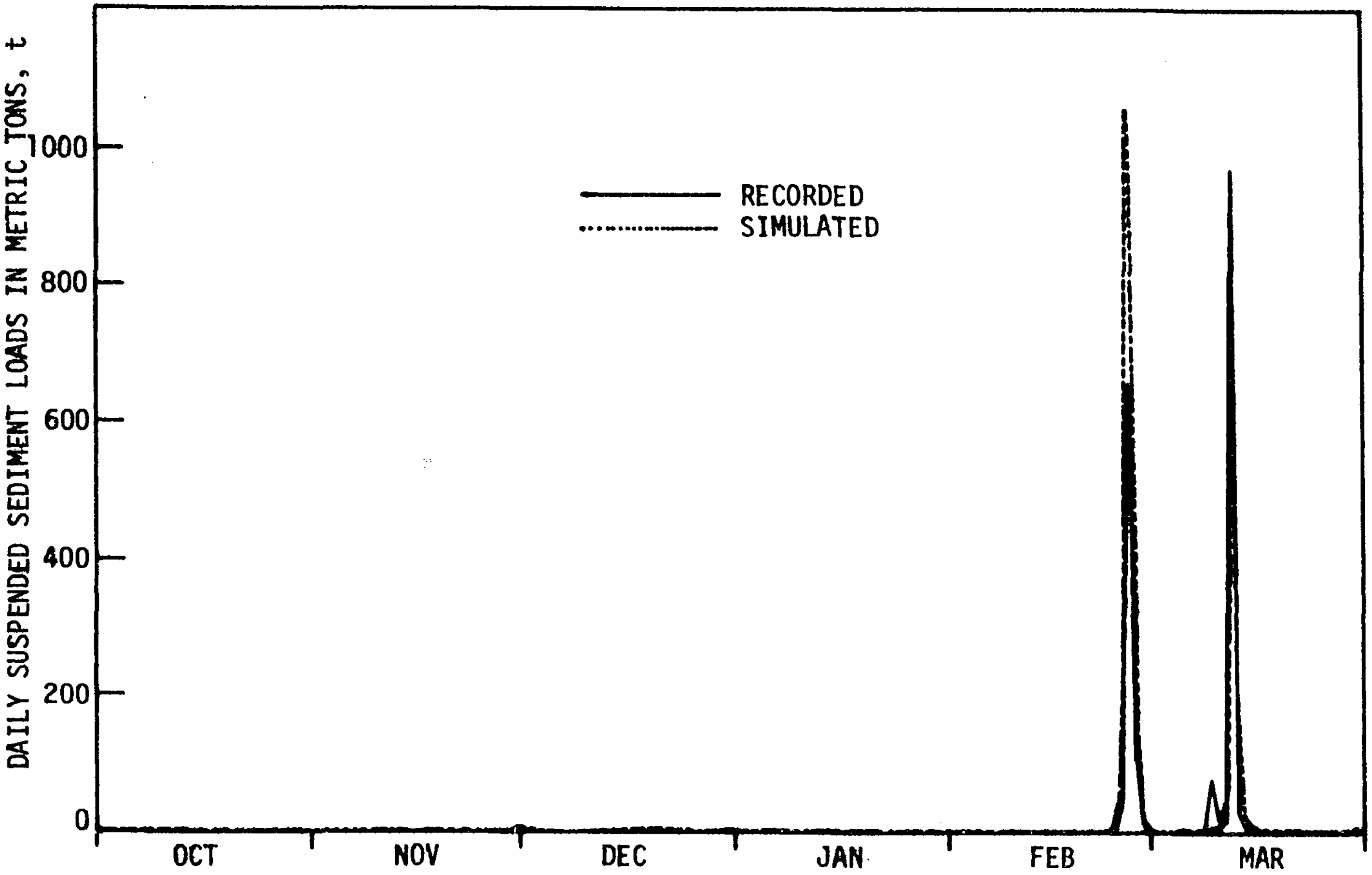


Figure 19. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1976 water year

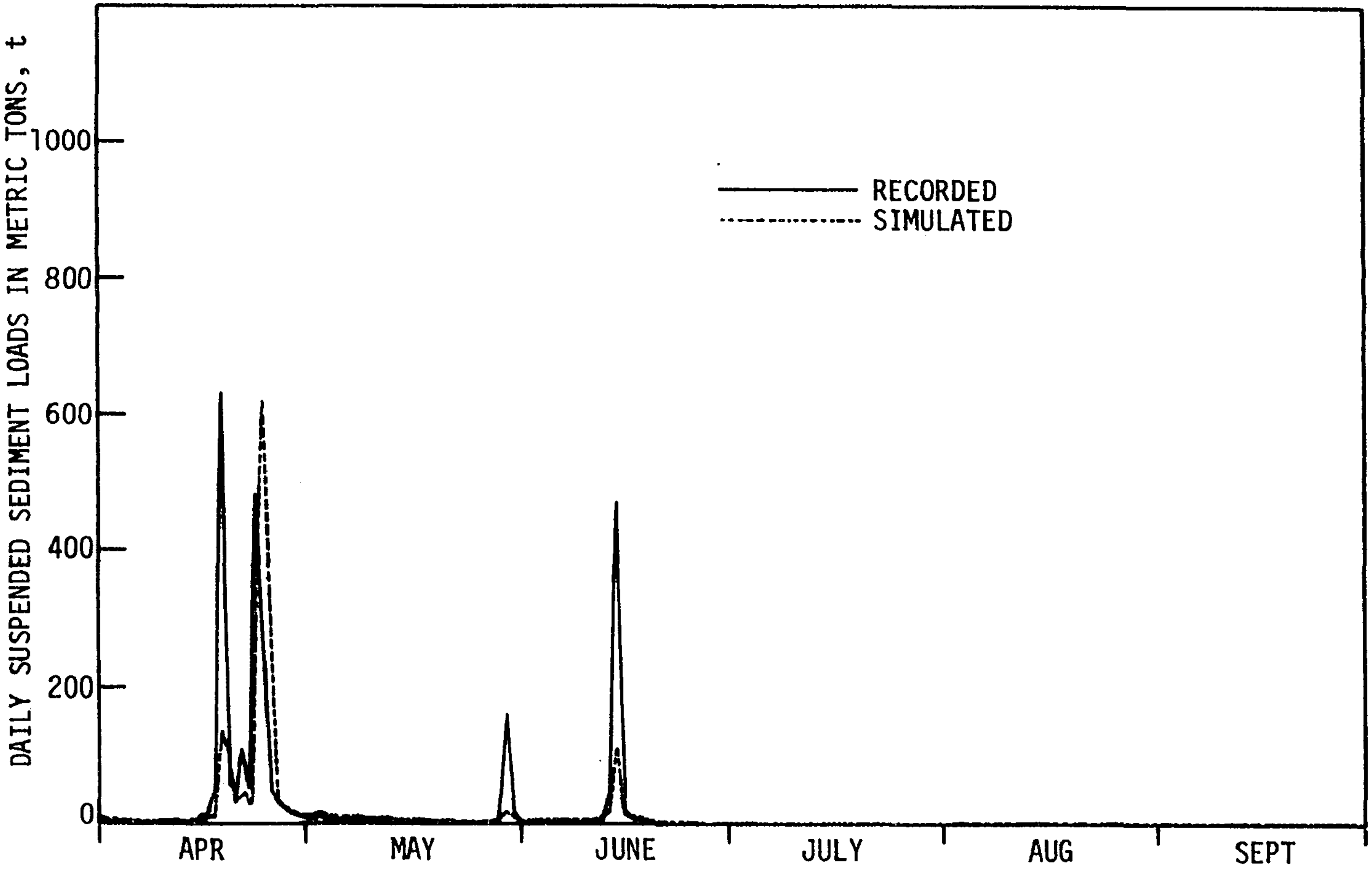


Figure 19. (continued)

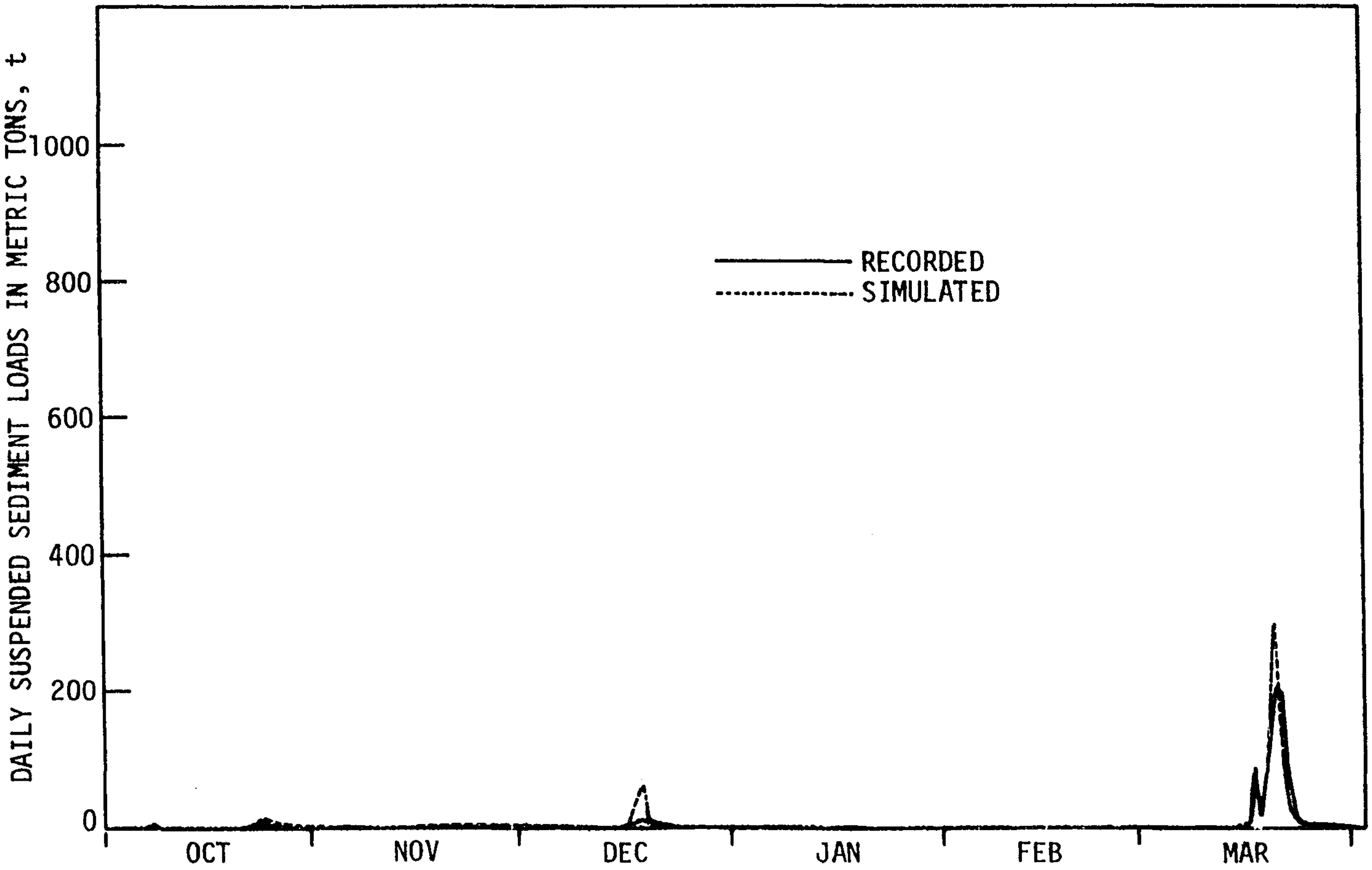
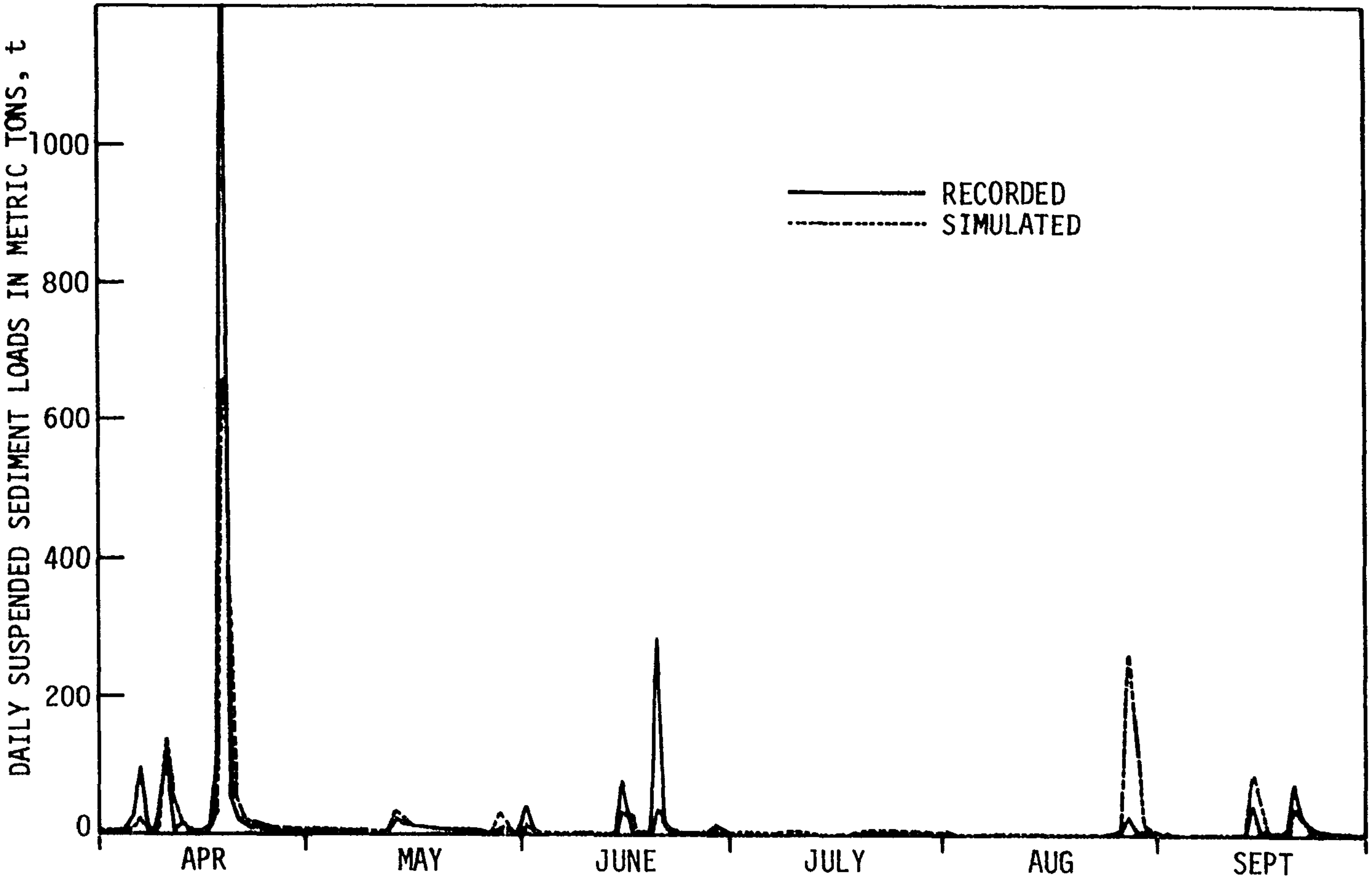


Figure 20. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1978 water year



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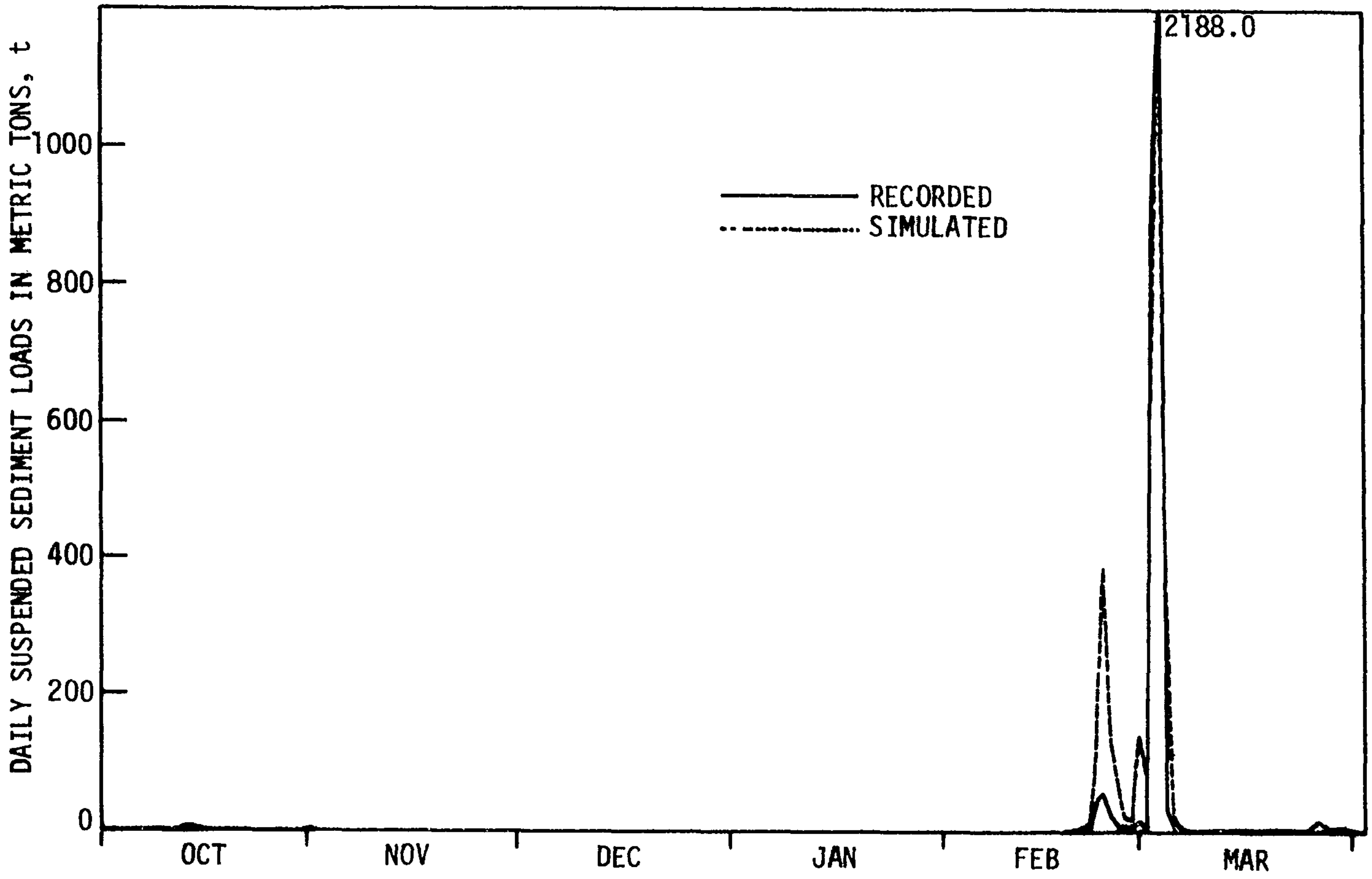

Figure 21. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

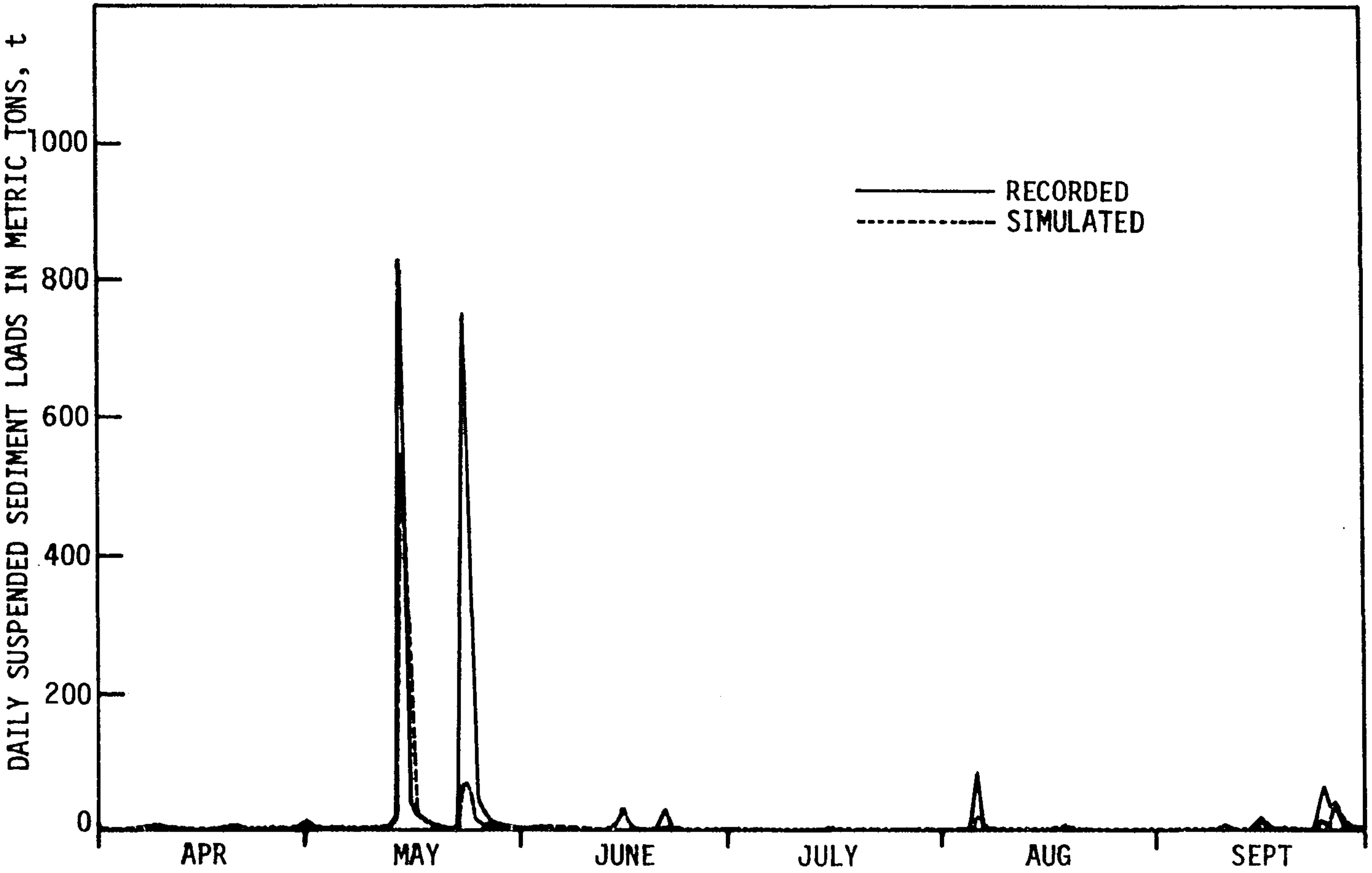

Figure 21. (continued)

Table 11 shows the monthly and annual simulated and recorded sediment load for 4 years. Appendix F gives the simulated and recorded mean daily sediment load for the 1976, 1977, 1978 and 1970 water years.

The general agreement between simulated and recorded daily values indicates almost the same trend as that for streamflow. The daily correlation coefficient between recorded and simulated sediment load for 1976, 1977, 1978 and 1979 was 0.83, 0.74, 0.83 and 0.82, respectively. The low correlation was obtained from the dry year of 1977. It is noted that the analysis of correlation coefficient includes the sediment load during low streamflow; the sediment yield is usually small and stable. It should be pointed out that if only sediment yield at high streamflow is considered, the correlation coefficient between two sediment discharges will be decreased.

In general, the erosion model shows generally good monthly, yearly and daily simulation, especially for the water years of 1976 and 1978. However, the daily results were not accurate for some storm events and snowmelt.

Considering the fact that erosion only takes place when overland flow occurs and is simulated using a power function of precipitation and overland flow depth, it is natural that erosion is very sensitive to errors in the simulation of the occurrence and intensity of precipitation and overland flow. There is no way to avoid this sensitivity because it is present in the natural process. Hence, errors in the simulation of sediment yield, especially in the high streamflow periods, will inevitably exceed the corresponding errors from streamflow.

Table 11. Monthly and annual recorded and simulated suspended sediment loads for the Four Mile Creek Watershed near Traer, Iowa

Month	Water Year 1976 Sediment loads,t		Water Year 1977 Sediment loads,t		Water Year 1978 Sediment loads,t		Water Year 1970 Sediment loads, t	
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated
October	9.2	6.2	1.1	0.3	43.7	67.7	40.9	28.7
November	15.7	21.9	0.8	0.0	27.1	42.2	27.5	30.2
December	16.9	18.8	0.0	0.0	64.3	154.5	15.2	13.7
January	5.1	4.1	0.0	0.0	45.9	28.5	10.8	8.9
February	845.1	1437.0	0.2	0.0	16.2	9.5	172.0	1167.0
March	1199.2	1290.0	12.4	9.4	753.2	604.6	2223.9	3434.4
April	1866.2	1459.5	7.4	12.8	1999.0	1481.0	29.1	79.6
May	265.8	166.7	1.8	5.5	150.2	274.0	2101.0	1218.0
June	590.8	245.2	0.1	34.3	511.5	177.1	53.2	97.5
July	14.8	78.3	8.9	152.2	63.5	54.4	10.0	23.2
August	2.9	2.3	28.6	208.5	53.2	423.3	108.8	52.6
September	2.2	0.5	69.9	222.1	250.8	279.1	179.6	120.8
Total	4833.9	4767.4	131.2	645.1	3978.6	3595.9	4972.0	6274.6
Daily correlation coefficient	0.83		0.74		0.83		0.82	

It is also obvious, from the comparison of both streamflow and sediment yield, that some poor simulations of daily sediment discharge are caused by inaccurate simulations in the watershed model. Inaccurate simulation of snowmelt in terms of time and magnitude might be another reason for the large differences between the recorded and simulated daily sediment load. More elaborate and accurate snowmelt subroutines will improve this problem greatly.

Two important flow regimes can be considered in eroded particle transport on an overland flow surface. The first is snowmelt flow with large overland flow depths because of snowmelting characteristics and the soil moisture condition in this period. The second is flow which occurs after a storm event and is associated with a relatively small overland flow due to increased rainfall interception, depressional storage and higher evapotranspiration rates. As a result, the flow is composed of higher proportion of base flow than of overland flow. This may even occur during periods of high streamflow.

In an agricultural watershed such as the Four Mile Creek with mild topographical conditions, the transport capacity is entirely dependent on the overland flow depth. Hence, the transport capacity of eroded particles on overland flow is greatly affected by the characteristics of flow regimes. In the snowmelt period, the transport capacity is generally not a limiting factor due to relatively large overland flow compared with total streamflow. Therefore, the sediment yield is governed by the amount of soil particles detached by precipitation and overland flow. Under this condition, frozen ground is an important factor for the detachment; the watershed and erosion model has not properly handled the frozen ground and its effect on the detachment. Sometimes this may create large discrepancies between recorded and simulated sediment yield in the snowmelt period.

For the general storm flows during April through September, the transport capacity is a limiting factor for the sediment yield. Hence, the ratio of overland flow to the total streamflow which is obviously related to the soil moisture condition is a very important factor when determining the magnitude of the transport capacity of detached soil particles to the stream. The other factor which can be affected in the overland flow is Manning's roughness coefficient. It must be varied with the surface condition as crop growing progresses. However, a constant value was used in the model due to the lack of information in this area.

Figures 22 and 23 show the comparison of recorded and simulated daily mean streamflow and sediment yield for the major 18 storms which showed the peak events in 1976 and 1978 water years. The rainfall intensity in Figures 22 and 23 was taken from the maximum intensity for that event.

As discussed in the previous section, the streamflow simulations were poorer in the higher intensity precipitation. This fact directly affected erosion simulation and sediment yield. It seemed that the discrepancies in sediment yield between recorded and simulated are much greater than that of streamflow simulation as shown in Figures 22 and 23.

Since there is no method available to evaluate overland flow directly from precipitation data, it is somewhat difficult to conclude how the

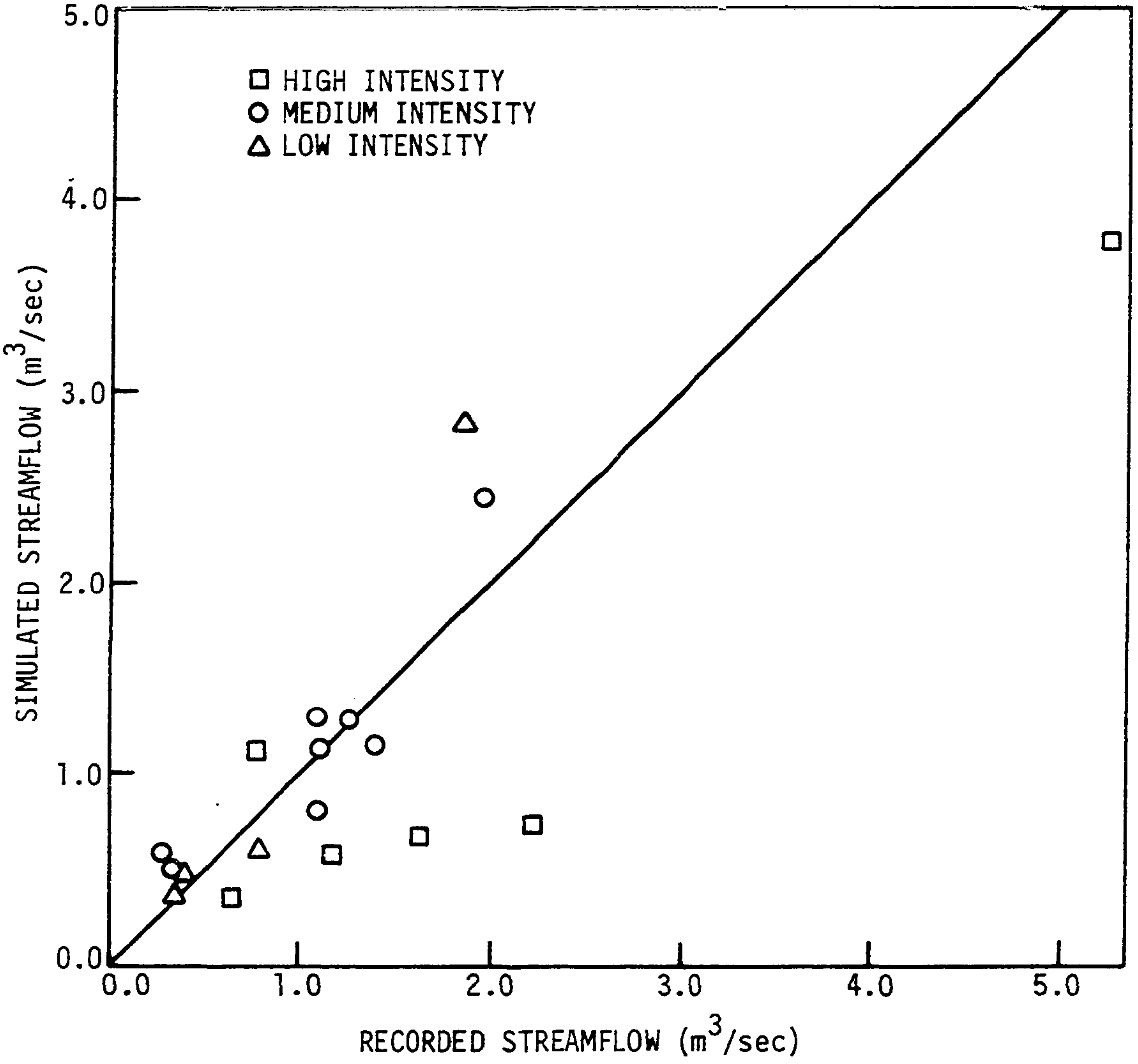

Figure 22. Comparison of simulated and recorded flow in different rainfall intensities

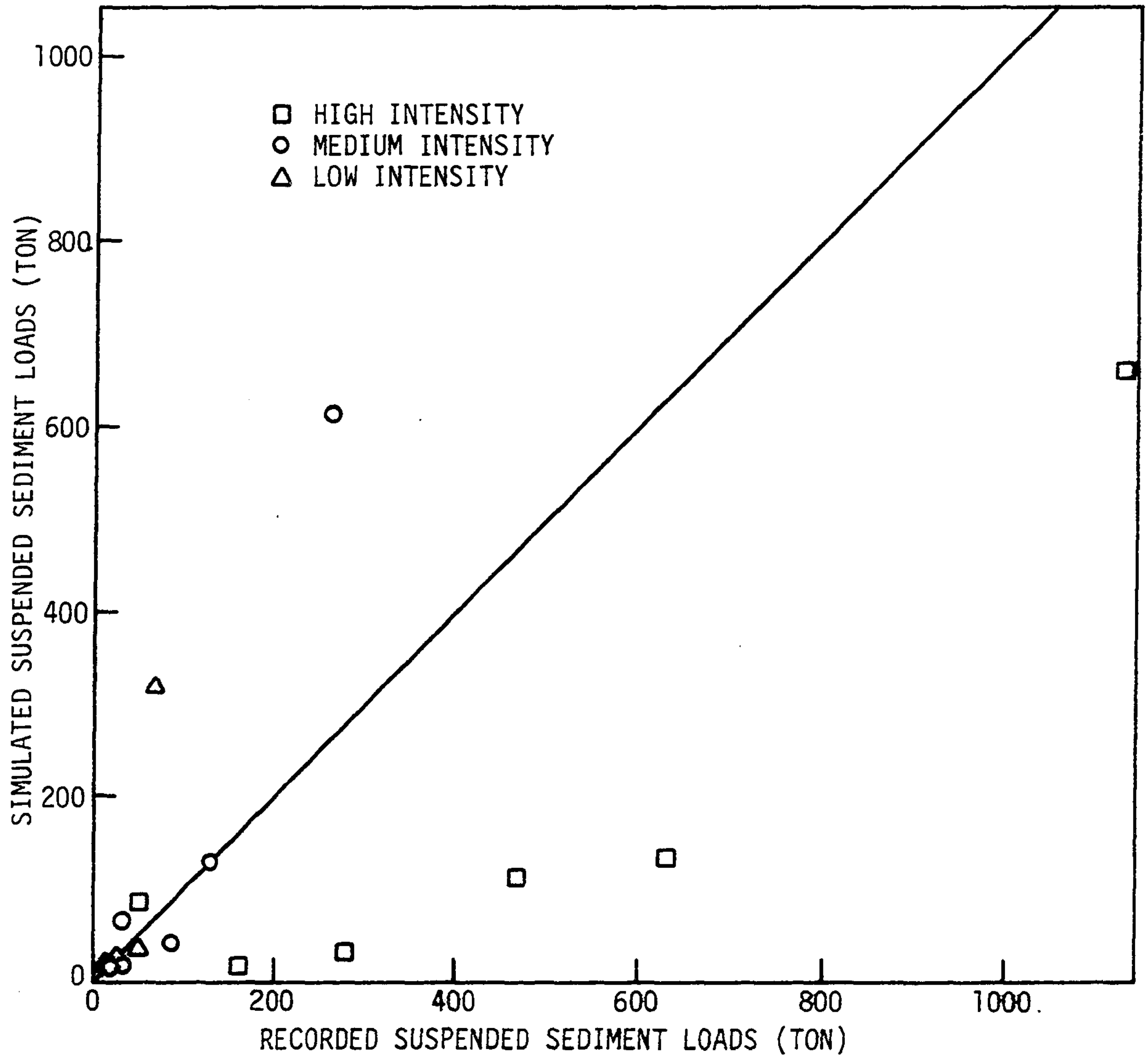

Figure 23. Comparison of simulated and recorded sediment loads in different rainfall intensities

rainfall intensity affects determination of overland flow depth. In most cases, sediment yield data and streamflow data are collected on a daily basis as concentration and discharge rates. However, it is estimated that overland flow is relatively smaller than what actually occurred when high intensity precipitation occurs because of the averaging effect of rainfall intensity. This might result in a smaller transport capacity than actually occurred during peak streamflow. This effect can be seen in the comparison of streamflow and sediment yield in Figures 15 through 21. The simulated values generally yield lower sediment loads than those measured in the stream. This is observed in all simulations while using realistic parameter values during the storm flow period. To resolve this problem, break point precipitation data must be used in both watershed and erosion models to obtain more realistic overland flow and associated transport capacity. However, computational time and efficiency must be considered in this regard.

The simulated sediment yield during the low flow period showed good agreement with the recorded sediment load in the stream. Since the channel erosion was modeled to be a power function of recorded streamflow data, the simulated streamflow has little effect on the sediment yield. However, if there are reliable data and associated theories available, this component must be modified to be a function of simulated streamflow.

In this model, channel erosion acts as a long term sediment yield from a watershed. The channel erosion component improved the general agreement between recorded and sediment streamflow.

The crop management and tillage operations are two major factors that have a great effect on the soil erosion simulation in an agricultural watershed such as the Four Mile Creek Watershed. If the response of the model to variations in these factors in different growing season was known precisely, then the erosion simulation could be improved. A systematic and consistent data search on crop effect needs to be conducted to obtain a more elaborate CROP model. Tillage operations have a major effect on overland flow and sediment yield. The effect on sediment yield appears to be somewhat equivalent to the effect on streamflow.

However, the biggest problem in the effect of the crop management and tillage operations are that these effects are changed abruptly not by natural processes but by man's activities such as plowing and other cultivation. This may hinder establishment of proper assumptions and simplifications essential to conceptual models.

Some deviation also might be caused by errors in the recorded data. One example is the storm of August 27, 1978. The total precipitation for that storm was 82.3 mm with the highest rainfall intensity of 34.5 mm/hr. However, the recorded streamflow data showed only 1.9 mm of runoff from such a rainstorm.

It is noted that the quality of the streamflow records during winter months are considered as poor due to effects of ice. Since the recorded suspended sediment load is computed by multiplying the mean streamflow discharge during a time interval by the concentration of the suspended particles measured during that time, the errors in the streamflow estimates may be transferred to the suspended sediment load data.

As was mentioned in Chapter IV, the erosion model is composed of two subroutines: EROS and CROP model. The EROS alogrithms were initially derived from the erosion model by David and Beer (1975) and have been substantially modified during the model development based on concepts presented by Meyer and Wischmeier (1969), Foster and Meyer (1972a) and Foster (1978). The major differences between two models is the use of fewer calibrated parameters by substituting values based on soil erosion processes. Other modifications are in computation of deposition and sediment storage in the model.

One of the dangers in erosion mathematical modeling is that almost any type of erosion model can generate sediment yields that appear to be reasonable. Some erosion models have gained acceptance through repeated use and improvement, not through repeated proof of accuracy. For this reason, this study has taken care to establish the accuracy of its model parameters and has provided means of checking their accuracy. The erosion model developed in this study includes the fundamental erosion process and depends solely on the watershed data as input, all of which can be obtained independently of the model.

CHAPTER VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The watershed and erosion model has been developed to simulate soil erosion and sediment yield from small agricultural watersheds. It is composed of two separate models: the modified Kentucky Watershed Model and an erosion model, which are linked by superimposition.

The erosion model utilizes physically based theories and empirical relationships which describe soil particle detachment and the processes of transport and deposition in upland and channel phases of erosion. The erosion model can be divided into two main parts: the EROS subroutine, which simulates the soil erosion and the sediment movement process and the CROP subroutine, which accounts for the effect of crop management on soil erosion and sediment yield.

Some field measurements of sediment sizes and soil properties would have reduced the number of calibrated parameters, thereby reducing the number of trial runs necessary to calibrate the model parameters. This experience showed the central importance of the further development of algorithms based on physical relationships of the erosion and sediment movement processes.

The watershed and erosion model was calibrated and tested using four years of data collected by Iowa State University Weather Station at the Four Mile Creek watershed near Traer, Iowa. The simulation of sediment yield in the Four Mile Creek watershed is an illustration of the potential application of the erosion model. The recorded and simulated values of suspended sediment loads in the stream are in good agreement except for one dry year.

The following conclusions were drawn from the results after testing the watershed and erosion model:

1. The watershed and erosion model is a deterministic lumped parameter model, and is capable of simulating the daily mean streamflow and suspended sediment load within a 20 percent error, when the correct watershed and erosion parameters are supplied.
2. It was found that soil erosion is sensitive to errors in simulation of occurrence and intensity of precipitation and of overland flow. Therefore, representative precipitation data and a watershed model which provides an accurate simulation of soil moisture and resulting overland flows are essential for the accurate simulation of soil erosion and subsequent sediment transport prediction.
3. Erroneous prediction of snowmelt in terms of time and magnitude in conjunction with the frozen ground could be the reason for the poor simulation of streamflow as well as sediment yield in the snowmelt period. More elaborate and accurate snowmelt submodels will greatly improve accuracy.
4. Sensitivity analysis was performed to check the relative value of the hydrologic, soil, flow resistance and vegetative parameters on the results of the simulation. Small changes in

the soil and hydrologic parameter values cause large variations in both the peak flow and streamflow volume. Changes in the flow resistance and vegetative parameters have relatively little affect on the simulation of streamflow.

5. Crop management and tillage operations are two major factors that have a great effect on soil erosion simulation. The erosion model attempts to evaluate the impact of crop management and tillage effects on sediment production. These effects on sediment yield appear to be somewhat equivalent to the effect of overland flow.
6. Poor simulation results can be attributed to deficiencies in the erosion model and to errors in the observed data such as the recorded daily streamflow and the sediment concentration.
7. The watershed and erosion model can be used as a tool for the planning and evaluation of agricultural management techniques for the control of soil erosion. Pesticide and nutrient losses can be predicted with further modification and expansion of the model.

The watershed and erosion model may be limited in its use depending on watershed size. Watersheds of area greater than 50 to 70 Km^2 may be approaching the models upper limit of applicability.

Suggestions for Further Research

A mathematical model such as that developed in this study is a tool whose utility is enhanced by repeated use. The model is based on sound theory but the parameters used must be measured or estimated with knowledge obtained from experience with the physical process and workings of the model. Well-planned field measurement programs, under diverse conditions, are necessary for meaningful comparisons with model simulations and enable the continuous improvement of the model.

Based on the experiences of this study, further suggestions can be offered as follows:

1. There is a need for a comprehensive mathematical submodel for the snowmelt and related frozen ground conditions.
2. The present algorithm in the erosion model does not explicitly handle the sediment size distribution in the sediment movement process. The erosion model requires this information because various particle sizes behave differently as they are moved, deposited and stored through the system. Some algorithms must be added to account for the sediment size distribution in the erosion model.
3. The impacts of different agricultural management practices on soil erosion needs to be further investigated. The crop residue cover effected by different cultivation methods was approximated using limited data due to a lack of pertinent

information and therefore has not been fully described. The effect of tillage operations should be varied as crop growth progresses. Further research is also needed for more complete modeling of the effects of agricultural management practices on both overland flow and sediment yield.

4. To obtain a more realistic sediment transport capacity value, the break point format of rainfall data must be used. The break point rainfall data in the model may require more computer execution time when a short time increment is used. However, adjustments can be made so that the short time interval is used only for the storm events.
5. To make the model more generally applicable, the channel erosion component should be expanded to the physically based algorithms including scour and deposition processes. In the model, the channel erosion is a simple power function of the daily recorded streamflow and all the parameters are estimated through calibration.
6. The application of the watershed and erosion model to larger watershed should be developed to use the model as a planning tool for watershed management.
7. Application and testing of the watershed and erosion model on watersheds in a variety of regions with different soils and meteorologic characteristics may be recommended to verify its general applicability and to detect the deficiencies of the model.

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APPENDIX A. GLOSSARY OF VARIABLES FOR WATERSHED AND EROSION MODEL

Variable	Definition
AA	Variable defined in the Yalins equation
ABFV	Annual base flow volume
ACRFMI	Accumulated cases in all recorded flood magnitude intervals
AETX	Annual evapotranspiration index
AEX90	Antecedent evaporation index, decay rate = 0.9
AEX96	Antecedent evaporation index, decay rate = 0.96
AFSIL	Annual forest snow interception loss
AID	Actual interrill detachment capacity
AIDS	Actual interrill detachment storage
AIFV	Annual interflow volume
ALP1	A soil factor for PWER
ALP2	A climatic factor for PWER
ALP3	Channel erosion exponent
AMBER	Annual moisture balance error
AMBF	Accumulated monthly base flow
AMFSIL	Accumulated monthly forest snow interception loss
AMIF	Accumulated monthly interflow
AMNET	Accumulated monthly net evapotranspiration
AMPET	Accumulated monthly potential evapotranspiration
AMPREC	Accumulated monthly precipitation
AMPRM	Accumulated monthly rain plus melt
AMRTF	Accumulated monthly recorded total flow
AMSE	Accumulated monthly stream evaporation
AMSNE	Accumulated monthly snow evaporation

Variable	Definition
AMSTF	Accumulated monthly synthesized total flow
ANET	Annual net evapotranspiration
AOFV	Annual overland flow volume
APREC	Annual precipitation
ARD	Actual rill detachment capacity
ARDS	Actual rill detachment storage
AREA	Area of watershed
ARHF	Accumulated routed hydrograph flow
ARPM	Annual rain plus melt
ARSF	Accumulated routed sediment flow
AS	Variable defined in the Yalin's equation
ASE	Annual snow evaporation
ASEV	Annual stream evaporation volume
ASM	Annual snowfall moisture
ASMRG	Annual snowfall moisture reaching ground
ATRF	Actual transport capacity of sediment by overland flow
AWSBIT	Accumulator for watershed bits
BCONO	Factor for canopy effect of soybean crop
BCOV	Factor for residue cover effect of soybeans
BDDFSM	Basic degree day factor for snow melt
BFHRC	Base flow hourly recession constant
BFNHR	Base flow hourly nonlinear recession adjustment factor
BFNLR	Base flow nonlinear recession adjustment factor
BFNRL	Base flow nonlinear recession logarithm

Variable	Definition
BFNX	Current value of base flow nonlinear recession index
BFRC	Base flow recession constant
BFRL	Base flow recession logarithm
BIVF	Basic interflow volume factor
BMIR	Basic maximum infiltration rate within watershed
BTRI	Base time routing increments
BUZC	Basic upper zone storage capacity factor
BYGWS	Beginning of year groundwater storage
BYIFS	Beginning of year interflow storage
BYLZS	Beginning of year lower zone storage
BYUZS	Beginning of year upper zone storage
CANO	Canopy factor affecting dissipation of rainfall impact
CBF	Current base flow
CCOND	Factor for canopy effect of corn crop
CCOV	Factor for residue cover effect of corn crop
CCRFMI	Cases in current recorded flow magnitude interval
CDSDR	Current day for which storm details requested
CHCAP	Channel capacity - indexed to basin outlet
CIVM	Current interflow volume multiplier
CMIR	Current maximum infiltration rate during period
CN	1 = A.M., 2 = P.M.
CONOPT	Control option
COVT	Overall residue cover
COVA	Residue cover for corn

Variable	Definition
COVB	Residue cover for soybeans
COVC	Residue cover for meadow
COVER	Crop management factor due to soil surface cover
CRFAC	Crop management reduction factor for rill erosion
CRFMI	Cases recorded in flow magnitude interval
CSRX	Channel storage routing index
CTRI	Current time routing increments
CZ (S)	Fractional area for various cultivation methods
C1	Correction factor for rainfall intensity averaged
C2	Exponent related to rainfall energy reduction by overland flow depth
C3	Constant representing sediment characteristics and channel roughness for channel erosion computation
DATE	Current day of the month
DAY	Current day of the year
DDIW	Dated diversion into watershed
DEPO	Deposition of sediment
DFCC	Daily flow correlation coefficient
DFI	Daily flow regression intercept
DFRC	Daily flow regression coefficient
DIA (I)	Sediment diameters
DMNT	Dated minimum temperature
DMXT	Dated maximum temperature
DPET	Dated potential evapotranspiration

Variable	Definition
DPSE	Dated potential snow evaporation
DPY	Days per year
DRGPM	Dated recording gage precipitation multiplier
DRHP	Dated recorded hourly precipitation
DRSF	Dated recorded streamflow
DRSGP	Dated recorded storage gage precipitation
DRSL	Dated recorded sediment load
DS	Deposition of sediment for 15 min time interval
DSCC	Daily sediment load correlation coefficient
DSI	Daily sediment load regression intercept
DSMGH	Rate of daily snowmelt from ground heat
DSRC	Daily snowmelt load regression coefficient
DSSE	Dated synthesized sheet erosion
DSSF	Dated synthesized streamflow
DSSL	Dated synthesized sediment load
EDLZS	End of day values of LZS
EHSGD	Ending hour of storage gage day
EHSGDF	Ending hour of storage gage day - floating point
EID	Exponent of infiltration rate decay with increased soil moisture content
ELDIF	Elevation difference between base thermometer and basin mean elevation
EMBFNX	End of month base flow nonlinear recession index
EMGWS	End of month groundwater storage

Variable	Definition
EMIFS	End of month interflow storage
EMLZS	End of month lower zone storage
EMSIAM	End of month seasonal infiltration adjustment multiplier
EMUZC	End of month upper zone storage capacity
EMUZS	End of month upper zone storage
EPAET	Estimated potential annual evapotranspiration
EPCM	Evaporation pan coefficient for month
EQD	Equilibrium depth of overland flow
EQDF	Equilibrium depth factor for overland flow
EQDFIS	Equilibrium depth factor for overland flow, impervious surfaces
EQDIS	Equilibrium depth of overland flow impervious surfaces
ERKI	Erodibility K factor for interrill erosion
ERKR	Erodibility K factor for rill erosion
EROA	Sediment load in rills for 15 min time interval
ERR	Difference between recorded and synthesized dated streamflow
ETIBF	Error table interval boundary floods
ETLF	Evapotranspiration loss factor
EXQPV	Exponent of flow proportional to velocity
FCCM	Monthly flow correlation coefficient
FDSC	First difference of sine curve magnitude
FFOR	Fraction of the watershed being forest
FFSI	Fraction of snow on forest intercepted

Variable	Definition
FIM	Monthly flow regression intercept
FIMP	Fraction of the watershed being impervious
FIRR	Fraction of incoming radiation reflected by snow surface as a function of age
FKRFMI	Floating point value of KRFMI
FL	Grain movement of y direction of flow
FLC	Critical lift force from Shield's diagram
FMR	Fraction of moisture retention
FMXTRI	Floating point maximum number of time routing increments
FNBTRI	Floating point number of basic time routing increments
FNPTRI	Floating point number of previous time routing increments
FNSTRI	Floating point number of subsequent time routing increments
FNTRI	Floating point number of time routing increments
FPER	Fraction of the watershed being pervious
FRCM	Monthly flow regression coefficient
FSIL	Hourly forest snow interception loss
FSRX	Flood plain storage routing index
FTA	Factor for estimating diurnal temperature variation based on sine curve
FWTR	Fraction of the watershed being water
GF (I)	Specific gravity of soil particles
GFIE	Index of the effect of ground freezing on the infiltration capacity of the soil
GWET	Current hourly groundwater evapotranspiration

Variable	Definition
GWETF	Groundwater evapotranspiration factor
GWS	Current groundwater storage
HOUR	Current hour of the day
HRF	First hour of loop
HRL	Last hour of loop
HSE	Current hourly stream evaporation
HSF	Hourly snowfall
HSFRG	Hourly snowfall reaching ground
HSM	Hourly snowmelt rate
IDAY1	Index to 10-day period
IDAY2	Index within 10-day period
IDC	Potential interrill detachment capacity
IFPRC	Interflow period recession constant
IFRC	Interflow recession constant
IFRL	Interflow recession logarithm
IFS	Interflow storage
IMPU	Sediment picked up from impervious areas
ISGRD	Current storage gage rainfall day
KAA	Counter of appropriate element from albedo array
KAAO	Preceding value of KAA
KB1-7	Counters for combining watershed bits
KDAY1	First day to change the value of ALP2 due to thawing
KDAY2	Last day to change the value of ALP2 due to freezing
KHOUR	Counter for hour of day

Variable	Definition
KIA	Counter for initializing arrays
KP	Empirical constant for erosion from impervious areas
KMO	Counter indexing month of the year
KPRD	Counter for period
KRD	Counter for reading data arrays
KRFMI	Counter for recorded flow magnitude interval
KRIA	Counter of appropriate element from radiation incidence array
KTA	Counter for title array
KTRI	Counter for time routing increments
KT20	Counter for top 20 values
KWD	Counter for writing data arrays
LDAY	Last day of year
LHOUR	Last hour of day
LSHFT	Logical variable set true while shifting the number of time routing increments
LZC	Lower zone storage capacity
LZRX	Lower zone moisture retention index
LZS	Current lower zone storage
LZSR	Current lower zone storage ratio (LZS/LZC)
MDAY	Day of year of last day of previous month
MEDCY	Month end dates - calendar year
MEDWY	Month end dates - water year
MHSM	Minimum hourly snowmelt rate

Variable	Definition
MNRD	Mean annual number of rainy days
MONTH	Current month of the year
MRNSM	Maximum rate of negative snowmelt (snow chilling)
MXTRI	Maximum number of time routing increments
NBTRI	Number of base time routing increments
NCSTRI	Number of current time routing increments during shifting
NCTRI	Number of current time routing increments
NDAY	Next day of year
NDFM	First day in which pan evaporation measurements are restarted
NDFM1	Subtract one day from NDFM
NDIM	Last day in which pan evaporation measurements are taken
NDIM2	Add one day to NDIM
NDSDP	Number of days for which storm details have already been printed
NDSDR	Number of days for which storm details requested
NDTUZ	Approximate date of the year in which the thawing of the upper soil surface begins
NHOUR	Next hour of day
NHPT	Number of hours between hydrograph printing points
NNSTRI	Number of next time routing increments during shifting
NRTRI	Number of time routing increments remaining to be routed
NSGRD	Number of storage gage rainfall days
NYSD	Number of years for simulation data

Variable	Definition
NYSQ	Number of years for simulation requested
OFMN	Overland flow Manning's n
OFMNIS	Overland flow Manning's n, impervious surfaces
OFR	Current overland flow runoff
OFRF	Overland flow routing factor
OFRFIS	Overland flow routing factor, impervious surfaces
OFRIS	Current overland flow runoff, impervious surfaces
OFS	Overland flow storage
OFSL	Overland flow surface length
OFSS	Overland flow surface slope
OFUS	Current overland flow unrouted storage
OFUSIS	Current overland flow unrouted storage, impervious surfaces
OVCO	Overall coefficient for areal unit conversion
PC	Percent of clay in the soil
PDAY	Previous day of the year
PE	Effective P for particle type in a mixture in Yalin's equation
PEAI	Precipitation excess after infiltration
PEBI	Precipitation excess, before infiltration
PEIS	Precipitation excess on impervious surfaces
PEP	Precipitation estimated for period
PET	Current daily potential evapotranspiration
PETU	Unadjusted current daily potential evapotranspiration
PE4P	Precipitation estimates for 4 periods

Variable	Definition
PGW	Percolation to ground water
PLZS	Percolation to lower zone storage
PMEIFS	Period moisture entering interflow storage
PMELZS	Period moisture entering lower zone storage
PMEOFS	Period moisture entering overland flow storage
PMEUZS	Period moisture entering upper zone storage
PPEP	Precipitation estimated for interrill detachment computation
PPI	Precipitation passing interception
PPRH	Precipitation recorded for hour for interrill detachment computation
PRD	Current period of the hour
PRDF	Current period of the hour - floating point
PRH	Precipitation recorded for hour
PWER	Exponent index representing the aggregation of soil particle to soil mass
PRLH	Precipitation recorded for last hour
PRNH	Precipitation recorded for next hour
PXCSA	Precipitation index for changing snow albedo
RATFV	Recorded annual total flow volume
RATSV	Recorded annual total sediment volume
RDC	Potential rill detachment capacity
RDPT	Recorded daily precipitation total
REDX	Reduction of interrill detachment due to overland flow depth

Variable	Definition
REFAC	Reduction of interrill detachment due to crop management
RES	Reynolds number
RESD	Crop residue cover factor
RGPM	Recording gage precipitation multiplier
RGPMB	Recording gage precipitation multiplier - basic
RHFMC	Routed hydrograph flow at minimum cutoff
RHFO	Preceding routed hydrograph flow
RHF1	Current routed hydrograph flow (excluding base flow)
RHPD	Recorded hydrograph peak day
RHPH	Recorded hydrograph peak hour
RICD	Radiation incidence for the current day
RICY	Radiation incidence over the calendar year
RMPF	Requested minimum daily peak flow to be printed
RSBD	Recession sequence beginning day
RSDFO	Preceding routed sediment flow
RSDF1	Current routed sediment flow
RSPTF	Routed synthesized period total flow
RULF	Crop management factor - residual land use factor
RWPD	Hourly precipitation in input data
S	Dimensionless excess of the lift force in Yalin's equation
SARAX	Snow albedo rainfall aging index
SASFX	Snow albedo snowfall freshening index
SATFV	Synthesized annual total flow volume
SATFVI	Synthesized annual total flow volume in inches

Variable	Definition
SATRI	Shift adjustments for time routing increments
SATSV	Recorded annual total sediment volume
SAX	Snow albedo index
SCOUR	Daily sediment load due to channel bed and bank scouring
SDEPTH	Average depth of snow on ground
SDSC	Second differential of sine curve magnitude
SE	Current daily snow evaporation
SERA	Accumulated absolute differences between recorded and synthesized daily streamflows for interval
SERAV	Average interval absolute difference between recorded and synthesized daily streamflows
SERR	Accumulated differences between recorded and synthesized daily streamflows for interval
SERRV	Average interval differnce between recorded and synthesized daily streamflows
SESF	Standard error of synthesized flows by magnitude interval
SET	Current hourly soil evapotranspiration
SFMD	Snow frozen moisture density
SGMD	Storage gage moving day (when it is moved during water year)
SGRT	Storage gage reading time
SGRT2	Second storage gage reading time
SHEAR	Shear stress exerted on soil surface by overland flow
SIAC	Seasonal infiltration adjustment constant

Variable	Definition
SIAM	Seasonal infiltration adjustment multiplier
SLFAC	Slope factor for interrill detachment by rainfall impact energy
SLOPE	Linear regression slope between recorded and simulated one
SOFRF	Snow overland flow routing factor
SOFRFI	Snow overland flow routing factor impervious surfaces
SPBF	Synthesized period base flow
SPBFLW	Snow pack basic maximum fraction in liquid water
SPDR	Synthesized period direct runoff
SPIF	Synthesized period interflow
SPIX	Effective rainfall intensity squared
SPLW	Snow pack liquid water content
SPLWC	Snowpack liquid water holding capacity
SPM	Snow precipitation multiplier
SPOF	Synthesized period overland flow (including channel precipitation)
SPTF	Synthesized period total flow
SPTW	Snow pack total water content
SPTWCC	Snowpack minimum total water for complete basin coverage
SQER	Accumulated squares of differences between recorded and synthesized daily streamflows
SRX	Current storage routing index

Variable	Definition
SSERA	Accumulated absolute differences between recorded and synthesized flows over intervals
SSERAV	Overall average absolute difference between recorded and synthesized flows
SSERR	Accumulated differences between recorded and synthesized flows over intervals
SSERRV	Overall average difference between recorded and synthesized flows
SSESF	Accumulated standard error of synthesized flow over intervals
SSRT	Square root of overland flow surface slope
STMD	Snow total moisture density
STOR	Storage deposition in rills
SUBWF	Subsurface water flow out of the basin
SUMX	Summation of x
SUMXY	Summation of xy
SUMX2	Sum of x squared
SUMY	Summation of y
SUMY2	Sum of y squared
SUZC	Seasonal upper zone storage capacity factor
SVEL	Shear velocity of overland flow
TANSM	Total accumulated negative snowmelt (snow chilling)
TAUC	Critical tractive force for erosion resistance factor
TDA	Total detachment capacity for transport

Variable	Definition
TDFP12	Time of daily flood peak, 12-hour clock
TDFP24	Time of daily flood peak, 24-hour clock
TDSF	Total daily streamflow
TDSSL	Total daily suspended sediment load
TEH	Temperature estimated for hour
TEHCO	Temperature estimate for hour considering elevation
TFCFS	Current total flow
TFMAX	Maximum total flow during current day
TFMRT	Total streamflow at maximum stream routing time
TFX	Total streamflow index
THGR	Total hourly gross runoff
THSF	Total hourly streamflow
TILL	Tillage effect for rill detachment capacity
TITLE	Title of current station year (streamgage location and date)
TMBF	Totals of monthly base flow
TMFSIL	Totals of monthly forest snow interception loss
TMIF	Totals of monthly interflow
TMNET	Totals of monthly net evapotranspiration
TMOF	Totals of monthly overland flow
TMPET	Totals of monthly potential evapotranspiration
TMPREC	Totals of monthly precipitation
TMRPM	Totals of monthly rain plus melt
TMRTF	Totals of monthly recorded total flow

Varibale	Definition
TMSE	Totals of monthly stream evaporation
TMSNE	Totals of monthly snow evaporation
TMSTF	Totals of monthly synthesized total flow
TMSTFI	Totals of monthly synthesized total flow in inches
TNTDS	Current loose soil particle storage in rills
TOFR	Current total overland flow runoff
TPLR	Total to pervious land ratio
TQ	Total amount of sediment being moved in rills
TR (I)	Transport capacity of overland flow for particle size I
TRF	Transport capacity of overland flow in Ton/ha/hr
TRHF	Current time routed hydrograph flow
TRSF	Current time routed sediment flow
TSSF	Total suspended sediment flow for an hour
TS (I)	Transport capacity of overland flow for particle size I in gm/m/sec
T20OFH	Top 20 values during the year of hourly overland flow
T20PRH	Top 20 values during the year of hourly precipitation
UHFA	Unrouted hydrograph flow array
URHF	Current unrouted hydrograph flow
URSF	Current unrouted sediment flow
USFA	Total sheet erosion rate for the specific period
UZC	Upper zone storage capacity
UZINFX	Upper zone infiltration index
UZINLZ	Current upper infiltration to lower zone

Variable	Definition
UZRX	Upper zone moisture retention index
UZS	Current upper zone storage
VDCY	Value dated by calendar day
VDMD	Value dated by month day
VINTOR	Vegetative interception - current rate per period
VINTMR	Vegetative interception - maximum rate
VWIN	Volume of an inch of runoff from watershed
WCFS	Watershed cfs equalling one inch per hour
WEIFS	Water entering interflow storage
WI	Water infiltration
WSBIT	Watershed bit for restructuring time-area histogram
WSG	Weighting factor for storage rain gage
WSG2	Second weighting factor for storage rain gage
WT4AM	Average 4 A.M. temperature over watershed
WT4PM	Average 4 P.M. temperature over watershed
XDNFS	Index density of new-fallen snow
XELR	Rain index for estimating lapse rate 0.0 = dry, 4.0 = rain
YEAR	Last two digits of current year
YR1	Last two digits of first calendar year in water year
YR2	Last two digits of second calendar year in water year
YTITLE	Year title
ZONE (S)	Fraction of area on which a specific crop is being cultivated

APPENDIX B. LISTING OF WATERSHED AND EROSION MODEL

LISTING OF WATERSHED AND EROSION MODELS

```
C    EROSION MODEL MODIFIED BY SOON KUK KWUN, 1979
C   SUPERIMPOSED ON THE KENTUCKY WATERSHED MODEL OF JUNE 6, 1970
C   WHICH IS BASED ON THE STANFORD WATERSHED MODELS III & IV
C
      DIMENSION BTRI(99), CONOPT(20), CRFMI(22), CTRI(99), DDIW(366),
     1  DMNT(366), DMXT(366), DPSE(366), DRGPM(366), DRHP(366,24),
     2  DRSGP(366), DPET(366), DRSF(366), DSSF(366), EDLZS(366),
     3  EMBFNX(12), EMGWS(12), EMIFS(12), EMLZS(12), EMSIAM(12),
     4  EMUZC(12), EMUZS(12), EPCM(12), FIRR(15), MEDCY(12), MEDWY(12)
      DIMENSION  SATRI(99), SERA(22), SERR(22), SESF(22), SQER(22),
     6  THSF(24), TITLE(20), TMBF(12), TMFSIL(12), TMIF(12), TMNET(12),
     7  TMOF(12), TMPET(12), TMPREC(12), TMRPM(12), TMRTF(12), TMSE(12),
     8  TMSNE(12), TMSTF(12),  TMSTFI(12),  T20OFH(21), T20PRH(21),
     9  UHFA(99), YTITLE(20),RICY(366),RWPD(12)
      DIMENSION DRSL(366),DSSL(366),USFA(99),TSSF(24),SCOUR(366),
     1 DSSE(366),GF(10),DIA(10),P(10),PE(10)
      LOGICAL  LSHFT
      INTEGER  CDSDR,CN,CONOPT,DATE,DAY,DPY,EHSGD,HOUR,HRF,HRL,PDAY,
     1  PRD,RHPD,RHPH,RSBD,SGMD,SGRT,SGRT2,YEAR,YR1,YR2,IRUN
      REAL  IFPRC,IFRC,IFRL,IFS,LZC,LZRX,LZS,LZSR,MHSM,MNRD,MRNSM,NHPT,
     1  K,KP
      DATA  MEDCY/  0,  31,59,90,120,151,181,212,243,273,304,334/
      DATA MEDWY/304,334,365,31,59,90,120,151,181,212,243,273/
      NYSD = 0
  100 CONTINUE
      READ(5,70)(CONOPT(I),I=1,20)
   70 FORMAT(20I3)
      DO 102 KIA = 1,99
      SATRI(KIA) = 0.0
      CTRI(KIA) = 0.0
      BTRI(KIA) = 0.0
```

```
      USFA(KIA) = 0.0
  102 UHFA(KIA) = 0.0
      READ(5,95) NYSQ
   95 FORMAT(I2)
      READ(5,71) NCTRI
   71 FORMAT(I3)
      READ(5,72)(CTRI(KRD),KRD=1,NCTRI)
   72 FORMAT(11F7.4)
      IF(CONOPT(7) .NE. 1) GO TO 110
      READ(5,73)(FIRR(I),I=1,15)
   73 FORMAT(15F5.2)
      DO 106 KRD = 274,360,10
  106 READ(5,75)DPSE(KRD)
   75 FORMAT(F6.3)
      DO 107 KRD = 1,273,10
  107 READ(5,75)DPSE(KRD)
      DO 109 IDAY2 = 1, 9
      DO 108 IDAY1 = 274,360,10
      DAY = IDAY1 + IDAY2
  108 DPSE(DAY) = DPSE(IDAY1)
      DO 109 IDAY1 = 1,273,10
      DAY = IDAY1 + IDAY2
      IF(DAY .GT. 273) GO TO 109
      DPSE(DAY) = DPSE(IDAY1)
  109 CONTINUE
      DPSE(366) = DPSE(59)
      DPSE(365) = DPSE(363)
      DPSE(364) = DPSE(363)
      READ(5,77) BDDFSM,SPBFLW,SPTWCC,SPM,ELDIF,XDNFS,FFOR,FFSI,MRNSM,
     1  DSMGH,PXCSA
   77 FORMAT(11F7.4)
  110 READ(5,78) RMPF,RGPMB,AREA,FIMP,FWTR
   78 FORMAT(2F6.2,F7.2,2F7.4)
      READ(5,79) VINTMR,BUZC,SUZC,LZC,ETLF,SUBWF,GWETF,SIAC,BMTR,BIVF
   79 FORMAT(10F7.3)
```

```
      READ(5,80) OFSL,CHCAP,OFSS,OFMN,OFMNIS,IFRC,CSRX,FSRX,EXQPV,BFNLR,
     1  BFRC
   80 FORMAT(2F7.1,9F7.4)
      BFHRC = BFRC**(1.0/24.0)
      BFRL = -ALOG(BFHRC)
      BFNRL = 0.0
      IF(BFNLR .LT. 0.00001 .OR. BFNLR .GT. 0.9999) GO TO 111
      BFNHR = BFNLR**(1.0/24.0)
      BFNRL = -ALOG(BFNHR)
  111 IFPRC = IFRC**(1.0/96.0)
      IFRL = -ALOG(IFPRC)
      READ(5,81) GWS,UZS,LZS,BFNX,IFS,GFIE,NDTUZ
   81 FORMAT(6F7.4,I3)
      IF(CONOPT(15).NE.1) GO TO 444
      READ(5,303) ERKI,PC,RULF,TILL,ERKR
  303 FORMAT(5F9.3)
      READ(5,304) C1,C2,C3,KP,ALP1,ALP2,ALP3
  304 FORMAT(7F8.3)
      READ(5,305) ZONE1,ZONE2,ZONE3,CZ1,CZ2,CZ3,CZ4,KDAY1,KDAY2
  305 FORMAT(7F8.3,2I4)
      READ(5,307) (DIA(I),I=1,5)
      READ(5,307) (GF(I),I=1,5)
  307 FORMAT(5F8.5)
  444 CONTINUE
      LSHFT = .FALSE.
      IF(CONOPT(13) .NE. 1) GO TO 113
      NBTRI = NCTRI
      FNTRI = NCTRI
      MXTRI = (10.0**EXQPV)*FNTRI + 0.5
      IF(MXTRI .GE. 98) WRITE(6,1)
    1 FORMAT(29HWARNING: EXQPV ARRAY OVER RUN)
      NCSTRI = 99
      DO 112 KIA = 1, NBTRI
  112 BTRI(KIA) = CTRI(KIA)
      TFCFS = 1.0
```

```
      CALL RTVARY (CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCSTRI,EXQPV,LSHFT,
     1  TFCFS)
  113 EPAET = 0.0
      FPER = 1.0 - FIMP - FWTR
      IF(FPER .GT. 0.01) GO TO 114
      TPLR = 100.0
      FPER = 0.01
      GO TO 115
  114 TPLR = (1.0 - FWTR)/FPER
  115 VINTCR = 0.25*VINTMR
      HSE = 0.0
      NRTRI = 0
      PEAI = 0.0
      SPIF = 0.0
      CBF = GWS*BFRL*(1.0 + BFNRL*BFNX)
      SPDR = 0.0
      OFUS = 0.0
      OFUSIS = 0.0
      OFR = 0.0
      OFRIS = 0.0
      PEIS = 0.0
      RHFO = 0.0
      RSDFO=0.0
      URHF = 0.0
      URSF = 0.0
      TNTDS=0.0
      AMIF = 0.0
      AMNET = 0.0
      AMPET = 0.0
      AMSNE = 0.0
      AMFSIL = 0.0
      SASFX = 0.0
      SARAX = 0.0
      SRX = CSRX
      VWIN = 26.8888*AREA
```

```
      WCFS = 24.0*VWIN
      RHFMC = 0.025/WCFS
      TFCFS = CBF*WCFS
      SSRT = SQRT(OFSS)
      OFRF = 1020.0*SSRT/(OFMN*OFSL)
      OFRFIS = 1020.0*SSRT/(OFMNIS*OFSL)
      EQOF = 0.00982*((OFMN*OFSL/SSRT)**0.6)
      EQOFIS = 0.00982*((OFMNIS*OFSL/SSRT)**0.6)
      SOFRF = OFRF
      SOFRFI = OFRFIS
      SDEPTH = 0.0
      ASM = 0.0
      IF(CONOPT(7) .EQ. 0) GO TO 116
      WT4AM = 60.0
      WT4PM = 60.0
      SAX = 15.0
      TANSM = 0.0
      SPTW = 0.0
      STMD = 0.7
      SFMD = 0.7
      ASMRG = 0.0
      OVCO=259.0*AREA
  116 READ(5,2) TITLE
    2 FORMAT(20A4)
C  BEGIN NEW YEAR
  117 BYLZS = LZS
      BYUZS = UZS
      NYSD = NYSD + 1
      BYGWS = GWS
      BYIFS = IFS
      DO 118 KIA = 1,22
      CRFMI(KIA) = 0.0
      SESF(KIA) = 0.0
      SERR(KIA) = 0.0
      SERA(KIA) = 0.0
```

```
  118 SQER(KIA) = 0.0
      RGPM = RGPMB
      DO 119 KIA = 1,21
      T20OFH(KIA) = 0.0
  119 T20PRH(KIA) = 0.0
      DO 120 KIA = 1,12
  120 EPCM(KIA) = 1.0
      RDPT = 0.0
      PDAY = 274
      READ(5,82) YR1,YR2
   82 FORMAT(2I3)
      READ (5,2)YTITLE
      DPY = 365
      IF(MOD(YR2,4) .EQ. 0) DPY = 366
      IF(CONOPT(1).EQ.1) READ(5,67) CDSDR,NDSDR
   67 FORMAT(2I4)
      NDSDP = 0
      MEDWY(5) = 59
      IF(DPY .EQ. 366) MEDWY(5) = 366
C  READ EVAPORATION DATA
      IF(CONOPT( 3) .NE. 1) GO TO 125
      DO 121 KRD = 274,360,10
  121 READ(5,83) DPET(KRD)
   83 FORMAT(F5.3)
      DO 122 KRD = 1,273,10
  122 READ(5,83) DPET(KRD)
      DO 124 IDAY2 = 1,9
      DO 123 IDAY1 = 274,360,10
      DAY = IDAY1 + IDAY2
  123 DPET(DAY) = DPET(IDAY1)
      DO 124 IDAY1 = 1,273,10
      DAY = IDAY1 + IDAY2
      IF(DAY .GT. 273) GO TO 124
      DPET(DAY) = DPET(IDAY1)
  124 CONTINUE
```

```
      DPET(366) = DPET(59)
      DPET(365) = DPET(363)
      DPET(364) = DPET(363)
      GO TO 127
  125 READ(5,84) NDIM,NDFM
   84 FORMAT(2I4)
      NDIM2 = NDIM + 1
      NDFM1 = NDFM - 1
      DO 60 ICP = NDIM2,DPY
   60 DPET(ICP) = 0.03
      DO 61 IP = 1,60
   61 DPET(IP) = 0.03
      DO 62 IK = 61,NDFM1
   62 DPET(IK) = 0.15
      READ(5,85)(DPET(DAY),DAY =NDFM,NDIM)
   85 FORMAT(15F5.2)
  127 IF(EPAET .NE. 0.0) GO TO 381
      DO 129 DAY = 1,DPY
  129 EPAET = EPAET + 0.60*DPET(DAY)
  131 AETX = 24.0*EPAET/365.0
      AEX96 = 1.2*AETX
      AEX90 = 0.3*AETX
      SIAM = 1.2**SIAC
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)
      IF(UZC .LT. 0.25) UZC = 0.25
  381 SGRT = 0
      DO 132 DAY = 1,366
      DDIW(DAY) = 0.0
      DRSF(DAY) = 0.0
      DRSL(DAY) = 0.0
      DRGPM(DAY) = RGPMB
      DRSGP(DAY) = 0.0
      DO 132 HOUR = 1,24
  132 DRHP(DAY,HOUR) = 0.0
  133 IF(CONOPT(9) .NE. 1) GO TO 138
```

```
      DRSF(366) = 0.0
      READ(5,86)(DRSF(DAY),DAY = 1,DPY)
   86 FORMAT(12F6.1)
  138 IF(CONOPT(16).NE.1) GO TO 135
      DRSL(366) = 0.0
      READ(5,300)(DRSL(DAY), DAY = 1,DPY)
  300 FORMAT(8F10.2)
  135 IF(CONOPT(11) .NE. 1) GO TO 137
      DDIW(366) = 0.0
  136 READ(5,86)(DDIW(DAY),DAY = 1,DPY)
  137 IF(CONOPT(7) .EQ. 0) GO TO 139
      DO 65 I = 121,304
   65 RICY(I) = 48.0
      READ(5,66)(RICY(DAY),DAY = 1,120)
      READ(5,66)(RICY(DAY),DAY = 305,366)
   66 FORMAT(13F6.1)
      DO 68 IN = 121,304
      DMXT(IN) = 80.0
   68 DMNT(IN) = 60.0
      READ(5,69)(DMXT(DAY),DAY = 1,120)
      READ(5,69)(DMXT(DAY),DAY = 305,366)
      READ(5,69)(DMNT(DAY),DAY = 1,120)
      READ(5,69)(DMNT(DAY),DAY = 305,366)
   69 FORMAT(15F5.1)
  139 READ(5,87) NSGRD
   87 FORMAT(I3)
      IF(NSGRD .EQ. 0) GO TO 141
      READ(5,88) WSG,SGRT
   88 FORMAT(F7.4,I3)
      IF(CONOPT(8).EQ.1) READ(5,89) WSG2,SGRT2,SGMD
   89 FORMAT(F7.4,2I3)
      DO 140 KRD = 1,NSGRD
  140 READ(5,90) ISGRD,DRSGP(ISGRD)
   90 FORMAT(I3,F7.4)
C   READ RECORDING RAIN GAGE HOURLY TOTALS
```

```
  141 READ(5,91) YEAR,MONTH,DATE,CN,(RWPD(I),I = 1,12)
   91 FORMAT(3I4,I3,12F5.2)
C  PUNCH NO NUMBER AFTER CN ON YEAR .EQ. 98 CARD
      IF(YEAR .GE. 98) GO TO 144
      HRF = 12*(CN - 1) + 1
      HRL = 12*(CN - 1) + 12
      LSD = HRF - 1
      DAY = MEDCY(MONTH) + DATE
      DO 142 HOUR = HRF, HRL
  142 DRHP(DAY,HOUR) = RWPD(HOUR - LSD)
      IF(DPY .NE. 366 .OR. MONTH .NE. 2 .OR. DATE .NE. 29) GO TO 141
      DO 143 HOUR = HRF, HRL
      DRHP(366,HOUR) = DRHP(60,HOUR)
  143 DRHP(60,HOUR) = 0.0
      GO TO 141
C  CALCULATE PRECIPITATION WEIGHTING FACTORS
  144 DAY = 274
      IF(NSGRD .EQ. 0) GO TO 151
      PDAY = 274
      RDPT = 0.0
  145 EHSGD = SGRT
      IF(SGRT .EQ. 0) EHSGD = 24
      EHSGDF = EHSGD
  146 CONTINUE
      DO 150 HOUR = 1,24
      RDPT = RDPT + DRHP(DAY,HOUR)
      IF(HOUR .NE. EHSGD) GO TO 150
      IF(RDPT .LE. 0.0) GO TO 147
      IF(SGRT .EQ. 0) PDAY = DAY
      DRGPM (PDAY) = (DRSGP(DAY)*WSG + RDPT*(1.0 - WSG))/RDPT
      IF(CONOPT(3) .NE. 0) DPET(PDAY) = 0.5*DPET(PDAY)
      IF(SGRT .NE. 0) PDAY = DAY
      RDPT = 0.0
      GO TO 150
  147 IF(DRSGP(DAY) .LE. 0.0) GO TO 149
```

```
      DO 148 KHOUR = 1,EHSGD
  148 DRHP(DAY,KHOUR) = (WSG*DRSGP(DAY))/EHSGDF
  149 IF(SGRT .NE. 0) PDAY = DAY
  150 CONTINUE
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 151
      IF(CONOPT(8) .EQ. 0) GO TO 146
      IF(DAY .NE. SGMD) GO TO 146
      WSG = WSG2
      SGRT = SGRT2
      GO TO 145
  151 MONTH = 1
      MDAY = 273
      AMRPM = 0.0
      AMPREC = 0.0
      AMBF = 0.0
      AMSE = 0.0
      AMSTF = 0.0
      AMRTF = 0.0
      WRITE(6,3) (TITLE(KTA), KTA = 1,20)
    3 FORMAT(1H1,10X,20A4)
      WRITE(6,4) (YTITLE(KTA), KTA = 1,20),YR1,YR2
    4 FORMAT(1H0,20A4,2X,13HWATER YEAR 19,I2,1H-,I2)
      WRITE(6,5)
    5 FORMAT(8H OCTOBER)
C   BEGIN DAY LOOP
  152 TDSF = 0.0
      IF(DAY.LT.90.OR.DAY.GT.288) PET=0.35*DPET(DAY)
      IF(DAY.GE.90.AND.DAY.LT.105) PET=0.37*DPET(DAY)
      IF(DAY.GE.105.AND.DAY.LT.151) PET=0.41*DPET(DAY)
      IF(DAY.GE.151.AND.DAY.LT.181) PET=0.43*DPET(DAY)
      IF(DAY.GE.181.AND.DAY.LT.196) PET=0.68*DPET(DAY)
      IF(DAY.GE.196.AND.DAY.LT.212) PET=0.74*DPET(DAY)
      IF(DAY.GE.212.AND.DAY.LT.243) PET=0.80*DPET(DAY)
      IF(DAY.GE.243.AND.DAY.LT.258) PET=0.72*DPET(DAY)
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```
      IF(DAY.GE.258.AND.DAY.LT.273) PET=0.56*DPET(DAY)
      IF(DAY.GE.273.AND.DAY.LE.288) PET=0.41*DPET(DAY)
      PETU = PET
      TFMAX = 0.0
      BMIR = BMTR
      IF(DAY .LT. NDTUZ) BMIR = BMTR/GFIE
      IF(CONOPT(15) .NE. 1) GO TO 322
C     ENTER CROP SUBROUTINE
      CALL CROP(ZONE1,ZONE2,ZONE3,CZ1,CZ2,CZ3,CZ4,DAY,RESD,CANO,COVT)
      PWER = ALP1
      IF(DAY .LT. KDAY1 .OR. DAY .GT. KDAY2) PWER = ALP1/ALP2
  322 TDSSL = 0.0
C  EVAPOTRANSPIRATION ADJUSTMENTS
      IF(CONOPT(7) .NE. 1) GO TO 153
      IF(DMXT(DAY) - 4.0*ELDIF .LT. 40.0) PET = 0.0
      IF(SPTW .GT. SPTWCC) PET = FFOR*PET
C  CALCULATION OF SNOW EVAPORATION
      IF(DMNT(DAY) .GT. 32.0 .OR. SPTW .LE. DPSE(DAY)) GO TO 153
      SE = DPSE(DAY)
      AMSNE = AMSNE + SE
      SPTW = SPTW - SE
      IF(SFMD .GT. 0.0) SDEPTH = SDEPTH - SE/SFMD
C*    BEGIN HOUR LOOP  *    ***    ***    ***    ***    ***    ***    ***    ***
  153 DO 202 HOUR = 1,24
      IF((NSGRD .EQ. 0) .AND. (DRHP(DAY,HOUR) .NE. 0.0)  .AND. (PET .EQ.
     1  PETU) .AND. (CONOPT(3) .EQ. 1)) PET = 0.5*PET
  154 IF(HOUR .EQ. SGRT + 1) RGPM = DRGPM(DAY)
      IF(HOUR .EQ. 9) HSE = (FWTR*PET)/12.0
      IF(HOUR .EQ.21) HSE = 0.0
      PRH = RGPM*DRHP(DAY,HOUR)
      PPRH=PRH
      AMPREC = AMPREC + PRH
C  ENTER SNOWMELT SUBROUTINE
      IF(CONOPT(7) .EQ. 1) CALL SNOMEL(BDDFSM,SPTWCC,SPM,ELDIF,DAY,
     1  SPBFLW, XDNFS,FFOR,FFSI,MRNSM,DSMGH,SDEPTH,STMD, PXCSA,HOUR,
```

```
     2  SAX,SOFRF,OFRFIS,SOFRFI,AMFSIL,PRH,SPTW,TANSM,SPLW,SFMD,OFRF,
     3  WT4AM,WT4PM,ASM,ASMRG,SASFX,SARAX,DMXT,DMNT,RICY,FIRR,TEH)
      TEHCO = TEH - 4.0*ELDIF
  155 AMRPM = AMRPM + PRH
  156 TOFR = 0.0
      ARHF = 0.0
      ARSF = 0.0
      DS=0.0
      IF(CONOPT(15) .EQ. 1) TNTDS=TNTDS*EXP(-PWER)
      IF(TNTDS.LE.0.0001) TNTDS=0.0
C  15 MINUTE ACCOUNTING AND ROUTING LOOP
      DO 187 PRD = 1,4
      PEBI = 0.0
      PPI = 0.0
      OFR = 0.0
      OFRIS = 0.0
      WI = 0.0
      WEIFS = 0.0
      PMEUZS = 0.0
      PMELZS = 0.0
      PMEIFS = 0.0
      PMEOFS = 0.0
      PEP = 0.25*PRH
      PPEP=0.25*PPRH
      IF(CONOPT(2) .EQ. 1) CALL PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,
     1  PRH)
  325 IF(PEP .GT. 0.0) GO TO 157
      IF(OFUS .GT. 0.0) GO TO 159
      IF(IFS .GT. 0.0) GO TO 170
      IF(NRTRI .GT. 0) GO TO 172
      TRHF = 0.0
      TRSF = 0.0
      IF(RHFO .GT. 0.0) GO TO 181
      GO TO 184
C  RAINFALL UPPER ZONE INTERACTION
```

```
  157 IF(PEP .GE. VINTCR) GO TO 158
      UZS = UZS + PEP*TPLR
      VINTCR = VINTCR - PEP
      PPI = 0.0
      PEBI = 0.0
      PMEUZS = PEP
      IF(OFUS .GT. 0.0) GO TO 159
      GO TO 170
  158 PPI = PEP - VINTCR
      UZS = UZS + VINTCR*TPLR
      VINTCR = 0.0
      LZSR = LZS/LZC
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZSR)
      IF(UZC .LT. 0.25) UZC = 0.25
      UZRX = 2.0*ABS(UZS/UZC - 1.0) + 1.0
      FMR = (1.0/(1.0 + UZRX))**UZRX
      IF(UZS .GT. UZC) FMR = 1.0 - FMR
      PEBI = PPI*FMR
      PMEUZS = PEP - PEBI
      UZS = UZS + PPI - PEBI
C  LOWER ZONE AND GROUNDWATER INFILTRATION
  159 LZSR = LZS/LZC
      EID = 4.0*LZSR
      IF(LZSR .LE. 1.0) GO TO 160
      EID = 4.0 + 2.0*(LZSR - 1.0)
      IF(LZSR .LE. 2.0) GO TO 160
      EID = 6.0
  160 PEBI = PEBI + OFUS
      CMIR = 0.25*SIAM*BMIR/(2.0**EID)
      CIVM = BIVF*2.0**LZSR
      IF(CIVM .LT. 1.0) CIVM = 1.0
      PEAI = PEBI*PEBI/(2.0*CMIR*CIVM)
      WI = PEBI*PEBI/(2.0*CMIR)
      IF(PEBI .GE. CMIR) WI = PEBI - 0.5*CMIR
      IF(PEBI .GE. CMIR*CIVM) PEAI = PEBI - 0.5*CMIR*CIVM
```

```
      WEIFS = WI - PEAI
      IF(PEBI .LE. OFUS) GO TO 161
      PMELZS = (PEBI - WI)*((PEBI - OFUS)/PEBI)
      PMEIFS = WEIFS*((PEBI - OFUS)/PEBI)
      PMEOFS = PEAI*((PEBI - OFUS)/PEBI)
  161 CONTINUE
      IF((PEAI - OFUS) .GT. 0.0) GO TO 162
      EQD = (OFUS + PEAI)/2.0
      GO TO 163
  162 EQD = EQDF*((PEAI - OFUS)**0.6)
  163 IF((OFUS + PEAI) .GT. (2.0*EQD)) EQD = 0.5*(OFUS + PEAI)
      IF((OFUS + PEAI) .LE. 0.001) GO TO 164
      OFR = 0.25*OFRF*(((OFUS + PEAI)*0.5)**1.67)*((1.0 + 0.6*((OFUS +
     1  PEAI)/(2.0*EQD))**3.0)**1.67)
      IF(OFR .GT. (0.75*PEAI)) OFR = 0.75*PEAI
  164 IF(FIMP .EQ. 0.0) GO TO 168
  165 PEIS = PPI + OFUSIS
      IF((PEIS - OFUSIS) .GT. 0.0) GO TO 166
      EQDIS = (OFUSIS + PEIS)/2.0
      GO TO 167
  166 EQDIS = EQDFIS*((PEIS - OFUSIS)**0.6)
  167 IF((OFUSIS + PEIS) .GT. (2.0*EQDIS)) EQDIS = 0.5*(OFUSIS + PEIS)
      IF((OFUSIS + PEIS) .LE. 0.01) GO TO 168
      OFRIS = 0.25*OFRFIS*(((OFUSIS + PEIS)*0.5)**1.67)*((1.0 + 0.6*((
     1  OFUSIS + PEIS)/(2.0*EQDFIS))**3.0)**1.67)
      IF(OFRIS .GT. PEIS) OFRIS = PEIS
  168 TOFR = TOFR + FPER*OFR + FIMP*OFRIS + PPI*FWTR
      OFUSIS = PEIS - OFRIS
      OFUS = PEAI - OFR
      IF(OFUS .GE. 0.001) GO TO 169
      LZS = LZS + OFUS
      OFUS = 0.0
      OFRIS = OFRIS + OFUSIS
      OFUSIS = 0.0
  169 LZRX = 1.5*ABS(LZS/LZC - 1.0) + 1.0
```

```
      FMR = (1.0/(1.0 + LZRX))**LZRX
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*(LZS/LZC)
      PLZS = FMR*(PEBI - WI)
      PGW = (1.0 -FMR)*(PEBI - WI)*(1.0 - SUBWF)*FPER
      GWS = GWS + PGW
      BFNX = BFNX + PGW
      LZS = LZS + PLZS
      IFS = IFS + WEIFS*FPER
  170 SPIF = IFRL*IFS
      AMIF = AMIF + SPIF
      IFS = IFS - SPIF
      IF(IFS .GE. 0.0001) GO TO 171
      LZS = LZS + IFS
      IFS = 0.0
  171 UHFA(1) = FPER*OFR + PPI*FWTR + FIMP*OFRIS + SPIF
      SPDR = UHFA(1)
C     ENTER EROS SUBROUTINE
      IF(CONOPT(15).EQ.1)CALL EROS(PPEP,TEHCO,OFSS,ERKI,RULF,
     1  TILL,ERKR,GF,DIA,C1,C2,KP,TNTDS,SPDR,TRSF,USFA(1),COVT,
     2FIMP,OFSL,OVCO,RESD,CANO,SDEPTH,PC)
C  ROUTING
  172 IF(CONOPT(12) .NE. 1) GO TO 173
      URHF = URHF + 0.25*UHFA(1)
      IF(CONOPT(15) .EQ. 1) URSF = URSF + 0.25*USFA(1)
      IF(PRD .NE. 4) GO TO 181
      UHFA(1) = URHF
      IF(CONOPT(15) .EQ. 1) USFA(1) = URSF
  173 TRHF = 0.0
      TRSF = 0.0
      KTRI = NCTRI
      IF(CONOPT(13) .EQ. 1) KTRI = NCSTRI
  174 URHF = UHFA(KTRI)
      IF(CONOPT(15) .EQ. 1) URSF = USFA(KTRI)
      IF(URHF.LE.0.0) GO TO 176
  175 TRHF = TRHF + URHF*CTRI(KTRI)
```

```
      IF(CONOPT(13) .EQ. 1 .AND. LSHFT .AND. KTRI .GE. 2) TRHF = TRHF +
     1  URHF*SATRI(KTRI - 1)
      UHFA(KTRI + 1) = URHF
      IF(CONOPT(15) .EQ. 1)  TRSF = TRSF + URSF*CTRI(KTRI)
      IF(CONOPT(13) .EQ. 1 .AND. LSHFT .AND. KTRI .GE. 2 .AND. CONOPT(15
     *) .EQ. 1) TRSF = TRSF +URSF*SATRI(KTRI -1)
      IF(CONOPT(15) .EQ. 1) USFA(KTRI + 1) = URSF
C
C  PROGRAM ASSUMES THAT WHEN TRHF = 0.0 THEN TRSF = 0.0
      GO TO 177
  176 UHFA(KTRI+ 1) = 0.0
      IF(CONOPT(15) .EQ. 1)  USFA(KTRI + 1) = 0.0
  177 KTRI = KTRI - 1
      IF(KTRI .GE. 1) GO TO 174
  178 IF(URHF .LE. 0.0) GO TO 179
      NRTRI = NCTRI
      IF(CONOPT(13) .EQ. 1) NRTRI = MXTRI
  179 NRTRI = NRTRI - 1
      UHFA(1) = 0.0
      USFA(1) = 0.0
      IF(CONOPT(13) .NE. 1) GO TO 180
      NNSTRI = NCSTRI + 1
      UHFA(NNSTRI) = 0.0
      USFA(NNSTRI) = 0.0
  180 URHF = 0.0
      URSF = 0.0
  181 IF(SRX .LE. CSRX) SRX = CSRX
      RHF1 = TRHF - SRX*(TRHF - RHF0)
      RHF0 = RHF1
      IF(CONOPT(15) .EQ. 1) RSDF1 = TRSF - SRX*(TRSF - RSDF0)
      IF(CONOPT(15) .EQ. 1) RSDF0 = RSDF1
      IF(RHF0 .LT. RHFMC) RHF0 = 0.0
      TFCFS = (4.0*RHF1 + CBF - HSE)*WCFS
      IF(CONOPT(13) .NE. 1) GO TO 182
      IF(CONOPT(12) .EQ. 1 .AND. PRD .NE. 4) GO TO 182
```

```
      CALL RTVARY (CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCSTRI,EXQPV,LSHFT,
     1  TFCFS)
      DATE = MOD(DAY,MDAY)
      IF(LSHFT) WRITE(6,6) DATE,HOUR,PRD,NCSTRI
    6 FORMAT(2X,I2,2X,I2,2X,I2,2X,20HHISTOGRAM CHANGES TO,1X,I2,1X,
     1  8HELEMENTS)
  182 CONTINUE
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX = CSRX
     1  +(FSRX - CSRX)*((TFCFS - 0.5*CHCAP)/(1.5*CHCAP))**3
      IF(TFCFS .GT. 2.0*CHCAP) SRX = FSRX
      IF(TFCFS .LE. TFMAX) GO TO 183
      PRDF = PRD
      TDFP24 = HOUR
      IF(PRD .LE. 3) TDFP24 = (TDFP24 - 1.0) + 0.15*PRDF
      TFMAX = TFCFS
  183 ARHF = ARHF + RHF1
      IF(CONOPT(15) .EQ. 1) ARSF = ARSF + RSDF1
C  STORM OUTPUT REQUESTED BY CONOPT(1)
  184 IF(CONOPT(1) .NE. 1) GO TO 186
      IF(DAY .NE. CDSDR) GO TO 186
      IF(HOUR .EQ. 1 .AND. PRD .EQ. 1) WRITE(6,7)
    7 FORMAT(1H//,21X,19HRAINFALL DEPOSITION,12X,16HMOISTURE STORAGE,
     1  14X,17HSTREAMFLOW ORIGIN,6X,14HSTREAM OUTFLOW/2X,116HDY HR PD RA
     2IN   EUZS   ELZS   EIFS   EOFS      UZS    LZS    IFS    OFS     S
     OPOF   SPIF   SPBF   SPTF  INCHES    CFS)
      DATE = MOD(DAY,MDAY)
      OFS = OFUS*FPER + OFUSIS*FIMP
      SPOF = OFR*FPER + OFRIS*FIMP + PPI*FWTR
      SPBF = 0.25*(CBF-HSE)
      SPTF = SPDR + SPBF
      SPDR = 0.0
      IF(RHFO .LE. 0.0) TFCFS = (CBF - HSE)*WCFS
      RSPTF = 0.25*TFCFS/WCFS
      WRITE(6,8) DATE,HOUR,PRD,PEP,PMEUZS,PMELZS,PMEIFS,PMEOFS,UZS,LZS
```

```
    8 FORMAT(2X,I2,1X,I2,1X,I1,5(1X,F6.4),2X,4(F7.4),2X,5(1X,F6.4),1X,
     1  F7.1)
      IF(HOUR .EQ. 24 .AND. PRD .EQ. 4) GO TO 185
      GO TO 186
  185 NDSDP = NDSDP + 1
      IF(NDSDR .EQ. NDSDP) GO TO 186
      CALL DAYNXT(CDSDR,DPY)
  186 CONTINUE
      IF(VINTCR .LT. 0.25*VINTMR) VINTCR = VINTCR + DPET(DAY)/96.0
  187 CONTINUE
C  END OF 15 MINUTE LOOP
      IF(CONOPT(5) .NE. 1) GO TO 197
C  HOURLY OVERLAND FLOW AND RAINFALL SORTING
      IF(TOFR .LE. 0.0) GO TO 193
      KT20 = 20
  188 IF(KT20 .LT. 1) GO TO 192
      IF(TOFR .GT. T20OFH(KT20)) GO TO 189
      GO TO 190
  189 T20OFH(KT20+1) = T20OFH(KT20)
      GO TO 191
  190 T20OFH(KT20+1) = TOFR
      GO TO 193
  191 KT20 = KT20 - 1
      GO TO 188
  192 T20OFH(1) = TOFR
  193 IF(PRH .LE. 0.0) GO TO 197
      KT20 = 20
  194 IF(KT20 .LT. 1) GO TO 196
      T20PRH(KT20 + 1) = PRH
      IF(PRH .GT. T20PRH(KT20)) GO TO 195
      GO TO 197
  195 T20PRH(KT20+1) = T20PRH(KT20)
      KT20 = KT20 - 1
      GO TO 194
  196 T20PRH(1)=PRH
```

```
C  ADDING GROUNDWATER FLOW
  197 CBF = GWS*BFRL*(1.0 + BFNRL*BFNX)
      GWS = GWS - CBF
      AMBF = AMBF + CBF
      THGR = ARHF + CBF
      IF(HSE .GT. THGR) HSE = THGR
      AMSE = AMSE + HSE
      IF(CONOPT(15) .EQ. 1) TSSF(HOUR) = ARSF
      THSF(HOUR) = (THGR - HSE)*WCFS
      TDSF = TDSF + THSF(HOUR)
      IF(CONOPT(15) .EQ. 1) TDSSL = TDSSL + TSSF(HOUR)
C  DRAINING OF UPPER ZONE STORAGE
      UZINFX = (UZS/UZC) - (LZS/LZC)
      IF(UZINFX .LE. 0.0) GO TO 198
      LZSR = LZS/LZC
      UZINLZ = 0.003*BMIR*UZC*UZINFX**3.0
      IF(UZINLZ .GT. UZS) UZINLZ = UZS
      UZS = UZS - UZINLZ
      LZRX = 1.5*ABS(LZSR - 1.0) + 1.0
      FMR = (1.0/(1.0 + LZRX))**LZRX
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*LZSR
      PGW = (1.0-FMR)*UZINLZ*(1.0 - SUBWF)*FPER
      PLZS = FMR*UZINLZ
      LZS = LZS + PLZS
      GWS = GWS + PGW
      BFNX = BFNX + PGW
C  4 PM ADJUSTMENTS OF VARIOUS VALUES
  198 IF(HOUR .NE. 16) GO TO 202
      AEX90 = 0.9*(AEX90 + PET)
      AEX96 = 0.96*(AEX96 + PET)
C  INFILTRATION CORRECTION
      SIAM = (AEX96/AETX)**SIAC
      IF(SIAM .LT. 0.33) SIAM = 0.33
      BFNX = 0.97*BFNX
      IF(PET .EQ. 0.0) GO TO 202
```

```
C  EVAP-TRANS LOSS FROM GROUNDWATER
      GWET = GWS*GWETF*PET*FPER
      GWS = GWS - GWET
      BFNX = BFNX - GWET
      IF(BFNX .LT. 0.0) BFNX = 0.0
      AMPET = AMPET + PET
      IF(PET .GE. UZS) GO TO 199
      UZS = UZS - PET
      AMNET = AMNET + PET
      GO TO 202
  199 PET = PET - UZS
      AMNET = AMNET + UZS
      UZS = 0.0
      LZSR = LZS/LZC
      IF(PET .GE. ETLF*LZSR) GO TO 200
      SET = PET*(1.0 - PET/(2.0*ETLF*LZSR))
      GO TO 201
  200 SET = 0.5*ETLF*LZSR
  201 LZS = LZS - SET
      AMNET = AMNET + SET
  202 CONTINUE
C  END OF HOUR LOOP
      DSSF(DAY) = TDSF/24.0
      IF(CONOPT(11) .EQ. 1) DSSF(DAY) = DSSF(DAY) + DDIW(DAY)
      IF(CONOPT(15) .NE. 1) GO TO 203
      DSSE(DAY) = TDSSL
      SCOUR(DAY) = C3*DRSF(DAY)**ALP3
      DSSL(DAY) = SCOUR(DAY) + DSSE(DAY)
  203 AMRTF = AMRTF + DRSF(DAY)
      AMSTF = AMSTF + DSSF(DAY)
      IF(CONOPT(6) .EQ. 1) EDLZS(DAY) = LZS
C  STORE ERRORS AND FLOW DURATION
      IF(CONOPT(4) .NE. 1) GO TO 204
      ERR = DSSF(DAY) - DRSF(DAY)
      IF(DRSF(DAY) .LT. 1.0) KRFMI = 1.0
```

```
      IF(DRSF(DAY) .GT. 1.0) KRFMI= 2.0*ALOG(DRSF(DAY)) + 2.0
      CRFMI(KRFMI) = CRFMI(KRFMI) + 1.0
      SERR(KRFMI) = SERR(KRFMI) + ERR
      SERA(KRFMI) = SERA(KRFMI) + ABS(ERR)
      SQER(KRFMI) = SQER(KRFMI) + ERR*ERR
      SESF(KRFMI) = 0.0
      IF(CRFMI(KRFMI) .GT. 1.0) SESF(KRFMI) = SQRT(ABS((SQER(KRFMI) -
     1  SERR(KRFMI)**2/CRFMI(KRFMI))/(CRFMI(KRFMI) - 1.0)))
  204 IF(DAY .EQ. 366) MDAY = 337
      DATE = MOD(DAY,MDAY)
      IF(TFMAX .LE. RMPF) GO TO 206
      WRITE(6,9) DATE, (THSF(HOUR),HOUR=1,12)
    9 FORMAT(1H/,1X/,1X,I4,2X,2HAM,1X,6F8.1,3X,6F8.1)
      WRITE(6,10) (THSF(HOUR),HOUR=13,24), DSSF(DAY)
   10 FORMAT(1HJ,6X,2HPM,1X,6F8.1,3X,7F8.1)
      IF(TDFP24 .LT. 12.0) GO TO 205
      TDFP12 = TDFP24 - 12.0
      WRITE(6,11) TFMAX, TDFP12
   11 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,
     1  4HP.M.)
      GO TO 206
  205 WRITE(6,12) TFMAX,TDFP24
   12 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,
     1  4HA.M.)
  206 IF(CONOPT(7) .EQ. 1 .AND. SDEPTH .GT. 0.0) WRITE(6,13)DATE,
     1SDEPTH,STMD,SAX,TANSM,SPLW
   13 FORMAT(3X,I4,2X,7HSDEPTH=,F8.2,2X,5HSTMD=,F6.2.2X,4HSAX=,F6.2,
     1  2X,6HTANSM=,F6.2,2X,5HSPLW=,F6.2)
C   MONTHLY SUMMARY STORAGE
      IF(DAY .NE. MEDWY(MONTH)) GO TO 220
      TMSTF(MONTH) = AMSTF
      AMSTF = 0.0
      TMRTF(MONTH) = AMRTF
      AMRTF = 0.0
      EMBFNX(MONTH) = BFNX
```

```
      TMPREC(MONTH) = AMPREC
      AMPREC = 0.0
      TMRPM(MONTH) = AMRPM
      AMRPM = 0.0
      TMBF(MONTH) = AMBF
      AMBF = 0.0
      TMIF(MONTH) = AMIF
      AMIF = 0.0
      TMSE(MONTH) = AMSE
      AMSE = 0.0
      TMPET(MONTH) = AMPET
      AMPET = 0.0
      TMNET(MONTH) = AMNET
      AMNET = 0.0
      TMSNE(MONTH) = AMSNE
      AMSNE = 0.0
      TMFSIL(MONTH) = AMFSIL
      AMFSIL = 0.0
      EMGWS(MONTH) = GWS
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)
      IF(UZC .LT. 0.25) UZC = 0.25
      EMUZC(MONTH) = UZC
      EMUZS(MONTH) = UZS
      EMSIAM(MONTH) = SIAM
      EMLZS(MONTH) = LZS
      EMIFS(MONTH) = IFS
      IF(MONTH .EQ. 5) MEDWY(5) = 59
      MDAY = MEDWY(MONTH)
  207 IF(MONTH .NE. 0) GO TO (208,209,210,211,212,213,214,215,216,217,
     1  218,219),MONTH
  208 WRITE(6,14)
   14 FORMAT(1H/,8HNOVEMBER)
      GO TO 219
  209 WRITE(6,15)
   15 FORMAT(1H/,8HDECEMBER)
```

```
      GO TO 219
  210 WRITE(6,16)
   16 FORMAT(1H/,7HJANUARY)
      GO TO 219
  211 WRITE(6,17)
   17 FORMAT(1H/,8HFEBRUARY)
      GO TO 219
  212 WRITE(6,18)
   18 FORMAT(1H/,5HMARCH)
      GO TO 219
  213 WRITE(6,19)
   19 FORMAT(1H/,5HAPRIL)
      GO TO 219
  214 WRITE(6,20)
   20 FORMAT(1H/,3HMAY)
      GO TO 219
  215 WRITE(6,21)
   21 FORMAT(1H/,4HJUNE)
      GO TO 219
  216 WRITE(6,22)
   22 FORMAT(1H/,4HJULY)
      GO TO 219
  217 WRITE(6,23)
   23 FORMAT(1H/,6HAUGUST)
      GO TO 219
  218 WRITE(6,24)
   24 FORMAT(1H/,9HSEPTEMBER)
  219 MONTH = MONTH + 1
  220 CALL DAYNXT(DAY,DPY)
      IF(DAY .NE. 274) GO TO 152
C  END OF DAY LOOP
  221 CONTINUE
  222 WRITE(6,25) (TITLE(KTA), KTA=1,20,1)
   25 FORMAT(1H1,10X,20A4)
      WRITE(6,26) (YTITLE(KTA),KTA=1,15,1),YR1,YR2
```

```
   26 FORMAT(1H/,15A4,3X,14HWATER YEAR  19,I2,1H-,I2,7X,
     1 ' KENTUCKY WATERSHED MODEL')
C   ANNUAL SUMMARY
      SATFV = 0.0
      RATFV = 0.0
      APREC = 0.0
      ABFV = 0.0
      ARPM = 0.0
       ASEV = 0.0
      ANET = 0.0
      APET = 0.0
      AIFV = 0.0
      ASE = 0.0
      AFSIL = 0.0
      DO 223 MONTH = 1,12
      SATFV = SATFV + TMSTF(MONTH)
      RATFV = RATFV + TMRTF(MONTH)
      APREC = APREC + TMPREC(MONTH)
      ABFV = ABFV + TMBF(MONTH)
      ARPM = ARPM + TMRPM(MONTH)
      ASEV = ASEV + TMSE(MONTH)
      ANET = ANET + TMNET(MONTH)
      APET = APET + TMPET(MONTH)
      AIFV = AIFV + TMIF(MONTH)
      ASE = ASE + TMSNE(MONTH)
  223 AFSIL = AFSIL + TMFSIL(MONTH)
      IF(CONOPT(14) .NE. 1) GO TO 224
      WRITE(6,27)
   27 FORMAT(1H0//44X,' RECORDED    FLOWS')
      CALL DAYOUT(DRSF,MEDWY,DPY)
      WRITE(6,28)
   28 FORMAT(1H0//44X,'  SYNTHESIZED      FLOWS')
  224 CALL DAY OUT(DSSF, MEDWY, DPY)
      WRITE(6,29) (TMSTF(KWD), KWD=1,12), SATFV
   29 FORMAT(1X, 9HSYNTHETIC,3X,12F8.1,2X,F10.1,2X,3HSFD)
```

```
      DO 225 MONTH = 1,12
  225 TMSTFI(MONTH) = (TMSTF(MONTH))/VWIN
      SATFVI = SATFV/VWIN
      WRITE(6,30) (TMSTFI(KWD), KWD=1,12),SATFVI
   30 FORMAT(1X,5HTOTAL,8X,12F8.3,4X,F7.3,2X,6HINCHES)
      DO 226 MONTH = 1,12
      TMOF(MONTH) = TMSTFI(MONTH)- TMIF(MONTH) - TMBF(MONTH) +
     1  TMSE(MONTH)
  226 IF(TMOF(MONTH) .LT. 0.0) TMOF(MONTH) = 0.0
      AOFV = SATFVI - AIFV - ABFV + ASEV
      IF(AOFV .LT. 0.0) AOFV = 0.0
      WRITE(6,31) (TMOF(KWD), KWD=1,12), AOFV
   31 FORMAT(1X,8HOVERLAND ,5X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,32) (TMIF(KWD), KWD=1,12),AIFV
   32 FORMAT(1X,9HINTERFLOW,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,33) (TMBF(KWD), KWD=1,12),ABFV
   33 FORMAT(1X,4HBASE,9X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,34) (TMSE(KWD), KWD=1,12), ASEV
   34 FORMAT(1X,9HSTRM EVAP,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      IF(CONOPT(9) .EQ. 0) GO TO 227
      WRITE(6,35) (TMRTF(KWD), KWD=1,12),RATFV
   35 FORMAT(1X,8HRECORDED,4X,12F8.1,2X,F10.1,2X,3HSFD)
      RATFVI = RATFV/VWIN
      WRITE(6,36) RATFVI
   36 FORMAT(112X,F9.2,2X,6HINCHES)
  227 WRITE(6,37) (TMPREC(KWD), KWD=1,12),APREC
   37 FORMAT( 1X,6HPRECIP,7X,12F8.2,3X,F8.2, 2X,6HINCHES)
      IF(CONOPT(7) .EQ.1) WRITE(6,38) (TMRPM(KWD), KWD=1,12),ARPM
   38 FORMAT(1X,9HRAIN+MELT,4X,12F8.2,3X,F8.2,2X,6HINCHES)
      IF(CONOPT(7) .EQ.1) WRITE(6,39) (TMSNE(KWD), KWD=1,12),ASE
   39 FORMAT(1X,11HSURSNOWEVAP,3X,12F8.3,3X,F7.3,2X,6HINCHES)
      IF(CONOPT(7) .EQ.1) WRITE(6,40) (TMFSIL(KWD), KWD=1,12),AFSIL
   40 FORMAT(1X,11HINTSNOWLOSS,3X,12F8.3,3X,F7.3,2X,6HINCHES)
      WRITE(6,41) (TMNET(KWD), KWD=1,12),ANET
   41 FORMAT(1X,12HEVP/TRAN-NET,2X,12F8.3,3X,F7.3,2X,6HINCHES)
```

```
      WRITE(6,42) (TMPET(KWD), KWD=1,12),APET
   42 FORMAT(3X,10H-POTENTIAL,2X,12F8.3,3X,F7.3,2X,6HINCHES)
      WRITE(6,43) (EMUZS(KWD), KWD=1,12)
   43 FORMAT(1X,12HSTORAGES-UZS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,44) (EMLZS(KWD), KWD=1,12)
   44 FORMAT(10X,3HLZS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,45) (EMIFS(KWD), KWD=1,12)
   45 FORMAT(10X,3HIFS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,46) (EMGWS(KWD), KWD=1,12)
   46 FORMAT(10X,3HGWS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,47) (EMUZC(KWD), KWD=1,12)
   47 FORMAT(1X,12HINDICES- UZC,2X,12F8.3)
      WRITE(6,48) (EMBFNX(KWD), KWD=1,12)
   48 FORMAT(9X,4HBFNX,2X,12F8.3)
      WRITE(6,49) (EMSIAM(KWD), KWD=1,12)
   49 FORMAT(9X,4HSIAM,2X,12F8.3)
      IF(CONOPT(7) .NE. 1) SPM = 1.0
      AMBER = (LZS - BYLZS + IFS - BYIFS)*FPER + (UZS - BYUZS + GWS -
     1  BYGWS)*(1.0 - FWTR) + SATFV/VWIN + ANET*FPER + ASEV - APREC
     2  + ASE + AFSIL - ((SPM - 1.0)/SPM)*ASM
      WRITE(6,50) AMBER
   50 FORMAT(1H0,'BALANCE',5X,F10.4,2X,'INCHES')
      IF(CONOPT(7) .NE. 1) GO TO 228
      WRITE(6,51) ASM, ASMRG
   51 FORMAT(1H/,13HCHECK ON SNOW,5X,F10.4,5X,F10.4)
      ASM = 0.0
      ASMRG = 0.0
  228 CONTINUE
      IF(CONOPT(4) .NE. 1) GO TO 232
      WRITE(6,52)
   52 FORMAT(1H1,10X,35HDAILY FLOW DURATION AND ERROR TABLE)
      WRITE(6,53)
   53 FORMAT(1H/,10X,13HFLOW INTERVAL,5X,5HCASES,3X,8HAV.ERROR,3X,
     1 16H AVR. ABS. ERROR,3X,14HSTANDARD ERROR)
      SSESF = 0.0
```

```
      SSERA = 0.0
      SSERR = 0.0
      ACRFMI = 0.0
      DO 230 KRFMI = 1,22
      IF(KRFMI .EQ. 1) ETIBF = 0.0
      IF(KRFMI .EQ. 2) ETIBF = 1.0
      FKRFMI = KRFMI
      IF(KRFMI .GT. 2) ETIBF = EXP((FKRFMI/2.0) - 1.0)
      CCRFMI = CRFMI(KRFMI)
      IF(CCRFMI .EQ. 0.0) WRITE(6,54) ETIBF, CCRFMI
   54 FORMAT(1X,13X,F8.1,1H-,F9.1,F12.1,5X,F8.2,5X,F8.2)
      IF(CCRFMI .EQ. 0.0) GO TO 229
      SERAV = SERA(KRFMI)/CCRFMI
      SERRV = SERR(KRFMI)/CCRFMI
      IF(CCRFMI .EQ. 1) WRITE(6,54) ETIBF,CCRFMI,SERRV,SERAV
      IF(CCRFMI .NE. 1) WRITE(6,54) ETIBF,CCRFMI,SERRV,SERAV,
     1SESF(KRFMI)
  229 ACRFMI = ACRFMI + CRFMI(KRFMI)
      IF(ACRFMI .EQ. 0.0) GO TO 230
      SSERR= SSERR + SERR(KRFMI)
      SSERRV= SSERR/ACRFMI
      SSERA = SSERA + SERA(KRFMI)
      SSERAV = SSERA/ACRFMI
  230 SSESF = SSESF + SESF(KRFMI)
      WRITE(6,55) ACRFMI,SSERRV,SSERAV,SSESF
   55 FORMAT(1H/,22X,F9.1,F12.1,5X,F8.2,5X,F8.2)
      CALL REGC(DRSF,DSSF,DPY,DFRC,DFI,DFCC)
      WRITE(6,56)DFRC,DFI,DFCC
   56 FORMAT(1H-,10X,'DAILY FLOW REGRESSION COEFFICIENT =',F10.4/20X,
     *'INTERCEPT =',F10.4/10X,'DAILY FLOW CORRELATION COEFFICIENT =',
     *F10.4)
      CALL REGC(TMRTF,TMSTF,12,FRCM,FIM,FCCM)
      WRITE(6,63)FRCM,FIM,FCCM
   63 FORMAT(1H-,10X,'MONTHLY FLOW REGRESSION COEFFICIENT =',F10.4/20X,'
     *INTERCEPT =',F10.4/10X,'MONTHLY FLOW CORRELATION COEFFICIENT =',
```

```
     *F10.4)
  232 CONTINUE
      IF(CONOPT(5) .NE. 1) GO TO 233
C  OUTPUT MAXIMUM RUNOFF, PRECIPITATION AT END OF YEARS
      WRITE(6,57)
   57 FORMAT(1H/,10X,58HTWENTY HIGHEST CLOCKHOUR RAINFALL EVENTS IN THE
     1WATER YEAR)
      WRITE(6,58) (T20PRH(KT20), KT20=1,20)
   58 FORMAT(1H/,5X,20F6.3)
      WRITE(6,59)
   59 FORMAT(1H/,10X,70HTWENTY HIGHEST CLOCKHOUR OVERLAND FLOW RUNOFF EV
     1ENTS IN THE WATER YEAR)
      WRITE(6,58) (T20OFH(KT20), KT20=1,20)
  233 CONTINUE
      IF(CONOPT(6) .EQ. 0) GO TO 234
      WRITE(6,99)
   99 FORMAT(1H1,30X,27HDAILY SOIL MOISTURE OUTPUT )
      CALL DAYOUT(EDLZS,MEDWY,DPY)
  234 CONTINUE
      IF(CONOPT(15).NE.1) GO TO 399
      WRITE(6,350)
  350 FORMAT(1H1,35X,32HDAILY SHEET EROSION LOSS IN TONS//)
      CALL DAYOUT(DSSE,MEDWY,DPY)
      WRITE(6,352)
  352 FORMAT(1H1,37X,27HDAILY CHANNEL SCOUR IN TONS//)
      CALL DAYOUT(SCOUR,MEDWY,DPY)
      WRITE(6,354)
  354 FORMAT(1H1,32X,39HDAILY SYNTHESIZED SEDIMENT LOAD IN TONS//)
      CALL DAYOUT(DSSL,MEDWY,DPY)
      IF(CONOPT(16).NE.1) GO TO 399
      WRITE(6,356)
  356 FORMAT(1H1,33X,36HDAILY RECORDED SEDIMENT LOAD IN TONS//)
      CALL DAYOUT(DRSL,MEDWY,DPY)
  357 RATSV = 0.0
      SATSV = 0.0
```

```
      DO 236 DAY = 1,DPY
      RATSV = RATSV + DRSL(DAY)
  236 SATSV = SATSV + DSSL(DAY)
      CALL REGC(DRSL.DSSL,DPY,DSRC,DSI,DSCC)
      WRITE(6,240)DSRC,DSI,DSCC
  240 FORMAT(1H-,10X,'DAILY SEDIMENT REGRESSION COEFFICIENT =',F10.4/20X
     *,'INTERCEPT =',F10.4/10X,'DAILY SEDIMENT CORRELATION COEFFICIENT =
     *',F10.4)
  399 IF(NYSQ.LE.NYSD) GO TO 400
      IF(CONOPT(10) .EQ. 1) GO TO 100
      GO TO 117
  400 STOP
      END
C
C     SUBROUTINE DAYNXT
C
      SUBROUTINE DAYNXT(DAY,DPY)
C  DETERMINES NUMBER OF NEXT DAY OF THE YEAR
      INTEGER  DAY,DPY
      DAY = DAY + 1
      IF(DAY .EQ. 366) DAY = 1
      IF(DAY .EQ. 60 .AND. DPY .EQ. 366) DAY = 366
      IF(DAY .EQ. 367) DAY = 60
      RETURN
      END
C
C
C
C
C     SUBROUTINE DAYOUT
      SUBROUTINE DAYOUT(VDCY,MEDWY,DPY)
C  PRINTS TABLE OF DAILY VALUES
      DIMENSION MEDWY(12),VDCY(366),VDMD(12)
      INTEGER  DATE,DAY,DPY
  100 WRITE(6,1)
```

```
    1 FORMAT(7X,3HDAY,7X,3HOCT,5X,3HNOV,5X,3HDEC,5X,3HJAN,5X,3HFEB,5X,
     1  3HMAR,5X,3HAPR,5X,3HMAY,5X,3HJUN,5X,3HJUL,5X,3HAUG,5X,4HSEPT)
      MEDWY(3) = 0
      DO 104 DATE = 1,28,1
      IF(MOD(DATE,5) .NE. 1) GO TO 102
      DO 101 KMO = 1,12
      DAY = MEDWY(KMO) + DATE
  101  VDMD(KMO) = VDCY(DAY)
      WRITE(6,2) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)
    2 FORMAT(1H0,3X,I6,3X,12F8.1)
      GO TO 104
  102 DO 103 KMO = 1,12
       DAY = MEDWY(KMO) + DATE
  103 VDMD(KMO) = VDCY(DAY)
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD = 1,11)
    3 FORMAT(1X,3X,I6,3X,12F8.1)
  104 CONTINUE
      IF(DPY .NE. 366) GO TO 106
      DATE = 29
      VDCY(60) = VDCY(366)
      DO 105 KMO = 1,12
      DAY = MEDWY(KMO) + DATE
  105 VDMD(KMO) = VDCY(DAY)
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)
      GO TO 107
  106 CONTINUE
      WRITE(6,4) VDCY(302),VDCY(333),VDCY(363),VDCY(29),VDCY(88),
     1VDCY(119),VDCY(149),VDCY(180),VDCY(210),VDCY(241),VDCY(272)
    4 FORMAT(1X,7X,2H29,3X,4F8.1,8X,7F8.1)
  107 CONTINUE
  108 WRITE(6,5) VDCY(303),VDCY(334),VDCY(364),VDCY(30),VDCY(89),
     1VDCY(120),VDCY(150),VDCY(181),VDCY(211),VDCY(242),VDCY(273)
    5 FORMAT(1X,7X,2H30,3X,4F8.1,8X,7F8.1)
      WRITE(6,6) VDCY(304),VDCY(365),VDCY(31),VDCY(90),VDCY(151),
     1VDCY(212),VDCY(243)
```

```
    6 FORMAT(1H/,7X,2H31,3X,F8.1,8X,2F8.1,8X,F8.1,8X,F8.1,8X,2F8.1)
      MEDWY(3) = 365
      RETURN
      END
C
C
C     SUBROUTINE PREPRD
C
      SUBROUTINE PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,PRH)
C  DIVIDES HOURLY PRECIPITATION TOTALS AMONG PERIODS FOR SMALL BASINS
      DIMENSION DRHP(366,24), PE4P(4)
      INTEGER DAY,DPY,HOUR,PRD
      PEP = 0.0
      IF(PRH .EQ. 0.0) RETURN
      IF(PRD .EQ. 1) GO TO 100
      PEP = PE4P(PRD)
      RETURN
  100 LHOUR = HOUR - 1
      LDAY = DAY
      IF(LHOUR .GE. 1) GO TO 101
      LHOUR = 24
      LDAY = DAY - 1
      IF(LDAY .EQ. 0) LDAY = 365
      IF(LDAY .EQ. 365) LDAY = 59
      IF(LDAY .EQ. 59 .AND. DPY .EQ. 366) LDAY = 366
  101 PRLH = RGPM*DRHP(LDAY,LHOUR)
      NHOUR = HOUR + 1
      NDAY = DAY
      IF(NHOUR .LE. 24) GO TO 102
      NHOUR = 1
      CALL DAYNXT(NDAY,DPY)
  102 PRNH = RGPM*DRHP(NDAY,NHOUR)
      IF(PRH .GT. PRLH .AND. PRH .GT. PRNH) GO TO 103
      GO TO 104
  103 PE4P(1) = 0.10
```

```
      PE4P(2) = 0.28
      PE4P(3) = 0.46
      PE4P(4) = 0.16
      GO TO 108
  104 IF(PRH .LT. PRLH .AND. PRH .LT. PRNH) GO TO 105
      GO TO 106
  105 PE4P(1) = 0.28
      PE4P(2) = 0.10
      PE4P(3) = 0.16
      PE4P(4) = 0.46
      GO TO 108
  106 IF(PRNH .GE. PRLH) GO TO 107
      PE4P(1) = 0.46
      PE4P(2) = 0.16
      PE4P(3) = 0.28
      PE4P(4) = 0.10
      GO TO 108
  107 PE4P(1) = 0.10
      PE4P(2) = 0.28
      PE4P(3) = 0.16
      PE4P(4) = 0.46
  108 DO 109 KPRD = 1,4
  109 PE4P(KPRD) = PE4P(KPRD)*PRH
      PEP = PE4P(1)
      RETURN
      END
C
C
C
C     SUBROUTINE RTVARY
      SUBROUTINE RTVARY(CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCTRI,EXQPV,
     1  LSHFT,TFCFS)
      DIMENSION  AWSBIT(99),BTRI(99),CTRI(99),SATRI(99)
      LOGICAL  LSHFT
      DO 100 KIA = 1,MXTRI
```

```
      SATRI(KIA) = 0.0
  100 AWSBIT(KIA) = 0.0
      LSHFT = .FALSE.
      FMXTRI = MXTRI
      FNBTRI = NBTRI
      FNPTRI = NCTRI
      TFX = TFCFS
      TFMRT = 0.1*CHCAP
      IF(TFX .LT. TFMRT) TFX = TFMRT
      IF(FNPTRI .EQ. FMXTRI .AND. TFX .EQ. TFMRT) RETURN
      FNTRI = FNBTRI*(CHCAP/TFX)**EXQPV + 0.5
      IF(FNTRI .LT. 1.0) FNTRI = 1.01
      NCTRI = FNTRI
      FNSTRI = NCTRI
      IF(FNSTRI .NE. FNPTRI) LSHFT = .TRUE.
      IF(.NOT. LSHFT) RETURN
      IF(FNPTRI .GT. 98.5) GO TO 101
      FONTRI = ABS(FNSTRI - FNPTRI)
      IF(FCNTRI .LE. 1.1) GO TO 101
      IF(FNSTRI .GT. FNPTRI) FNSTRI = FNPTRI + 1.0
      IF(FNSTRI .LT. FNPTRI) FNSTRI = FNPTRI - 1.0
      NCTRI = FNSTRI
  101 KB1 = 0
      KB2 = 1
      KB3 = 0
  102 KB1 = KB1 + 1
      IF(KB1 .GT. NBTRI) GO TO 105
      KB4 = 0
      WSBIT = BTRI(KB1)/FNSTRI
  103 KB4 = KB4 + 1
      IF(KB4 .GT. NCTRI) GO TO 102
      AWSBIT(KB2) = AWSBIT(KB2) + WSBIT
      KB3 = KB3 + 1
      IF(KB3 .LT. NBTRI) GO TO 104
      KB3 = 0
```

```
      KB2 = KB2 + 1
  104 GO TO 103
  105 IF(FNPTRI .GT. 98.5) GO TO 108
      DO 107 KB6 = 1,NCTRI
      DO 106 KB7 = 1,KB6
  106 SATRI(KB6) = SATRI(KB6) + AWSBIT(KB7) - CTRI(KB7)
  107 CONTINUE
  108 DO 109 KB5 = 1,MXTRI
  109 CTRI(KB5) = AWSBIT(KB5)
      RETURN
      END
C
C
C
C
C
C     SUBROUTINE SNOMEL
      SUBROUTINE SNOMEL(BDDFSM,SPTWCC,SPM,ELDIF,DAY,SPBFLW,XDNFS,FFOR,
     1  FFSI,MRNSM,DSMGH,SDEPTH,STMD,PXCSA,HOUR,SAX,SOFRF,OFRFIS,SOFRFI,
     2  AMFSIL,PRH,SPTW,TANSM,SPLW,SFMD,OFRF,WT4AM,WT4PM,ASM,ASMRG,
     3  SASFX,SARAX,DMXT,DMNT,RICY,FIRR,TEH)
C  SNOWMELT COMPUTATION
      DIMENSION  DMNT(366),DMXT(366),FIRR(15),RICY(366)
      INTEGER  DAY,HOUR
      REAL  MHSM,MRNSM
      IF((DAY .NE. 274) .OR. (HOUR .NE. 1)) GO TO 100
      SPLW = 0.0
      XELR = 0.0
      SDSC = 0.0278
      FDSC = 0.0
      FTA = 0.0
      RICD = 0.0
      KRIA = 0
  100 CONTINUE
C  CALCULATION OF HOURLY AIR TEMPERATURE
```

```
C    DMXT CURRENT DAY, DMNT NEXT DAY
      IF(HOUR .NE. 4) GO TO 101
      FDSC = 0.0
      FTA = FDSC
      WT4PM = DMXT(DAY) - 4.0*ELDIF + (XELR/4.0)*0.7*ELDIF
  101 IF(HOUR .EQ. 10) SDSC = -0.0278
      IF(HOUR .EQ. 22) SDSC = 0.0278
      IF(HOUR .NE. 16) GO TO 102
      NDAY = DAY + 1
      IF(NDAY .EQ. 366) NDAY = 1
      IF(NDAY .EQ. 60 .AND. DMXT(366) .NE. 0.0) NDAY = 366
      IF(NDAY .EQ. 367) NDAY = 60
      WT4AM = DMNT(NDAY) - (XELR/4.0)*3.3*ELDIF
  102 IF(PRH .LE. 0.0 .OR. XELR .GE. 4.0) GO TO 103
      WT4AM = WT4AM - 0.825*ELDIF
      WT4PM = WT4PM + 0.175*ELDIF
      XELR = XELR + 1.0
  103 IF(PRH .NE. 0.0 .OR. XELR .LE. 0.0) GO TO 104
      WT4AM = WT4AM + 0.825*ELDIF
      WT4PM = WT4PM - 0.175*ELDIF
      XELR = XELR - 1.0
  104 TEH = WT4AM + FTA*(WT4PM - WT4AM)
      FDSC = FDSC + SDSC
      FTA = FTA + FDSC
      IF(PRH+SPTW .EQ. 0.0) GO TO 128
      IF(HOUR .NE. 24) GO TO 105
C  CALCULATION OF TIME AGING OF THE SNOWPACK
      SAX = SAX + 1.0
      IF(SAX .GT. 15.0) SAX = 15.0
  105 IF(TEH .GT. 32.0) GO TO 110
C  PRECIPITATION IN FORM OF SNOW - CALCULATE INTERCEPTION DENSITY OF NEW
C     SNOW COMPACTION, AND SETTLING SNOW PACK AND THE EFFECT ON ALBEDO
      IF(PRH .LE. 0.0) GO TO 110
      PRH = SPM*PRH
      HSF = PRH
```

```
      ASM = ASM + HSF
      PRH = (1.0 - (FFSI*FFOR))*PRH
      HSFRG = PRH
      ASMRG = ASMRG + HSFRG
      FSIL = FFSI*FFOR*HSF
      AMFSIL = AMFSIL + FSIL
      IF(TEH .LE. 0.0) GO TO 106
      DNFS = XDNFS + ((0.01*TEH)**2)
      GO TO 107
  106 DNFS = XDNFS
  107 IF(SPTW .GT. 0.0 .AND. SDEPTH .GT. SPTW) SDEPTH = SDEPTH - ((PRH*
     1  SDEPTH/SPTW)*((0.10*SDEPTH)**0.25))
      SPTW = SPTW + PRH
      SDEPTH = SDEPTH + (PRH/DNFS)
      SASFX = SASFX + PRH
      IF(SASFX .GE. PXCSA) GO TO 108
      GO TO 109
  108 SAX = SAX - 1.0
      IF(SAX .LT. 0.0) SAX = 0.0
      SASFX = SASFX - PXCSA
  109 PRH = 0.0
  110 CONTINUE
      IF(SPTW .LE. 0.0) GO TO 127
C  SEASONAL MELT FACTOR ADJUSTMENT
C  PROGRAM MODIFICATION
      KAAO = KRIA
C  PROGRAM MODIFICATION
      RICD = RICY(DAY)
      IF(TEH .LE. 32.0) GO TO 111
      GO TO 114
C  CALCULATION OF NEGATIVE MELT
  111 IF(TANSM .LE. 11.5*MRNSM) GO TO 112
      IF(TANSM .LT. 1.0) TANSM = TANSM + ((5.0*MRNSM)**(1.3 + 2.0*
     1  TANSM))
      GO TO 113
```

```
  112 TANSM = TANSM + MRNSM
  113 IF(TANSM .GT. 0.08*SPTW) TANSM = 0.08*SPTW
      GO TO 127
C  EFFECT OF RAIN ON ALBEDO
  114 SARAX = SARAX + PRH
      IF(SARAX .LT. PXCSA/2.0) GO TO 115
      SAX = SAX + 1.0
      IF(SAX .GT. 15.0) SAX = 15.0
      SASFX = 0.0
      SARAX = SARAX - (PXCSA/2.0)
  115 IF(TEH .GT. 32.0) HSM = (TEH -32.0)*BDDFSM
      IF(TEH .LT. 32.0) HSM = 0.0
      HSM = HSM*RICD
      KAA = 1.0 + SAX
      IF(SAX .LT. 15.0) HSM = HSM*(1.0 - ((1.0 - FFOR)*FIRR(KAA)))
      IF(SAX .EQ. 15.0) HSM = HSM*(1.0 - ((1.0 - FFOR)*FIRR(15)))
      IF(PRH .GT. 0.0) HSM = HSM + ((TEH - 32.0)*(PRH/144.0))
      IF(STMD .GT. 0.3 .AND. SPTW .LT. SPTWCC) GO TO 116
      GO TO 117
  116 MHSM = HSM
      HSM = (SPTW/SPTWCC)*HSM
      IF(HSM .LT. 0.1*MHSM) HSM = 0.1*MHSM
  117 IF(HSM .LT. SPTW) GO TO 118
      HSM = SPTW
      SDEPTH = 0.0
      SPTW = 0.0
      SPLW = 0.0
      RICD = 0.0
      TANSM = 0.0
      SAX = 15.0
      OFRF = SOFRF
      OFRFIS = SOFRFI
      GO TO 122
  118 SPTW = SPTW - HSM
      IF(SFMD .LE. 0.0) GO TO 122
```

```
      IF(SAX .GE. 15.0) GO TO 121
      IF(SAX .GE. 6.0) GO TO 119
      SDEPTH = SDEPTH - (HSM/(0.5*SFMD))
      GO TO 122
  119 IF(SAX .LE. 10.0) GO TO 120
      SDEPTH = SDEPTH - (HSM/(0.9*SFMD))
      GO TO 122
  120 SDEPTH = SDEPTH - (HSM/(0.7*SFMD))
      GO TO 122
  121 SDEPTH = SDEPTH - (HSM/SFMD)
  122 CONTINUE
      IF(SPTW .LT. 0.00001) SPTW = 0.0
C  CALCULATION OF LIQUID-WATER-HOLDING CAPACITY
      SPLWC = SPBFLW*SPTW
      IF(SFMD .GT. 0.6) SPLWC = SPBFLW*(3.0 - 3.33*SFMD)*SPTW
      IF(SPLWC .LT. 0.0) SPLWC = 0.0
C  ACCOUNTING OF MELT WATER AND RAIN
      IF((SPLW + HSM + PRH) .GT. (SPLWC + TANSM)) GO TO 123
      GO TO 124
  123 PRH = HSM + PRH + SPLW - SPLWC - TANSM
      SPLW = SPLWC
      SPTW = SPTW + TANSM
      TANSM = 0.0
      GO TO 127
  124 IF((HSM + PRH) .LE. TANSM) GO TO 126
  125 SPTW = SPTW + TANSM
      SPLW = SPLW + HSM + PRH - TANSM
      PRH = 0.0
      TANSM = 0.0
      GO TO 127
  126 TANSM = TANSM - HSM - PRH
      SPTW = SPTW + HSM + PRH
      PRH = 0.0
  127 CONTINUE
      HSM = 0.0
```

```
C   CALCULATION OF DENSITY AND ADJUSTMENT OF OVERLAND FLOW TIME
      IF(SDEPTH .LE. 0.0 .OR. SPTW .GE. SDEPTH) GO TO 128
      STMD = (SPTW + SPLW)/SDEPTH
      SFMD = SPTW/SDEPTH
      OFRF = 0.33*SOFRF
      IF(SPTW .LE. SPTWCC) OFRF = (1.0 - (SPTW/SPTWCC)*0.67)*SOFRF
  128 IF(SDEPTH .LE. 0.0) OFRF = SOFRF
      OFRFIS = SOFRFI*OFRF/SOFRF
C   CALCULATION OF GROUNDMELT
      IF( HOUR .NE. 12 .OR. SPTW .LE. 0.0) RETURN
      IF(SPTW .LE. DSMGH) GO TO 129
      PRH = PRH + DSMGH
      SPTW = SPTW - DSMGH
      IF(STMD .LT. 0.50 .AND. SDEPTH .GT. 2.0*DSMGH) SDEPTH = SDEPTH -
     1  2.0*DSMGH
      RETURN
  129 PRH = SPTW + PRH + SPLW
      TANSM = 0.0
      RICD = 0.0
      SPLW = 0.0
      SDEPTH = 0.0
      SPTW = 0.0
      SAX = 15.0
      OFRF = SOFRF
      OFRFIS = SOFRFI
      RETURN
      END
      SUBROUTINE REGC(X,Y,N,SLOPE,YINT,R)
      DIMENSION X(N),Y(N)
      SUMX=0.0
      SUMY=0.0
      SUMX2=0.0
      SUMXY=0.0
      SUMY2=0.0
      DO100I=1,N
```

```
      SUMX=SUMX+X(I)
      SUMY=SUMY+Y(I)
      SUMX2=SUMX2+X(I)*X(I)
      SUMY2=SUMY2+Y(I)*Y(I)
  100 SUMXY=SUMXY+X(I)*Y(I)
      SLOPE=(N*SUMXY-SUMX*SUMY)/(N*SUMX2-SUMX*SUMX)
      YINT=(SUMY-SLOPE*SUMX)/N
      SX2=(SUMX2-SUMX*SUMX/N)/(N-1.0)
      SY2=(SUMY2-SUMY*SUMY/N)/(N-1.0)
      R=SQRT(SLOPE*SLOPE*SX2/SY2)
      RETURN
      END
C    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    C
C                                                                                C
C     SUBROUTINE  EROS, SOON KUK KWUN, OCTOBER 1979                              C
C     IOWA STATE UNIVERSITY, AMES, IOWA.                                         C
C     THIS SUBROUTINE SIMULATES SOIL EROSION WITHIN THE 15MIN.                   C
C     LOOP IN THE KENTUCKY WATERSHED MODEL.                                      C
C                                                                                C
C    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    C
C
C                                                                                C
      SUBROUTINE EROS(PPEP,TEHCO,OFSS,ERKI,RULF,TILL,
     1ERKR,GF,DIA,C1,C2,KP,TNTDS,SPDR,TRSF,USFA,
     2 COVT,FIMP,OFSL,OVCO,RESD,CANO,SDEPTH,PC)
      DIMENSION DIA(6),GF(6),RES(6),FLC(6),FL(6),AA(6),S(6),P(6),PE(6),
     1  AS(6),TS(6),TR(6)
      REAL IDC,IMPU,KP
C
C     INTERRILL DETACHMENT CAPACITY
C
      IF(PPEP.LE.0.0.OR.TEHCO.LT.28.0.OR.SDEPTH.GT.0.5) GO TO 100
      RINT=PPEP*2.54*4.0
      SPIX=(RINT*CANO)**2.0
      IDC=C1*ERKI*SPIX
```

```
      GO TO 101
  100 SPIX=0.0
      IDC=0.0
  101 CONTINUE
C
C     INDIRECT FACTORS AFFECTING INTERRILL EROSION
C
      DEG=ATAN(OFSS)
      SLFAC=2.96*((SIN(DEG))**0.79)+0.56
      IF(COVT.LE.83.0) COVER=1.0-0.012*COVT
      IF(COVT.GT.83.0) COVER=0.0
      REFAC=SLFAC*COVER*RULF
      REDX=EXP(-C2*SPDR*2.54)
      IF(SPDR.LE.0.0) GO TO 104
C
C     CALCULATE THE ACTUAL INTERRILL DETACHMENT
C
      AIDS=IDC*REDX*REFAC
      GO TO 105
  104 AIDS=IDC*REFAC
  105 TRSF=0.0
C
C     RILL DETACHMENT CAPACITY COMPUTATION
C
      IF(SPDR.LE.0.0.OR.TEHCO.LT.30.0) GO TO 106
      SHEAR=97.87*SPDR*2.54*OFSS
      TAUC=0.0503*10.0**(0.0183*PC)
      IF(SHEAR.LE.TAUC) GO TO 106
      RDC=ERKR*(SHEAR-TAUC)**1.10
      CRFAC=TILL*RULF*RESD
      ARDS=RDC*CRFAC
      GO TO 107
  106 ARDS=0.0
  107 AID=10.0*AIDS
      ARD=10.0*ARDS
```

```
      TDA=AID+ARD
C
C     CALCULATE RILL TRANSPORT CAPACITY BY YALIN'S EQUATION
C
      IF(SPDR.LE.0.0) GO TO 400
      TQ=0.0
      TRF=0.0
      DO 200 I=1,5
         RES(I)=0.0
         FLC(I)=0.0
         FL(I)=0.0
         AA(I)=0.0
         S(I)=0.0
         AS(I)=0.0
      P(I)=0.0
      PE(I)=0.0
         TS(I)=0.0
         TR(I)=0.0
  200 CONTINUE
      DO 210 I=1,5
         SVEL=SQRT(980.0*SPDR*2.54*OFSS)
         RES(I)=SVEL*DIA(I)/0.0153
C
C     ENTER SHILD'S DIAGRAM
C
         IF(RES(I).LE.2.0) FLC(I)=0.114/RES(I)**0.9
         IF(RES(I).GT.2.0.AND.RES(I).LE.4.0)FLC(I)=0.09/RES(I)**0.585
         IF(RES(I).GT.4.0.AND.RES(I).LE.10.0)FLC(I)=0.056/RES(I)**0.243
         IF(RES(I).GT.10.0.AND.RES(I).LE.30.0) FLC(I)=0.0258*RES(I)
     1   **0.0815
         IF(RES(I).GT.30.0) FLC(I)=0.081*RES(I)**0.193
         FL(I)=SVEL**2.0/(GF(I)-1.0)*980.0*DIA(I)
         S(I)=FL(I)/FLC(I)-1.0
      IF(FL(I).LE.FLC(I)) S(I)=0.0
      TQ=TQ+S(I)
```

```
  210 CONTINUE
      IF(TQ.EQ.0.0) GO TO 400
C
C     YALIN'S EQUATION
C
      DO 220 I=1,5
         AA(I)=2.45*GF(I)**0.4*FLC(I)**0.5
         AS(I)=AA(I)*S(I)
      IF(AS(I).EQ.0.0) GO TO 108
         P(I)=0.635*S(I)*(1.0-(1.0/AS(I))*ALOG(1.0+AS(I)))
         PE(I)=P(I)*S(I)/TQ
         TS(I)=PE(I)*DIA(I)*SVEL*GF(I)
      GO TO 109
  108 TS(I)=0.0
  109 TR(I)=2.25*TS(I)
      TRF=TRF+TR(I)
  220 CONTINUE
      ATRF=TRF*RULF*RESD
      GO TO 401
  400 ATRF=0.0
  401 CONTINUE
C
C     COMPARE DETACHMENT AND TRANSPORT CAPACITY
C
      IF(ATRF.GE.TDA) GO TO 110
      IF(ATRF.LT.AID) GO TO 300
      DEPO=0.0
      GO TO 301
  300 DEPO=AID-ATRF
  301 EROA=ATRF
      DS=DEPO*0.25
      TNTDS=TNTDS+DS*OVCO
      GO TO 115
  110 CONTINUE
      STOR=TNTDS/OVCO
```

```
      IF(STOR.LE.0.0) GO TO 113
      IF(STOR-(ATRF-TDA)*0.25)111,112,112
  111 EROA=TDA+STOR
      DS=0.0
      GO TO 114
  112 EROA=ATRF
      DS=STOR-(ATRF-TDA)*0.25
      IF(DS.LE.0.000001) DS=0.0
      GO TO 114
  113 EROA=TDA
      DS=0.0
  114 TNTDS=DS*OVCO
  115 CONTINUE
C
C     EROSION FROM IMPERVIOUS AREA
C
      IMPU=KP*FIMP*SPIX
C
C     TOTAL UNROUTED EROSION FOR 15 MIN. TIME INTERVAL
C
      USFA=OVCO*(EROA*(1.0-FIMP)+IMPU)
      RETURN
      END
C   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C
C     SUBROUTINE CROP, SIMULATES CROP COVER AND CANOPY EFFECT ON EROSION
C
C   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
C
      SUBROUTINE CROP(ZONE1,ZONE2,ZONE3,CZ1,CZ2,CZ3,CZ4,DAY,RESD,
     1                CANO,COVT)
      INTEGER DAY
C
C     CALCULATION OF CROP RESIDUE COVER EFFECT
C
```

```
      IP=0
 1001 IP=IP+1
      IF(1P.EQ.3) GO TO 1005
      IF(IP.EQ.1) GO TO 999
C     CROP RESIDUE COVER FOR SOYBEAN
      IF(DAY.LT.105.OR.DAY.GT.319) COVB=(3.0*CZ1+16.0*(CZ2+CZ3)+
     1   40.1*CZ4)*ZONE2
      IF(DAY.GE.105.AND.DAY.LE.319) COVB=(3.0*CZ1+10.0*(CZ2+CZ3)+20.0
     1   *CZ4)*ZONE2
      GO TO 1000
C       CROP RESIDUE COVER FOR CORN
  999 CONTINUE
      IF(DAY.LT.105.OR.DAY.GT.319) COVA=(7.0*CZ1+45.0*CZ2+74.0*CZ3+
     1   80.0*CZ4)*ZONE1
      IF(DAY.GE.105.AND.DAY.LT.161) COVA=(7.0*CZ1+20.0*CZ2+34.0*CZ3
     1   +63.0*CZ4)*ZONE1
      IF(DAY.GE.161.AND.DAY.LE.319) COVA=(7.0*CZ1+20.0*CZ2+26.0*CZ3+
     1   37.0*CZ4)*ZONE1
      GO TO 1000
C     CROP RESIDUE COVER FOR PASTURE AND OTHER AREAS, ASSUMMING 100% COVER
 1005 COVC=100.0*ZONE3
 1000 IF(IP.LT.3) GO TO 1001
      COVT=COVA+COVB+COVC
C     CALCULATION OF RESIDUE EFFECT BY COVER
      IF(COVT.EQ.0.0) GO TO 1007
      IF(COVT.GT.0.0.AND.COVT.LT.10.0) RESD=1.06-0.029*COVT
      IF(COVT.GE.10.0.AND.COVT.LT.20.0) RESD=0.96-0.019*COVT
      IF(COVT.GE.20.0.AND.COVT.LT.30.0) RESD=0.83-0.011*COVT
      IF(COVT.GE.30.0.AND.COVT.LT.40.0) RESD=0.71-0.008*COVT
      IF(COVT.GE.60.0.AND.COVT.LT.80.0) RESD=0.62-0.006*COVT
      IF(COVT.GE.80.0) RESD=0.61-0.00525*COVT
      GO TO 1008
 1007 RESD=1.0
C
C     CALCULATION OF CROP CANOPY EFFECT
```

```
C
 1008 IC=0
 2001 IC=IC+1
      IF(IC.EQ.3) GO TO 2003
      IF(IC.EQ.2) GO TO 2002
C     CORN CANOPY
C     DEFINE CORN CANOPY COVER %
      IF(DAY.LT.130.OR.DAY.GT.304) GO TO 300
      IF(DAY.GE.130.AND.DAY.LT.171) CCOV=1.024*DAY-133.0
      IF(DAY.GE.171.AND.DAY.LT.182) CCOV=2.182*DAY-331.1
      IF(DAY.GE.182.AND.DAY.LT.191) CCOV=1.222*DAY-156.4
      IF(DAY.GE.191.AND.DAY.LT.233) CCOV=0.333*DAY+13.40
      IF(DAY.GE.233.AND.DAY.LE.304) CCOV=91.0
C     DEFINE CORN CANOPY EFFECT FROM HEIGHT AND COVER %
      IF(DAY.GE.130.AND.DAY.LT.171) CCONO=1.0-CCOV/100.0
      IF(DAY.GE.171.AND.DAY.LT.182) CCONO=1.0-0.0094*CCOV
      IF(DAY.GE.182.AND.DAY.LT.191) CCONO=1.0-0.0082*CCOV
      IF(DAY.GE.191.AND.DAY.LT.233) CCONO=1.0-0.0075*CCOV
      IF(DAY.GE.233.AND.DAY.LE.304) CCONO=1.0-0.0070*CCOV
      GO TO 301
  300 CCONO=1.0
  301 CC=CCONO
      GO TO 2000
C     SOYBEAN CANOPY
 2002 CONTINUE
C     DEFINE CANOPY COVER OF SOYBEAN
      IF(DAY.LT.140.OR.DAY.GT.304) GO TO 302
      IF(DAY.GE.140.AND.DAY.LT.179) BCOV=0.615*DAY-86.0
      IF(DAY.GE.179.AND.DAY.LT.190) BCOV=2.727*DAY-464.1
      IF(DAY.GE.190.AND.DAY.LT.222) BCOV=1.250*DAY-183.5
      IF(DAY.GE.222.AND.DAY.LE.304) BCOV=95.0
C     CALCULATE CANOPY EFFECT FROM COVER AND HEIGHT
      IF(DAY.GE.140.AND.DAY.LT.179) BCONO=1.0-BCOV/100.0
      IF(DAY.GE.179.AND.DAY.LT.190) BCONO=1.0-0.0094*BCOV
      IF(DAY.GE.190.AND.DAY.LT.222) BCONO=1.0-0.0082*BCOV
```

```
      IF(DAY.GE.222.AND.DAY.LE.304) BCONO=0.22
      GO TO 303
  302 BCONO=1.0
  303 BC=BCONO
      GO TO 2000
C     CANOPY EFFECT FOR PASTURE AND OTHERS
 2003 CONTINUE
      PC=0.0
 2000 IF(IC.LT.3) GO TO 2001
      CANO=ZONE1*CC+ZONE2*BC+ZONE3*PC
      RETURN
      END
```

APPENDIX C. CONTROL OPTIONS FOR PROGRAM LISTING ON APPENDIX B

CONTROL OPTION FOR PROGRAM LISTING ON APPENDIX B

OPTION	VALUE	DESCRIPTION
1	1	IF 15-MINUTE STORM DETAILS ARE REQUESTED.
2	1	IF RAIN IS NOT TO BE DIVIDED EQUALLY AMONG 15-MINUTE PERIODS.
3	1	IF EVAPORATION IS TO BE READ BY 10-DAY PERIODS. DAILY EVAPORATION DATA READ OTHERWISE.
4	1	IF A DAILY FLOW ERROR TABLE IS REQUESTED. THIS OPTION CANNOT BE USED IF OPTION 9 IS NOT IN EFFECT
5	1	IF THE TOP TWENTY HOURLY RAINFALLS AND OVERLAND FLOWS ARE REQUESTED.
6	1	IF DAILY SOIL MOISTURE VALUES ARE REQUESTED.
7	1	IF SNOW IS TO BE INCLUDED IN THE ANALYSIS.
8	1	IF THE RAINFALL STORAGE GAGE SITE IS REMOVED DURING THE WATER YEAR.
9	1	IF DAILY RECORDED STREAMFLOWS ARE TO BE READ.
10	1	IF NEXT YEAR OF DATA REQUIRES READING NEW PARAMETERS. THIS IS NORMALLY USED WHEN TWO WATERSHEDS ARE SYNTHESIZED IN THE SAME RUN.
11	1	IF STREAMFLOW DIVERSIONS ARE TO BE READ.
12	1	IF STREAM ROUTING IS TO BE DONE HOURLY. ROUTING IS DONE ON A 15-MINUTE INCREMENT OTHERWISE.

13	1	IF THE LENGTH OF THE TIME AREA HISTOGRAM IS TO BE VARIED WITH FLOW.
14	1	IF THE RECORDED STREAMFLOWS ARE TO BE PRINTED.
15	1	IF THE EROSION MODEL IS TO BE INCLUDED IN THE ANALYSIS. THIS OPTION CANNOT BE USED IF OPTION 9 IS NOT IN EFFECT.
16	1	IF RECORDED SUSPENDED LOADS ARE TO BE READ FOR COMPARISON WITH SYNTHESIZED SUSPENDED LOADS. THIS OPTION CANNOT BE USED IF OPTIONS 9 AND 15 ARE NOT IN EFFECT.

APPENDIX D. SAMPLE INPUT DATA FOR PROGRAM LISTING ON APPENDIX B

INPUT DATA FOR WATERSHED AND EROSION MODELS

```
  0   0   0   1   1   1   1   0   1   0   0   1   0   1   1   1
01
027
 0.0094  .0231  .0288  .0202  .0239  .0322  .0283  .0373  .0370  .0502  .0587
  .0438  .0373  .0344  .0442  .0540  .0460  .0513  .0536  .0613  .0434  .0367
  .0300  .0373  .0352  .0296  .0128
 0.76 0.75 0.74 0.73 0.72 0.71 0.70 0.69 0.68 0.66 0.64 0.62 0.60 0.58 0.56
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.001
 0.05
 0.05
 0.05
 0.05
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```

```
 0.005
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
 0.000
  .0008  .0500 2.0000 1.40    0.0     0.18    0.005   0.1     0.15    0.0001 0.05
250.00  1.00  19.51 0.025  0.000
  0.10   0.8    2.50   9.1    0.3     0.0     0.00    4.0    10.0     0.5
  600.0  350.0 0.0500 0.150  0.0150 0.3500 0.9750 0.9750 0.2000 1.0000 0.9630
 0.1    0.10   3.0    0.025  0.0    5.0     75
    0.026    3.000    0.820    0.530    0.045
   0.66    0.500    0.150    0.018    0.035    0.100    1.33
   0.540    0.240    0.220    0.442    0.358    0.192    0.008   70 360
 0.0032  0.0013  0.0007  0.00035 0.00014
 1.80    2.00    2.65    2.65    2.60
  DIGITAL SIMULATION OF STREAMFLOW, SHEET AND SCOUR EROSION- TRIAL RUN 1
 75 76
          FOUR MILE CREEK AREA NEAR TRAER, IOWA -
 315  91
 0.11 0.12 0.17 0.15 0.16 0.15 0.20 0.27 0.16 0.31 0.25 0.19 0.27 0.13 0.12
 0.27 0.28 0.20 0.14 0.19 0.12 0.13 0.31 0.03 0.12 0.14 0.13 0.08 0.20 0.19
 0.29 0.19 0.23 0.27 0.30 0.28 0.24 0.26 0.33 0.29 0.28 0.27 0.06 0.05 0.11
 0.10 0.21 0.25 0.30 0.35 0.28 0.25 0.05 0.14 0.23 0.27 0.21 0.25 0.16 0.19
 0.14 0.17 0.23 0.35 0.36 0.27 0.29 0.38 0.29 0.33 0.21 0.13 0.38 0.19 0.33
 0.39 0.26 0.27 0.34 0.28 0.30 0.27 0.32 0.28 0.15 0.32 0.34 0.12 0.32 0.27
 0.26 0.27 0.13 0.41 0.26 0.28 0.39 0.29 0.45 0.30 0.31 0.34 0.38 0.37 0.42
 0.27 0.34 0.33 0.33 0.16 0.27 0.10 0.12 0.21 0.38 0.31 0.16 0.23 0.27 0.19
 0.28 0.15 0.26 0.25 0.24 0.28 0.25 0.32 0.21 0.29 0.32 0.30 0.32 0.13 0.14
```

```
0.15 0.24 0.15 0.13 0.28 0.29 0.27 0.29 0.25 0.21 0.19 0.20 0.27 0.35 0.35
0.21 0.35 0.29 0.37 0.23 0.32 0.29 0.27 0.30 0.31 0.29 0.19 0.27 0.31 0.40
0.33 0.16 0.16 0.16 0.15 0.20 0.14 0.25 0.20 0.17 0.22 0.08 0.14 0.06 0.11
0.06 0.11 0.21 0.14 0.13 0.19 0.20 0.21 0.19 0.18 0.20 0.24 0.14 0.14 0.25
0.28 0.19 0.20 0.12 0.14 0.12 0.12 0.12 0.12 0.15 0.20 0.17 0.12 0.17 0.10
0.16 0.10 0.07 0.15 0.11 0.06 0.01 0.10 0.05 0.04 0.08 0.04 0.04 0.01 0.10
   1.5    1.2    1.0    0.7    1.0    0.9    0.7    0.6    0.7    1.0    1.2    1.1
   1.0    0.9    0.8    0.7    0.6    0.5    0.6    0.7    0.8    0.8    0.9    0.9
   1.0    0.7    0.4    0.6    0.9    1.1    1.0    0.8    0.7    0.8    1.0    1.5
   2.5    1.8    1.6    1.4    1.3    1.2    1.1    1.1    1.0    1.0    1.0    1.0
   0.9    0.9    0.9    0.9    1.0    1.2    1.7    3.5   20.0   87.0   39.0    7.2
   4.3    2.0    3.4    5.0    2.7    6.2    6.2   22.0   17.0   14.0  111.0   27.0
  14.0   11.0    9.9    8.3    8.2    8.4    9.5    8.5    7.6    7.2    6.8    6.3
   6.1    5.5    5.2    5.9   16.0   12.0    9.8    8.3    7.4    6.4    5.9    5.4
   4.9    4.6    4.3    4.2    4.0    3.7    3.8    3.9    5.6    4.5   18.0   79.0
  42.0   42.0   66.0   42.0   72.0   69.0   52.0   42.0   36.0   31.0   27.0   24.0
  22.0   24.0   20.0   18.0   17.0   15.0   14.0   14.0   13.0   13.0   12.0   12.0
  12.0   11.0   11.0   13.0   15.0   14.0   12.0   11.0   10.0   10.0   11.0   11.0
   9.8    9.0    8.4    8.3   23.0   14.0   12.0   11.0    9.9    9.2    8.6    8.0
   7.8    7.4    6.9    4.7    5.8    6.8    6.4   16.0   58.0   21.0   16.0   13.0
  12.0   11.0    9.8    9.1    8.7    8.0    8.4    7.5    6.9    6.4    6.3    6.3
   5.7    5.3    5.0    4.7    4.4    4.2    4.0    3.8    3.5    3.3    2.9    2.7
   2.5    2.4    2.2    2.0    1.9    1.8    1.7    1.6    1.9    1.9    1.6    1.5
   1.2    1.1    1.0    1.0    2.3    1.2    1.0    0.9    0.8    0.7    0.7    0.6
   0.6    0.6    0.5    0.5    0.5    0.4    0.4    0.7    0.8    0.4    0.5    0.3
   0.3    0.5    0.5    0.3    0.4    0.5    0.7    0.4    0.2    0.3    0.3    0.2
   0.1    0.1    0.0    0.3    0.2    0.2    0.3    0.2    0.2    0.2    0.1    0.2
   0.1    0.1    0.1    0.1    0.2    0.2    0.2    0.2    0.2    0.4    0.5    0.2
   0.2    0.1    0.1    0.2    0.3    0.2    0.2    0.3    0.3    1.3    1.2    1.2
   1.3    1.2    1.2    1.1    1.2    1.2    1.2    1.2    1.3    1.2    1.2    1.2
   1.2    1.2    1.3    1.3    1.3    1.3    1.3    1.3    1.2    1.2    1.2    1.3
   1.3    1.2    1.2    1.2    1.3    1.3    1.4    1.5    1.4    1.4    1.4    1.3
   1.8    2.2    1.4    1.3    1.2    1.1    1.3    1.2    1.2    1.2    1.1    1.6
   1.4    1.0    1.1    1.1    1.0    1.1    1.0    1.2    6.0   10.0    4.9    3.5
   3.0    2.8    3.1    2.2    2.5    2.3    2.2    2.1    2.0    1.8    2.1    3.2
```

```
2.1    2.0    1.3    0.8    1.3    1.9    1.9    1.8    1.8    1.7    1.7    1.7
1.6    1.4    1.2    1.1    1.3    16.0
     0.22       0.18       0.40       0.13       0.08       0.19       0.17       0.14
     0.22       0.11       0.14       0.02       0.05       0.20       0.16       0.20
     0.14       0.09       0.06       0.16       0.26       0.29       0.22       0.29
     0.29       0.18       0.03       0.12       0.01       0.02       0.16       0.17
     0.11       0.06       0.30       0.33       0.17       0.13       0.28       0.23
     0.10       0.05       0.13       0.17       0.08       0.51       0.24       0.23
     0.22       0.29       0.49       0.27       0.07       0.06       0.18       1.87
    48.14     658.58     120.42       1.64       0.92       0.72       1.73       2.14
     1.36       3.46       5.25      80.45      17.88      16.13     971.67      34.09
    10.69       1.75       5.79       3.66       3.07       3.02       4.97       3.58
     2.23       1.71       1.91       1.68       1.61       1.26       1.11       1.47
     9.04       3.14       2.64       2.31       1.74       1.21       1.17       0.48
     0.17       0.84       0.96       0.89       0.73       0.71       0.86       0.76
     0.79       1.10      53.04     633.14      58.31      59.54     116.44      54.40
   482.64     263.10      53.03      25.07      21.40      11.22      11.76       5.87
     7.59       9.54       5.09       4.36       3.24       1.72       2.23       3.39
     2.93       1.97       3.05       3.85       1.59       2.18       2.77       4.83
     1.91       2.81       2.70       2.56       2.06       2.67       2.83       0.62
     1.13       0.37       0.35       0.35     162.06      19.22       3.99       2.93
     2.79       1.62       1.54       0.84       0.71       1.10       1.43       0.71
     0.98       0.70       0.94      57.89     467.42      12.97       7.05       5.43
     7.25       3.77       2.42       1.22       0.49       0.76       2.67       1.49
     0.68       0.42       0.88       0.83       1.05       1.23       0.28       0.76
     1.03       1.01       0.95       0.89       0.39       0.37       0.34       0.17
     0.73       0.49       0.44       0.35       0.29       0.39       0.51       0.09
     0.33       0.42       0.42       0.29       0.30       0.13       0.26       0.14
     0.68       0.24       0.06       0.11       0.12       0.09       0.17       0.20
     0.08       0.03       0.31       0.06       0.05       0.04       0.04       0.08
     0.09       0.11       0.06       0.08       0.12       0.04       0.08       0.06
     0.31       0.17       0.18       0.06       0.08       0.05       0.05       0.05
     0.09       0.05       0.01       0.10       0.16       0.06       0.10       0.06
     0.06       0.10       0.05       0.09       0.03       0.04       0.03       0.02
     0.05       0.04       0.06       0.04       0.04       0.16       0.17       0.08
```

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     0.06        0.04        0.06        0.05        0.08        0.06        0.05        0.18
     0.11        0.29        0.26        0.26        0.29        0.26        0.26        0.24
     0.26        0.26        0.26        0.26        0.29        0.26        0.26        0.26
     0.26        0.26        0.26        0.29        0.29        0.29        0.29        0.29
     0.29        0.26        0.26        0.29        0.29        0.26        0.26        0.26
     0.39        0.39        0.42        0.45        0.42        0.42        0.42        0.39
     0.54        0.66        0.42        0.39        0.36        0.33        0.39        0.36
     0.36        0.36        0.33        0.48        0.42        0.30        0.33        0.33
     0.30        0.33        0.30        0.36        1.80        3.00        1.31        0.93
     0.80        0.75        0.83        0.59        0.67        0.61        0.59        0.56
     0.53        0.48        0.56        0.85        0.56        0.53        0.35        0.22
     0.35        0.51        0.51        0.48        0.48        0.45        0.45        0.45
     0.43        0.37        0.32        0.29        0.35       11.77
   1.2   6.0  16.9  20.0  17.9   2.1  19.9  20.2  16.3   8.9  14.5  15.9  16.2
  21.1  13.7  18.3  16.8  19.6   9.4  17.5  13.2  22.9  20.2  17.5   4.6  24.4
  25.3  21.6  23.8  10.4  13.4  24.8  13.1  21.9  19.6  11.1  28.9  27.4  28.1
  18.2  19.6  27.8  29.0  11.2  20.4  19.9   2.5   4.4  18.5  13.4  14.2  14.3
  24.1  36.2  36.3  19.9  36.6  31.5  31.6  24.4  12.5   1.1  11.1   3.7  40.6
  41.0  43.1  24.9  26.6  18.7  19.5   1.7  46.1  37.0  27.8  47.3  32.9  35.4
  39.7  44.8  47.9  35.7  45.3  45.5  28.3   5.9  51.6  37.3   2.0  34.2  34.4
  56.4  48.1  35.7  56.4  52.7  52.7  13.4  57.5  36.6  37.6  60.6  60.9  49.6
  34.2  34.2  50.0   5.7  48.2  55.1  10.9  32.7  61.7   8.7   2.5  59.8  53.3
  48.1  58.2  52.5
  27.4  10.7  10.7  12.8  10.7  21.8  18.3   9.9   9.6  28.0  14.4   9.6  19.5
  28.0  23.4  27.3  27.4  12.7  15.8   8.3  19.0  26.3  17.7   6.2   6.2   6.2
   9.4  12.6   7.7  10.7  13.4  19.7  20.3  22.7  11.8  21.3  16.6   7.7   7.7
  20.3   7.7   7.7   8.5   8.5  21.8  16.3  18.2  17.0  17.1   5.6  17.9  13.5
   5.1   5.0   5.1   4.5   5.3   6.1   7.2  12.1   6.6
 31.0 34.0 25.0  9.0 14.0 35.0 33.0  0.0  7.0 21.0 20.0 30.0 44.0 35.0 36.0
 47.0 22.0 20.0 33.0 39.0 37.0 32.0 31.0 41.0 40.0 30.0 17.0 20.0 49.0 40.0
 28.0 42.0 23.0 18.0 41.0 11.0 19.0 24.0 45.0 47.0 58.0 50.0 49.0 57.0 38.0
 51.0 55.0 36.0 36.0 36.0 49.0 48.0 28.0 30.0 28.0 42.0 41.0 47.0 55.0 49.0
 31.0 32.0 33.0 28.0 32.0 20.0 32.0 31.0 35.0 43.0 37.0 48.0 47.0 35.0 43.0
 34.0 28.0 43.0 67.0 73.0 56.0 34.0 51.0 66.0 59.0 70.0 55.0 48.0 66.0 50.0
 47.0 48.0 53.0 75.0 50.0 57.0 69.0 69.0 63.0 60.0 65.0 73.0 52.0 60.0 77.0
```

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 76.0 75.0 75.0 74.0 66.0 62.0 56.0 58.0 63.0 56.0 47.0 53.0 55.0 56.0 60.0
 69.0 65.0 62.0 64.0 67.0 64.0 68.0 63.0 53.0 55.0 53.0 52.0 24.0 32.0 46.0
 65.0 66.0 68.0 66.0 67.0 48.0 28.0 34.0 39.0 24.0 19.0 24.0 28.0 39.0 52.0
 18.0 28.0 32.0 36.0 53.0 60.0 27.0 36.0 34.0 34.0 48.0 31.0 38.0 57.0 35.0
 21.0 28.0 10.0 26.0 44.0 25.0 31.0 34.0 24.0 29.0 29.0 25.0 26.0 29.0 33.0
 38.0
 25.0 23.0  3.0 -6.0 -4.0 14.0 -8.0-12.0-12.0 -2.0 13.0 12.0 26.0  7.0  6.0
 11.0 -3.0 -3.0  7.0 -1.0 -1.0  9.0 10.0 11.0 23.0  6.0 -8.0 -9.0 14.0 14.0
 12.0 22.0 -5.0- 2.0  3.0  3.0  2.0  2.0 11.0 26.0 29.0 22.0 23.0 30.0 16.0
 23.0 30.0 30.0 30.0 27.0 27.0 27.0 10.0  7.0 20.0 28.0 24.0 26.0 29.0 28.0
 27.0 29.0 25.0 23.0 13.0 11.0 13.0 15.0 19.0 31.0 24.0 28.0 18.0 20.0 25.0
 24.0 21.0 26.0 38.0 42.0 24.0 21.0 27.0 35.0 28.0 41.0 36.0 34.0 46.0 34.0
 35.0 32.0 32.0 37.0 30.0 34.0 31.0 41.0 26.0 30.0 41.0 34.0 22.0 34.0 45.0
 49.0 61.0 55.0 55.0 36.0 44.0 46.0 44.0 47.0 47.0 35.0 33.0 34.0 35.0 36.0
 43.0 43.0 50.0 39.0 42.0 50.0 53.0 36.0 38.0 36.0 34.0 32.0 36.0 16.0 21.0
 30.0 36.0 46.0 48.0 48.0 25.0 15.0 15.0 24.0 18.0 16.0 14.0  8.0 19.0 16.0
  8.0 14.0 21.0 21.0 28.0 17.0 18.0 26.0 24.0 22.0 31.0 26.0 27.0 35.0  7.0
  7.0 -1.0 -4.0 -4.0 25.0  6.0  6.0 19.0 19.0 23.0 22.0 18.0 19.0 26.0 24.0
 17.0
 00
  75  10  14  1                                         0.02
  75  10  24  1                               0.01 0.01 0.18 0.03
  75  11   2  1                                    0.02 0.25 0.03      0.01
  75  11   3  1 0.01 0.10 0.06                     0.02      0.05 0.01
  75  11   9  2      0.04 0.02 0.01 0.14 0.09 0.01
  75  11  12  1                                                        0.01
  75  11  12  2 0.01
  75  11  20  1 0.02 0.08 0.13 0.02 0.03 0.07      0.03 0.04 0.01
  75  11  20  2                0.01      0.01                          0.02
  75  11  21  1 0.01 0.01 0.01
  75  11  24  1      0.01      0.01 0.01 0.02 0.04 0.05 0.05 0.01 0.04 0.01
  75  11  24  2 0.05 0.03 0.02 0.04      0.01
  75  11  26  1                                    0.02 0.01
  75  11  26  2           0.01 0.02 0.03 0.02 0.05 0.02 0.01
  75  11  29  1                                                   0.01 0.07
```

75	11	29	2	0.10	0.10	0.28	0.09	0.28	0.41	0.11	0.12			0.01	
75	12	13	2	0.01	0.01										
75	12	14	1			0.23	0.12								
76	1	2	1	0.02											
76	1	6	2					0.02	0.01						
76	1	25	1								0.02				
76	1	25	2	0.01	0.01	0.02	0.03		0.03						
76	2	15	1	0.14	0.03	0.01	0.01				0.01	0.01			
76	2	16	1								0.01	0.02	0.02		0.06
76	2	26	2	0.02	0.08	0.35	0.01								
76	3	2	1									0.08			
76	3	4	1						0.03	0.18	0.10	0.17	0.19	0.08	0.09
76	3	4	2	0.07	0.15	0.16	0.03	0.04	0.01	0.05					
76	3	11	1						0.03	0.02	0.03	0.04	0.02	0.10	0.13
76	3	11	2	0.13	0.13	0.01	0.01								
76	3	12	1	0.01	0.01										
76	3	26	2										0.02	0.04	0.03
76	3	28	2												0.16
76	3	29	2	0.01	0.01	0.05	0.06	0.07	0.10	0.03	0.01	0.02	0.12	0.21	0.09
76	3	30	1	0.01				0.01	0.02	0.01	0.01				
76	4	14	2									0.01	0.47	0.04	0.05
76	4	15	1	0.11	0.03										
76	4	17	1					0.08	0.10	0.17	0.18	0.04		0.37	
76	4	17	2						0.02	0.02			0.01	0.13	0.06
76	4	18	1	0.56	0.11	0.09	0.11	0.10	0.02	0.06	0.03	0.02			
76	4	20	1												0.10
76	4	20	2	0.07	0.13	0.12	0.19	0.16	0.19	0.12	0.04	0.06	0.02	0.01	
76	4	21	1	0.01	0.01										
76	4	21	2				0.11								
76	4	22	1							0.21					
76	4	23	1						0.01	0.05	0.13	0.22	0.28	0.12	
76	4	23	2				0.03		0.10	0.01	0.29				
76	4	24	1	0.23	0.08	0.02	0.03	0.01	0.07	0.01			0.01	0.03	0.01
76	4	24	2	0.02	0.01	0.01	0.01	0.02	0.04	0.01					
76	4	25	1	0.14		0.01	0.01	0.02	0.01	0.02					

```
76  5   2  1 0.01 0.06 0.13 0.10 0.09 0.05 0.02
76  5  12  2                                              0.01
76  5  13  1 0.02 0.02 0.04 0.01 0.04 0.04 0.02 0.02 0.03 0.04 0.01
76  5  15  1                                              0.06 0.02 0.02
76  5  15  2 0.01      0.03 0.01 0.02 0.01 0.01
76  5  16  1 0.04 0.03 0.05 0.02 0.05 0.05 0.01
76  5  16  2 0.10 0.08 0.11 0.02 0.02 0.05 0.04
76  5  22  1                                                   0.05 0.12
76  5  22  2 0.08 0.05 0.01 0.01                0.01 0.02 0.02 0.02 0.01
76  5  23  1 0.01 0.01      0.01 0.02 0.01 0.01 0.01 0.01
76  5  28  2                                    0.04 0.01 0.02 0.06 0.08
76  5  29  1 0.04 0.07                0.04 0.08 0.52
76  6  10  1                     0.19 0.17 0.10 0.06
76  6  12  2                               0.48 0.06
76  6  13  2                               0.69 0.42 0.32 0.14 0.02
76  6  17  2                          0.05 0.13 0.06
76  6  23  1                               0.15
76  6  24  1                                              0.20 0.26
76  6  25  1                                                   0.03
76  6  26  2                                              0.06 0.01
76  6  29  1                          0.09 0.12 0.04
76  7  16  1                          0.02
76  7  20  1                                    0.03 0.01
76  7  20  2                     0.10 0.02 0.06 0.01
76  7  26  1                                         0.01 0.02
76  7  28  1           0.70 0.22 0.11 0.01 0.01 0.01
76  7  30  2                                    0.02
76  8  11  2                     0.05 0.22
76  8  13  2                               0.06
76  8  17  1                0.12 0.06 0.04 0.04
76  9  13  1           0.05                                         0.03
76  9  19  1                          0.05 0.02 0.25 0.21 0.07
76  9  19  2      0.01                          0.06 0.03 0.01
76  9  27  2                                    0.01 0.03 0.01
98  9  30  1
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APPENDIX E. STREAMFLOW SIMULATION RESULTS FOR FOUR MILE CREEK WATERSHED NEAR TRAER, IOWA

TABLE E-1. Daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

Date	Mean daily streamflow (m^3/sec x 10^2)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	7.1	8.2	19.0	27.0	9.6	9.9	4.2	3.7
2	7.6	7.9	16.0	19.0	7.9	9.9	4.2	3.7
3	7.6	7.6	15.0	18.0	7.4	9.9	4.2	3.4
4	7.1	7.4	15.0	18.0	6.8	9.6	4.2	3.4
5	7.1	7.1	13.0	18.0	7.1	9.3	4.2	3.1
6	7.6	7.1	13.0	18.0	7.4	9.1	4.2	3.1
7	7.9	6.5	13.0	17.0	6.5	8.8	4.0	3.1
8	7.6	6.5	13.0	17.0	7.9	8.5	3.7	2.8
9	7.1	6.2	13.0	16.0	7.6	8.2	4.0	2.8
10	6.8	5.9	13.0	16.0	7.1	7.9	4.0	2.5
11	7.4	5.9	13.0	15.0	6.5	7.6	4.2	2.5
12	8.8	6.8	12.0	15.0	6.8	7.4	4.2	2.5
13	18.0	22.0	11.0	14.0	7.1	7.1	4.5	2.3
14	12.0	12.0	10.0	14.0	6.8	6.8	4.5	2.3
15	11.0	5.9	11.0	13.0	6.5	6.8	4.5	2.3
16	12.0	5.7	11.0	13.0	6.2	6.5	4.2	2.3
17	11.0	5.4	11.0	13.0	6.2	6.2	4.0	2.0
18	10.0	5.4	10.0	14.0	6.2	5.9	4.2	2.0
19	16.0	16.0	9.1	14.0	5.9	5.9	4.2	2.0
20	16.0	23.0	11.0	14.0	5.9	5.7	4.2	2.0
21	15.0	11.0	11.0	14.0	5.7	5.4	4.5	1.7
22	13.0	9.1	11.0	13.0	5.4	5.4	4.5	1.7
23	12.0	8.8	11.0	13.0	5.4	5.1	4.5	1.7
24	12.0	8.5	10.0	13.0	5.1	4.8	4.5	1.7
25	11.0	8.2	10.0	12.0	5.1	4.8	4.5	1.7
26	10.0	7.9	9.9	12.0	4.8	4.5	4.5	1.4
27	10.0	7.6	9.9	11.0	4.8	4.5	4.5	1.4
28	10.0	7.4	9.1	11.0	4.8	4.2	4.5	1.4
29	10.0	7.1	9.1	11.0	4.5	4.2	4.8	1.4
30	12.0	9.9	10.0	10.0	4.5	4.0	5.1	1.4
31	25.0	37.0			4.5	4.0	5.7	1.1
Total	323.7	301.0	353.1	443.0	187.8	207.9	135.2	70.4

TABLE E-1. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	6.2	1.1	34.0	122.0	27.0	26.0	16.0	27.0
2	5.9	1.1	1133.0	338.0	26.0	25.0	15.0	16.0
3	5.7	1.1	589.0	1443.0	24.0	24.0	15.0	12.0
4	5.7	1.1	79.0	315.0	22.0	23.0	14.0	12.0
5	7.1	1.1	48.0	72.0	23.0	22.0	14.0	11.0
6	6.2	1.1	40.0	48.0	22.0	22.0	13.0	11.0
7	6.8	1.1	34.0	44.0	21.0	21.0	13.0	10.0
8	7.4	0.8	28.0	42.0	21.0	20.0	13.0	10.0
9	8.2	0.8	26.0	40.0	20.0	19.0	13.0	9.6
10	7.6	0.8	24.0	39.0	20.0	19.0	13.0	9.3
11	6.8	0.8	23.0	38.0	19.0	18.0	13.0	9.1
12	6.2	0.8	22.0	36.0	19.0	18.0	13.0	22.0
13	5.9	0.8	22.0	35.0	21.0	29.0	31.0	44.0
14	5.4	0.8	20.0	34.0	19.0	22.0	312.0	194.0
15	5.1	0.8	19.0	32.0	19.0	18.0	102.0	177.0
16	5.7	0.8	19.0	31.0	19.0	17.0	68.0	56.0
17	6.5	2.3	19.0	30.0	18.0	16.0	54.0	38.0
18	9.9	54.0	18.0	29.0	17.0	16.0	45.0	33.0
19	17.0	73.0	19.0	33.0	21.0	16.0	40.0	31.0
20	37.0	27.0	19.0	52.0	28.0	33.0	34.0	29.0
21	85.0	15.0	21.0	39.0	25.0	20.0	31.0	28.0
22	227.0	140.0	26.0	34.0	24.0	17.0	28.0	27.0
23	363.0	292.0	26.0	32.0	20.0	17.0	244.0	49.0
24	227.0	100.0	23.0	31.0	20.0	15.0	144.0	72.0
25	85.0	177.0	34.0	31.0	18.0	14.0	54.0	60.0
26	43.0	130.0	51.0	30.0	18.0	14.0	40.0	44.0
27	28.0	65.0	37.0	29.0	17.0	13.0	37.0	38.0
28	227.0	327.0	28.0	28.0	16.0	13.0	34.0	36.0
29			31.0	27.0	16.0	13.0	31.0	34.0
30			28.0	26.0	16.0	30.0	31.0	33.0
31			27.0	25.0			28.0	32.0
Total	1457.3	1417.2	2567.0	3185.0	616.0	590.0	1553.0	1209.0

TABLE E-1. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	28.0	31.0	8.2	22.0	2.0	8.2	3.1	4.2
2	28.0	32.0	7.9	21.0	2.5	7.9	2.5	4.0
3	26.0	31.0	8.5	24.0	1.1	7.6	3.1	4.0
4	24.0	30.0	7.4	25.0	2.3	9.1	3.1	4.0
5	23.0	29.0	6.8	19.0	60.0	50.0	2.5	3.7
6	21.0	28.0	6.5	18.0	23.0	45.0	2.8	3.7
7	20.0	27.0	6.8	18.0	13.0	13.0	2.5	3.4
8	18.0	26.0	6.2	17.0	11.0	9.1	2.3	3.4
9	18.0	25.0	5.4	16.0	9.6	8.5	4.0	4.5
10	17.0	24.0	5.7	16.0	7.6	8.2	9.0	26.0
11	16.0	23.0	4.0	15.0	6.5	7.9	3.0	9.3
12	16.0	22.0	4.2	14.0	5.7	7.6	2.5	4.0
13	16.0	24.0	4.2	14.0	5.1	7.4	2.3	4.2
14	15.0	28.0	5.1	20.0	4.2	7.1	5.4	11.0
15	14.0	50.0	4.8	26.0	3.7	6.8	27.0	50.0
16	14.0	37.0	3.4	17.0	3.4	6.5	18.0	31.0
17	13.0	33.0	4.0	18.0	3.1	6.5	12.0	12.0
18	13.0	33.0	8.5	31.0	28.0	21.0	11.0	9.1
19	12.0	28.0	5.4	37.0	14.0	22.0	8.8	6.2
20	16.0	35.0	4.5	15.0	8.5	8.2	7.4	5.9
21	31.0	50.0	4.0	12.0	6.8	6.5	7.1	5.7
22	20.0	34.0	3.4	11.0	6.2	6.2	6.2	5.4
23	17.0	29.0	3.1	11.0	5.4	5.9	8.2	7.6
24	15.0	28.0	2.8	11.0	4.8	5.7	74.0	30.0
25	13.0	27.0	2.5	10.0	4.2	3.4	51.0	25.0
26	13.0	26.0	2.3	10.0	4.2	5.4	91.0	44.0
27	12.0	25.0	3.4	9.6	4.0	5.0	43.0	25.0
28	11.0	24.0	2.8	9.3	3.1	4.8	31.0	20.0
29	9.6	23.0	3.4	13.0	2.8	4.8	26.0	19.0
30	8.8	22.0	2.8	13.0	2.5	4.5	21.0	18.0
31			2.3	9.1	2.5	4.5		
Total	518.4	884.0	150.3	522.0	260.8	326.3	490.8	403.3

TABLE E-2. Daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1976 water year

Date	Mean daily streamflow (m^3/sec x 10^2)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	3.7	5.4	3.7	1.7	14.0	25.0	4.2	4.8
2	3.4	5.4	3.7	2.5	10.0	8.5	3.4	4.8
3	3.4	5.1	4.0	11.0	8.5	6.2	2.8	4.5
4	3.7	4.8	4.2	6.8	7.9	5.0	2.0	4.2
5	3.4	4.8	4.0	2.0	8.8	6.2	2.8	4.2
6	3.4	4.5	4.0	1.4	6.2	6.8	2.5	4.0
7	3.1	4.2	4.0	1.4	7.1	7.4	2.0	4.0
8	3.4	4.2	3.7	1.4	6.5	7.1	1.7	3.7
9	3.4	4.0	5.1	1.4	6.2	7.1	2.0	3.7
10	3.4	4.0	6.2	6.5	5.9	6.8	2.8	3.4
11	3.4	3.7	4.0	3.1	5.7	6.5	3.4	3.4
12	3.7	3.7	3.7	1.4	5.1	6.5	3.1	3.4
13	3.4	3.4	3.4	1.1	5.9	6.5	2.8	3.1
14	3.4	3.4	3.1	1.1	9.1	13.0	2.5	3.1
15	3.4	3.1	3.7	1.1	5.9	17.0	2.3	3.1
16	3.4	3.1	3.4	1.1	5.7	9.3	2.0	2.8
17	3.4	3.1	3.4	1.1	3.7	8.2	1.7	2.8
18	3.7	2.8	3.4	1.1	2.3	7.9	1.4	2.5
19	3.7	2.8	3.1	1.1	3.7	7.6	1.7	2.5
20	3.7	2.5	4.5	5.1	5.4	7.4	2.0	2.5
21	3.7	2.5	4.0	9.6	5.4	7.1	2.3	2.5
22	3.7	2.5	2.8	3.4	5.1	7.1	2.3	2.3
23	3.7	2.3	3.1	1.7	5.1	6.8	2.5	2.3
24	3.4	2.3	3.1	1.4	4.8	6.5	2.5	2.3
25	3.4	2.3	2.8	1.7	4.8	6.2	2.8	2.3
26	3.4	2.3	3.1	1.7	4.8	5.9	2.0	2.3
27	3.7	2.0	2.8	1.7	4.5	5.9	1.1	2.3
28	3.7	2.0	3.4	1.7	4.0	5.7	1.7	2.3
29	3.7	2.0	17.0	6.2	3.4	5.4	2.5	2.3
30	3.4	2.0	28.0	59.0	3.1	5.1	3.1	2.0
31	3.4	1.7			3.7	5.1	2.8	2.0
Total	108.7	102.3	148.4	141.5	182.3	243.7	74.7	95.4

TABLE E-2. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	2.3	2.0	20.0	4.2	28.0	9.6	62.0	54.0
2	2.0	2.0	12.0	3.7	24.0	8.5	68.0	62.0
3	2.3	2.0	5.7	3.7	21.0	8.2	57.0	65.0
4	2.8	1.7	9.6	6.8	18.0	7.0	51.0	55.0
5	4.2	1.7	14.0	35.0	17.0	7.6	48.0	52.0
6	7.1	1.7	7.6	12.0	15.0	7.4	43.0	50.0
7	5.1	1.7	18.0	5.4	14.0	7.1	40.0	49.0
8	4.5	1.7	18.0	4.8	13.0	6.8	40.0	47.0
9	4.0	1.4	62.0	4.5	12.0	6.5	37.0	45.0
10	3.7	1.4	48.0	4.5	12.0	6.2	37.0	43.0
11	3.4	1.4	40.0	73.0	11.0	6.2	34.0	42.0
12	3.1	1.4	314.0	451.0	11.0	5.9	34.0	40.0
13	3.1	1.4	77.0	96.0	11.0	5.7	34.0	39.0
14	2.8	1.1	40.0	22.0	11.0	5.4	31.0	38.0
15	2.8	1.4	31.0	49.0	16.0	20.0	31.0	37.0
16	2.8	1.7	28.0	20.0	13.0	14.0	37.0	40.0
17	2.8	1.7	24.0	13.0	51.0	16.0	43.0	52.0
18	2.5	1.7	23.0	11.0	224.0	68.0	40.0	39.0
19	2.5	1.7	24.0	11.0	119.0	46.0	34.0	35.0
20	2.5	1.7	27.0	11.0	119.0	24.0	31.0	34.0
21	2.5	2.0	24.0	11.0	187.0	65.0	28.0	33.0
22	2.8	2.3	22.0	9.9	119.0	50.0	28.0	32.0
23	3.4	2.3	20.0	9.6	204.0	86.0	31.0	35.0
24	4.8	2.3	19.0	9.3	195.0	245.0	31.0	32.0
25	9.9	2.3	18.0	9.1	147.0	131.0	28.0	29.0
26	57.0	27.0	17.0	8.5	119.0	75.0	26.0	28.0
27	246.0	245.0	16.0	8.5	102.0	63.0	24.0	27.0
28	110.0	59.0	15.0	7.9	88.0	50.0	24.0	26.0
29	45.0	8.8	17.0	8.8	77.0	58.0	65.0	38.0
30			45.0	27.0	68.0	56.0	40.0	47.0
31			34.0	17.0			34.0	30.0
Total	547.7	383.5	1089.9	968.2	2066.0	1176.0	1191.0	1275.0

TABLE E-2. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	31.0	26.0	15.0	16.0	2.3	5.4	0.8	1.7
2	28.0	25.0	14.0	16.0	2.0	5.4	0.6	1.7
3	26.1	24.0	13.0	15.0	2.0	5.1	0.6	1.7
4	24.0	24.0	13.0	15.0	1.7	4.8	0.8	1.4
5	23.0	23.0	12.0	14.0	1.7	4.8	0.6	1.4
6	22.0	22.0	11.0	14.0	1.7	4.5	0.6	1.4
7	21.0	21.0	11.0	13.0	1.4	4.2	0.6	1.4
8	20.0	20.0	9.9	13.0	1.4	4.2	0.3	1.4
9	13.0	19.0	9.3	12.0	1.4	4.0	0.6	1.4
10	16.0	23.0	8.2	12.0	1.1	4.0	0.3	1.1
11	19.0	28.0	7.6	11.0	1.1	3.7	0.3	1.1
12	18.0	20.0	7.1	11.0	2.0	7.6	0.3	1.1
13	45.0	33.0	6.8	11.0	2.3	5.1	0.3	1.1
14	164.0	69.0	6.2	10.0	1.1	4.2	0.6	1.1
15	60.0	41.0	5.7	9.6	1.4	3.4	0.6	1.1
16	45.0	26.0	5.4	9.3	0.8	3.1	0.6	0.8
17	37.0	24.0	5.1	9.1	0.8	3.1	0.6	0.8
18	34.0	24.0	4.8	8.8	1.4	3.1	0.6	0.8
19	31.0	23.0	4.5	8.5	1.4	2.8	1.1	5.7
20	28.0	22.0	5.4	8.2	0.8	2.8	1.4	16.0
21	26.0	21.0	5.4	7.9	1.1	2.5	0.6	3.1
22	25.0	20.0	4.5	7.4	1.4	2.5	0.6	0.8
23	23.0	20.0	4.2	7.4	2.0	2.5	0.3	0.8
24	24.0	22.0	3.4	7.1	1.1	2.3	0.3	0.8
25	21.0	30.0	3.1	6.8	0.6	2.3	0.6	0.8
26	20.0	21.0	2.8	6.5	0.8	2.3	0.8	0.6
27	18.0	19.0	2.8	6.2	0.8	2.0	0.6	0.6
28	18.0	18.0	6.5	22.0	0.6	2.0	0.6	0.6
29	18.0	18.0	3.4	25.0	0.3	2.0	0.8	0.6
30	16.0	17.0	2.8	7.6	0.3	2.0	0.8	0.6
31			2.5	5.7	0.0	1.7		
Total	914.0	743.0	216.4	346.1	38.8	109.4	18.2	53.5

TABLE E-3. Daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1977 water year

Date	Mean daily streamflow (m^3/sec x 10^2)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.6	0.8	0.6	1.4	0.0	0.0	0.0	0.0
2	0.3	0.8	0.6	0.3	0.0	0.0	0.0	0.0
3	0.3	0.8	0.8	0.3	0.0	0.0	0.0	0.0
4	0.3	0.8	0.6	0.3	0.0	0.0	0.0	0.0
5	0.8	5.9	0.6	0.3	0.0	0.0	0.0	0.0
6	0.3	3.1	0.6	0.3	0.0	0.0	0.0	0.0
7	0.8	0.8	0.6	0.3	0.0	0.0	0.0	0.0
8	0.3	0.6	0.6	0.3	0.0	0.0	0.0	0.0
9	0.3	0.6	0.8	0.3	0.0	0.0	0.0	0.0
10	0.3	0.6	0.6	0.3	0.0	0.0	0.0	0.0
11	1.1	0.6	0.6	0.3	0.0	0.0	0.0	0.0
12	0.3	0.6	0.3	0.3	0.0	0.0	0.0	0.0
13	0.3	0.6	0.3	0.3	0.0	0.0	0.0	0.0
14	0.6	0.6	0.3	0.3	0.0	0.0	0.0	0.0
15	0.8	0.6	0.6	0.3	0.0	0.0	0.0	0.0
16	0.3	0.3	0.6	0.3	0.0	0.0	0.0	0.0
17	0.3	0.3	0.8	0.0	0.0	0.0	0.0	0.0
18	0.6	0.3	0.8	0.0	0.0	0.0	0.0	0.0
19	0.6	0.6	0.8	0.0	0.0	0.0	0.0	0.0
20	0.6	0.3	0.8	0.0	0.0	0.0	0.0	0.0
21	0.6	0.3	0.8	0.0	0.0	0.0	0.0	0.0
22	0.6	0.3	0.8	0.0	0.0	0.0	0.0	0.0
23	0.6	0.3	0.6	0.0	0.0	0.0	0.0	0.0
24	0.8	0.6	0.6	0.0	0.0	0.0	0.0	0.0
25	0.8	6.2	1.1	0.0	0.0	0.0	0.0	0.0
26	0.6	1.7	1.1	0.0	0.0	0.0	0.0	0.0
27	0.6	0.3	0.3	0.0	0.0	0.0	0.0	0.0
28	0.6	0.3	0.3	0.0	0.0	0.0	0.0	0.0
29	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0
30	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0
31	0.8	4.8			0.0	0.0	0.0	0.0
Total	17.2	35.0	17.9	5.9	0.0	0.0	0.0	0.0

TABLE E-3. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.0	0.0	0.6	2.3	3.7	2.3	0.3	2.3
2	0.0	0.0	1.1	2.5	5.1	12.0	0.6	2.3
3	0.0	0.0	2.0	2.8	3.7	11.0	0.3	2.0
4	0.0	0.0	3.1	2.8	6.2	12.0	0.8	2.5
5	0.0	0.0	4.8	2.8	4.2	14.0	1.7	16.0
6	0.0	0.0	5.4	2.8	3.1	7.1	0.8	7.1
7	0.0	0.0	4.0	2.5	2.5	6.2	0.6	2.3
8	0.0	0.0	3.4	2.5	2.5	5.9	0.3	1.7
9	0.0	0.0	2.8	2.5	2.3	5.9	0.3	1.7
10	0.0	2.0	3.7	2.3	2.0	5.7	0.3	1.7
11	0.0	17.0	6.5	2.3	1.7	5.4	0.3	1.4
12	0.0	10.0	7.4	7.1	2.5	5.1	0.3	1.4
13	0.0	2.8	1.4	6.2	4.2	4.8	0.3	1.4
14	0.0	1.4	0.8	2.3	2.0	4.5	0.3	1.4
15	0.0	1.4	1.4	2.0	2.0	4.5	0.3	1.1
16	0.0	1.4	1.4	2.0	1.4	4.2	0.3	1.1
17	0.0	1.4	1.4	1.7	1.1	4.0	0.3	1.1
18	0.0	1.4	2.0	8.5	1.1	4.0	0.3	1.1
19	0.0	1.4	1.1	6.8	1.1	3.7	0.3	1.1
20	0.0	1.4	1.4	6.8	3.4	14.0	0.3	0.8
21	0.0	1.4	1.4	3.1	3.1	18.0	0.8	1.1
22	0.0	1.1	1.1	1.7	1.7	11.0	2.5	3.4
23	0.0	1.4	1.1	1.7	1.1	4.0	0.8	2.0
24	0.0	11.0	1.1	1.7	0.8	3.1	0.3	0.8
25	0.0	9.6	1.4	1.4	0.6	3.1	0.3	0.8
26	0.0	4.0	2.0	1.4	0.6	2.8	0.3	0.8
27	0.3	2.5	3.1	1.4	0.6	2.8	0.0	0.6
28	0.3	2.3	4.5	2.0	0.6	2.8	0.3	0.6
29			5.4	14.0	0.6	2.5	0.3	0.6
30			2.8	7.4	0.6	2.5	0.3	0.8
31			1.7	2.5			0.3	0.6
Total	0.6	74.9	81.3	109.8	66.1	188.9	15.2	63.6

TABLE E-3. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.0	0.6	0.0	0.3	0.0	0.6	22.0	18.0
2	0.0	0.6	0.0	0.3	2.0	25.0	7.4	7.1
3	0.0	0.6	0.0	2.3	1.4	9.9	4.5	3.4
4	0.0	0.6	0.0	7.9	0.3	0.8	2.8	7.9
5	0.0	0.6	0.0	1.1	0.6	3.1	2.3	3.4
6	0.0	0.6	0.0	0.3	3.4	16.0	2.0	2.3
7	0.0	0.3	2.8	26.0	1.1	2.8	1.4	2.3
8	0.0	0.6	0.6	13.0	4.2	13.0	1.1	2.0
9	0.0	0.6	0.3	1.1	4.2	18.0	1.1	2.0
10	0.0	0.3	0.0	0.3	3.7	10.0	0.8	2.0
11	0.0	0.3	0.0	0.3	1.1	1.4	0.6	2.0
12	0.0	0.3	0.0	0.0	0.6	0.3	0.6	1.7
13	0.0	0.3	0.0	0.0	0.3	0.3	0.6	1.7
14	0.0	0.3	0.0	0.0	0.3	0.3	0.6	1.7
15	0.0	0.3	0.0	0.3	0.6	0.6	0.6	1.7
16	0.0	0.3	0.3	17.0	22.0	35.0	0.6	1.7
17	0.3	2.5	0.3	7.4	19.0	20.0	22.0	4.0
18	1.1	19.0	0.3	5.1	8.5	2.5	105.0	59.0
19	0.3	4.0	0.3	4.0	3.7	0.8	43.0	38.0
20	0.0	0.6	0.0	0.6	1.4	0.8	21.0	11.0
21	0.0	0.3	0.0	0.3	1.1	0.8	13.0	8.2
22	0.0	0.3	0.0	0.3	0.6	0.8	9.1	7.9
23	0.0	1.4	0.0	0.0	0.6	0.8	8.5	8.8
24	0.3	8.5	0.0	0.0	0.6	0.8	16.0	22.0
25	0.3	1.7	0.0	0.0	0.3	0.8	13.0	13.0
26	0.0	0.3	0.0	0.0	0.8	13.0	9.3	8.8
27	0.0	0.3	0.0	0.0	3.1	9.3	7.4	7.9
28	0.0	0.3	1.4	1.4	7.1	21.0	5.9	7.6
29	0.0	0.3	13.0	26.0	6.2	17.0	5.4	7.4
30	0.0	0.3	2.0	8.0	4.8	3.1	9.9	14.0
31			0.3	1.1	2.8	5.4		
Total	2.3	47.0	21.6	124.4	106.4	234.0	337.5	278.5

TABLE E-4. Daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1978 water year

	Mean daily streamflow (m^3/sec x 10^2)							
Date	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	17.0	16.0	34.0	45.0	7.4	17.0	11.0	24.0
2	14.0	15.0	28.0	31.0	7.1	18.0	9.9	24.0
3	11.0	14.0	25.0	31.0	6.2	18.0	9.6	23.0
4	8.8	14.0	23.0	30.0	4.2	18.0	9.6	22.0
5	7.4	13.0	21.0	28.0	2.5	18.0	9.3	21.0
6	6.2	13.0	20.0	27.0	3.4	17.0	12.0	20.0
7	15.0	16.0	19.0	26.0	5.4	17.0	17.0	20.0
8	34.0	38.0	18.0	25.0	4.8	16.0	16.0	19.0
9	23.0	18.0	18.0	24.0	5.9	16.0	15.0	18.0
10	17.0	13.0	16.0	23.0	6.8	15.0	15.0	17.0
11	15.0	12.0	14.0	22.0	6.5	15.0	14.0	17.0
12	13.0	11.0	13.0	22.0	5.1	14.0	13.0	16.0
13	11.0	11.0	13.0	21.0	6.2	14.0	13.0	16.0
14	10.0	11.0	13.0	20.0	9.3	13.0	13.0	15.0
15	9.1	10.0	13.0	19.0	12.0	13.0	13.0	14.0
16	7.9	9.6	13.0	18.0	18.0	13.0	13.0	14.0
17	7.6	9.3	11.0	18.0	71.0	93.0	13.0	13.0
18	7.1	8.8	11.0	17.0	110.0	112.0	12.0	13.0
19	6.5	8.5	11.0	16.0	74.0	50.0	12.0	13.0
20	5.9	8.2	12.0	18.0	45.0	39.0	11.0	12.0
21	5.9	7.9	10.0	24.0	34.0	35.0	11.0	12.0
22	6.8	12.0	9.9	19.0	31.0	34.0	9.9	11.0
23	31.0	29.0	9.6	18.0	28.0	33.0	9.3	11.0
24	79.0	59.0	8.8	17.0	26.0	32.0	8.8	11.0
25	60.0	35.0	7.9	17.0	24.0	31.0	8.5	9.9
26	40.0	23.0	7.4	16.0	22.0	30.0	8.2	9.6
27	28.0	22.0	7.4	16.0	20.0	29.0	7.9	9.3
28	24.0	21.0	7.4	15.0	17.0	28.0	7.4	9.1
29	21.0	21.0	7.6	15.0	15.0	27.0	7.1	8.5
30	20.0	20.0	7.6	14.0	13.0	26.0	6.8	8.2
31	28.0	40.0			11.0	25.0	6.5	7.9
Total	590.2	559.3	429.6	652.0	651.8	876.0	342.8	458.5

TABLE E-4. (Continued)

	Mean daily streamflow (m^3/sec x 10^2)							
Date	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	6.5	7.6	4.8	4.0	34.0	57.0	40.0	45.0
2	6.2	7.4	4.5	4.0	28.0	55.0	37.0	43.0
3	6.2	7.1	4.8	4.0	26.0	52.0	45.0	41.0
4	5.9	6.8	4.8	3.7	25.0	50.0	34.0	39.0
5	5.9	6.5	4.8	3.7	51.0	50.0	34.0	38.0
6	5.7	6.5	4.8	3.4	110.0	80.0	31.0	36.0
7	5.7	6.2	5.1	3.4	51.0	62.0	40.0	45.0
8	5.7	5.9	5.1	3.4	31.0	50.0	43.0	61.0
9	4.8	5.7	5.4	3.1	60.0	51.0	40.0	53.0
10	5.4	5.7	5.7	3.1	139.0	112.0	37.0	41.0
11	5.4	5.4	6.2	3.1	79.0	78.0	34.0	37.0
12	5.1	5.1	7.1	3.1	60.0	53.0	34.0	35.0
13	5.1	5.1	7.6	2.8	43.0	46.0	125.0	103.0
14	5.1	4.8	8.5	2.8	37.0	43.0	91.0	129.0
15	5.1	4.5	9.9	2.8	34.0	41.0	74.0	73.0
16	5.1	4.5	48.0	3.4	28.0	39.0	65.0	55.0
17	4.8	4.2	210.0	5.1	96.0	51.0	57.0	48.0
18	4.8	4.2	156.0	5.1	527.0	380.0	51.0	44.0
19	4.8	4.0	340.0	42.0	184.0	290.0	48.0	42.0
20	4.8	4.0	368.0	492.0	144.0	101.0	45.0	39.0
21	4.8	3.7	227.0	357.0	122.0	70.0	43.0	38.0
22	4.8	3.7	153.0	183.0	105.0	62.0	40.0	52.0
23	4.8	3.4	99.0	113.0	105.0	72.0	40.0	49.0
24	4.8	3.4	48.0	89.0	82.0	71.0	37.0	39.0
25	4.8	3.4	37.0	80.0	68.0	63.0	34.0	36.0
26	4.8	4.5	37.0	75.0	60.0	58.0	34.0	33.0
27	4.8	4.2	45.0	71.0	51.0	55.0	74.0	34.0
28	4.8	4.2	48.0	68.0	51.0	52.0	65.0	59.0
29			43.0	65.0	48.0	50.0	45.0	43.0
30			40.0	63.0	45.0	47.0	40.0	34.0
31			43.0	60.0			37.0	31.0
Total	146.5	141.7	2031.1	1822.0	2524.0	2341.0	1494.0	1495.0

TABLE E-4. (Continued)

Date	Mean daily streamflow (m^3/sec x 10^2)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	68.0	31.0	23.0	22.0	6.5	12.0	5.1	11.0
2	31.0	31.0	21.0	21.0	5.9	11.0	4.5	11.0
3	28.0	27.0	20.0	20.0	5.4	11.0	4.2	9.9
4	26.0	26.0	19.0	19.0	5.1	10.0	3.7	9.3
5	22.0	24.0	17.0	18.0	4.8	9.6	3.4	9.1
6	20.0	23.0	17.0	22.0	4.5	9.1	3.1	8.5
7	19.0	22.0	17.0	37.0	4.2	8.5	3.1	7.9
8	16.0	21.0	15.0	29.0	4.0	8.2	2.8	7.6
9	14.0	20.0	16.0	25.0	3.7	7.6	3.1	7.4
10	12.0	19.0	14.0	22.0	3.4	7.1	2.5	6.8
11	11.0	18.0	13.0	18.0	3.4	6.8	2.5	6.5
12	9.3	17.0	13.0	18.0	3.1	6.5	2.8	6.2
13	6.2	16.0	13.0	17.0	2.8	6.2	12.0	35.0
14	5.4	16.0	11.0	16.0	2.5	5.7	77.0	109.0
15	51.0	43.0	11.0	16.0	2.5	5.4	25.0	69.0
16	23.0	38.0	9.9	15.0	2.3	5.1	16.0	31.0
17	12.0	19.0	9.9	14.0	2.3	4.8	15.0	34.0
18	7.9	17.0	12.0	19.0	2.3	4.5	25.0	52.0
19	5.1	15.0	28.0	54.0	2.0	4.2	34.0	48.0
20	113.0	61.0	18.0	39.0	1.7	4.2	150.0	119.0
21	54.0	65.0	16.0	23.0	2.5	6.2	108.0	124.0
22	43.0	32.0	15.0	22.0	3.4	25.0	71.0	88.0
23	37.0	27.0	13.0	19.0	2.3	8.8	57.0	80.0
24	34.0	25.0	12.0	17.0	2.0	4.2	45.0	76.0
25	31.0	24.0	11.0	16.0	2.0	3.7	40.0	73.0
26	28.0	23.0	11.0	16.1	10.0	7.6	34.0	69.0
27	25.0	22.0	9.1	16.0	68.0	93.0	31.0	67.0
28	37.0	23.0	7.9	14.0	22.0	54.0	27.0	66.0
29	31.0	37.0	7.9	14.0	11.0	17.0	26.0	63.0
30	24.0	27.0	7.4	13.0	7.6	13.0	26.0	61.0
31			7.1	13.0	5.9	12.0		
Total	843.9	809.0	435.2	644.0	209.1	392.0	859.8	1365.2

APPENDIX F. SEDIMENT SIMULATION RESULTS FOR FOUR MILE CREEK WATERSHED NEAR TRAER, IOWA

TABLE F-1. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

Date	Daily suspended sediment load (Tons*)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.8	0.5	2.5	2.0	0.7	0.8	0.3	0.3
2	0.9	0.6	1.9	1.6	0.7	0.6	0.3	0.3
3	0.9	0.6	1.4	1.3	0.6	0.5	0.3	0.3
4	0.8	0.5	1.2	1.4	0.6	0.5	0.3	0.3
5	0.8	0.5	0.9	1.2	0.6	0.5	0.3	0.3
6	0.9	0.6	0.9	1.2	0.6	0.5	0.3	0.3
7	0.9	0.6	0.8	1.1	0.5	0.5	0.3	0.2
8	0.9	0.6	0.8	1.1	0.6	0.6	0.3	0.2
9	0.8	0.5	0.8	1.1	0.6	0.6	0.3	0.2
10	0.8	0.5	0.8	1.1	0.5	0.5	0.3	0.2
11	0.8	0.5	0.7	1.1	0.5	0.5	0.3	0.3
12	1.3	0.7	0.7	1.0	0.5	0.5	0.3	0.3
13	2.8	1.9	0.6	0.9	0.5	0.5	0.3	0.3
14	1.6	1.1	0.9	0.8	0.5	0.5	0.4	0.3
15	1.2	0.9	1.0	0.9	0.5	0.5	0.4	0.3
16	1.3	1.0	1.0	0.9	0.5	0.4	0.4	0.3
17	1.1	0.9	1.0	0.9	0.5	0.4	0.4	0.2
18	1.1	0.8	0.9	0.9	0.5	0.4	0.4	0.3
19	1.7	1.8	0.7	0.7	0.5	0.4	0.4	0.3
20	1.7	2.0	0.9	0.9	0.5	0.4	0.4	0.3
21	1.6	1.4	0.8	0.9	0.5	0.4	0.4	0.4
22	1.4	1.1	0.8	0.9	0.4	0.4	0.4	0.3
23	1.3	1.0	0.8	0.9	0.4	0.4	0.4	0.3
24	1.3	1.0	0.7	0.8	0.4	0.3	0.4	0.3
25	1.2	0.9	0.7	0.8	0.4	0.3	0.3	0.3
26	1.4	0.8	0.7	0.8	0.4	0.3	0.3	0.3
27	1.6	0.8	0.7	0.8	0.4	0.3	0.3	0.3
28	1.6	0.8	0.6	0.7	0.4	0.3	0.3	0.3
29	1.5	0.8	0.6	0.7	0.3	0.3	0.4	0.3
30	1.6	1.0	0.7	0.8	0.3	0.3	0.4	0.3
31	3.3	2.0			0.3	0.3	0.5	0.4
Total	40.9	28.7	27.5	30.2	15.2	13.7	10.8	8.9

*Tons indicate metric tons.

TABLE F-1. (Continued)

	Daily suspended sediment load (Tons)							
Date	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.5	0.4	1.6	99.6	1.9	3.0	0.5	4.3
2	0.6	0.4	842.8	673.0	1.7	2.8	0.3	1.8
3	0.8	0.4	1240.0	2188.0	1.5	2.5	0.3	1.4
4	0.7	0.4	36.0	356.8	1.3	2.3	0.3	1.4
5	0.6	0.5	9.2	36.8	1.0	2.4	0.3	1.2
6	0.6	0.4	5.7	7.7	1.1	2.3	0.3	1.2
7	0.6	0.5	4.2	4.3	1.0	2.2	0.3	1.2
8	0.5	0.5	2.7	3.2	1.0	2.2	0.3	1.1
9	0.4	0.6	1.8	2.8	1.0	2.0	0.4	1.1
10	0.4	0.6	2.3	2.7	0.9	2.0	0.5	1.2
11	0.3	0.5	2.0	2.5	0.8	1.8	0.4	1.1
12	0.4	0.4	2.1	2.3	0.8	2.0	0.6	4.4
13	0.3	0.4	2.9	2.2	0.9	3.2	22.0	8.2
14	0.3	0.4	3.3	2.1	0.8	2.3	827.2	541.1
15	0.3	0.3	3.7	1.9	0.8	1.9	46.0	392.9
16	0.4	0.4	3.6	1.9	0.8	1.9	21.0	44.5
17	0.6	0.5	3.2	1.8	0.7	1.7	11.0	10.5
18	1.0	0.8	2.8	1.8	0.7	1.7	8.4	6.3
19	1.4	1.6	2.5	1.9	0.7	2.3	6.4	5.0
20	2.1	4.5	2.2	2.2	0.6	6.2	4.9	4.1
21	3.8	14.6	2.2	2.2	1.3	3.5	3.7	3.6
22	43.4	102.9	3.0	2.9	1.2	2.6	2.7	3.2
23	55.4	382.1	2.9	2.8	1.0	2.1	752.5	76.2
24	26.0	138.8	2.6	2.4	0.9	2.0	308.5	62.7
25	9.0	82.8	4.5	4.1	0.9	1.8	47.0	13.2
26	4.1	20.3	12.0	7.0	0.8	1.7	19.0	5.8
27	2.4	13.4	6.3	4.5	0.9	1.7	7.2	4.6
28	15.1	397.6	6.4	3.2	0.8	1.6	3.6	4.1
29			4.6	3.6	0.6	2.1	2.2	3.7
30			2.7	3.2	0.5	11.8	1.8	3.7
31			2.1	3.0			1.4	3.2
Total	172.0	1167.0	2223.9	3434.4	29.1	79.6	2101.0	1218.0

TABLE F-1. (Continued)

Date	Daily suspended sediment load (Tons)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	1.3	3.1	0.5	0.6	0.1	0.1	0.3	0.2
2	1.4	3.3	0.5	0.6	0.2	0.1	0.2	0.1
3	1.1	2.8	0.5	1.6	0.1	0.0	0.3	0.2
4	1.0	2.5	0.4	1.3	0.2	0.1	0.3	0.2
5	1.0	2.5	0.4	0.5	88.0	18.7	0.2	0.1
6	0.8	2.2	0.4	0.5	3.9	14.2	0.2	0.2
7	0.8	2.0	0.4	0.5	0.8	2.2	0.2	0.2
8	0.7	1.8	0.3	0.4	0.6	1.0	0.2	0.1
9	0.6	1.7	0.3	0.4	0.5	0.8	0.4	0.5
10	0.6	1.7	0.3	0.4	0.4	0.6	1.7	5.4
11	0.5	1.6	0.2	0.2	0.3	0.5	0.3	1.4
12	0.5	1.7	0.2	0.3	0.3	0.4	0.2	0.2
13	0.4	1.9	0.2	0.3	0.2	0.3	0.2	0.1
14	0.4	7.1	0.4	0.7	0.2	0.3	1.3	0.4
15	0.3	32.8	0.4	2.4	0.1	0.2	14.0	13.7
16	0.3	7.0	0.3	1.0	0.1	0.2	3.9	10.8
17	0.3	1.9	0.3	0.4	0.1	0.2	1.9	1.9
18	0.3	2.0	1.2	2.5	8.1	5.1	1.1	0.9
19	0.3	1.3	0.5	5.3	1.5	3.8	0.5	0.7
20	4.5	1.6	0.3	0.9	0.5	0.9	0.4	0.5
21	28.0	4.1	0.1	0.3	0.3	0.5	0.4	0.5
22	2.5	2.1	0.1	0.2	0.3	0.4	0.9	0.4
23	1.3	1.6	0.1	0.2	0.2	0.4	1.4	0.6
24	1.0	1.4	0.1	0.2	0.2	0.3	63.5	12.0
25	0.7	1.2	0.1	0.2	0.1	0.3	33.2	9.2
26	0.6	1.2	0.1	0.2	0.2	0.3	40.7	39.9
27	0.5	1.0	0.4	0.2	0.4	0.2	6.0	11.2
28	0.5	0.9	0.3	0.2	0.3	0.2	2.5	4.1
29	0.5	0.8	0.3	0.3	0.2	0.1	1.9	2.9
30	0.5	0.7	0.2	0.2	0.2	0.1	1.3	2.2
31			0.2	0.2	0.2	0.1		
Total	53.2	97.5	10.0	23.2	108.8	52.6	179.6	120.8

TABLE F-2. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1976 water year

Date	Daily suspended sediment load (Tons)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.3	0.2	0.4	0.2	1.3	2.6	0.2	0.3
2	0.3	0.2	0.4	0.7	0.9	0.9	0.2	0.2
3	0.3	0.2	0.4	1.6	0.8	0.7	0.4	0.2
4	0.3	0.2	0.4	0.7	0.8	0.6	0.1	0.1
5	0.3	0.2	0.4	0.3	0.8	0.7	0.1	0.2
6	0.3	0.2	0.4	0.2	0.6	0.4	0.2	0.1
7	0.2	0.2	0.4	0.2	0.7	0.5	0.2	0.1
8	0.3	0.2	0.4	0.2	0.6	0.5	0.1	0.1
9	0.3	0.2	0.5	0.4	0.6	0.4	0.2	0.1
10	0.3	0.2	0.7	1.2	0.6	0.4	0.2	0.2
11	0.3	0.2	0.4	0.5	0.5	0.4	0.2	0.2
12	0.3	0.2	0.4	0.2	0.5	0.3	0.0	0.2
13	0.3	0.2	0.4	0.2	0.6	0.4	0.0	0.2
14	0.3	0.2	0.4	0.2	0.8	2.0	0.2	0.1
15	0.3	0.2	0.4	0.2	0.6	3.4	0.2	0.1
16	0.3	0.2	0.4	0.2	0.5	0.7	0.2	0.1
17	0.3	0.2	0.4	0.2	0.3	0.2	0.1	0.1
18	0.3	0.2	0.4	0.2	0.2	0.1	0.1	0.1
19	0.3	0.2	0.3	0.2	0.3	0.2	0.1	0.1
20	0.3	0.2	0.5	0.6	0.5	0.4	0.2	0.1
21	0.3	0.2	0.4	0.8	0.5	0.4	0.3	0.1
22	0.3	0.2	0.3	0.2	0.5	0.3	0.3	0.1
23	0.3	0.2	0.3	0.2	0.5	0.3	0.2	0.1
24	0.3	0.2	0.3	0.2	0.4	0.3	0.3	0.1
25	0.3	0.2	0.3	0.2	0.4	0.3	0.3	0.2
26	0.3	0.2	0.3	0.2	0.4	0.3	0.2	0.1
27	0.3	0.2	0.3	0.2	0.4	0.3	0.0	0.0
28	0.3	0.2	0.4	0.2	0.4	0.2	0.1	0.1
29	0.3	0.2	1.8	1.8	0.3	0.2	0.0	0.1
30	0.3	0.2	3.0	9.5	0.3	0.2	0.0	0.2
31	0.3	0.2			0.3	0.2	0.2	0.1
Total	9.2	6.2	15.7	21.9	16.9	18.8	5.1	4.1

TABLE F-2. (Continued)

Date	Daily suspended sediment load (Tons)							
	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.2	0.1	1.6	3.5	2.6	3.2	7.6	9.2
2	0.1	0.1	0.9	1.1	2.3	2.5	9.5	11.0
3	0.1	0.1	0.7	0.4	1.7	2.1	5.1	8.8
4	0.3	0.1	1.7	1.5	1.2	1.8	4.4	7.1
5	0.3	0.3	2.1	7.5	1.2	1.6	3.2	6.5
6	0.2	0.5	1.4	2.0	0.5	1.4	1.7	5.5
7	0.1	0.3	3.5	1.8	0.2	1.2	2.2	5.0
8	0.3	0.3	5.3	1.7	0.8	1.1	3.4	5.0
9	0.2	0.2	80.4	9.2	1.0	1.0	2.9	4.5
10	0.1	0.2	17.9	6.5	0.9	1.0	2.0	4.5
11	0.0	0.2	16.1	66.8	0.7	0.9	3.0	4.1
12	0.1	0.2	971.7	945.1	0.7	0.9	3.8	4.1
13	0.2	0.2	34.1	175.5	0.9	0.9	1.6	4.2
14	0.1	0.1	10.7	19.4	0.8	1.0	2.2	3.8
15	0.5	0.2	1.8	4.9	0.8	14.3	2.8	3.7
16	0.2	0.2	5.8	3.3	1.1	8.5	4.8	4.8
17	0.2	0.2	3.7	2.5	53.0	10.0	1.9	6.4
18	0.2	0.1	3.1	2.5	633.1	133.1	2.8	5.2
19	0.3	0.1	3.0	2.5	58.3	104.9	2.7	4.1
20	0.5	0.1	5.0	3.0	59.5	29.4	2.6	3.6
21	0.3	0.1	3.6	2.6	116.4	43.6	2.1	3.2
22	0.1	0.2	2.2	2.2	54.4	26.6	2.7	3.3
23	0.1	0.2	1.7	2.1	482.6	208.3	2.8	3.9
24	0.2	0.3	1.9	1.9	263.1	613.8	0.6	3.7
25	1.9	0.8	1.7	1.7	53.0	190.3	1.1	3.1
26	48.1	95.5	1.6	1.7	25.1	36.5	0.4	2.8
27	658.6	1062.2	1.3	1.5	21.4	18.9	0.3	2.5
28	120.4	247.8	1.1	1.4	11.2	14.4	0.3	2.5
29	11.8	26.1	1.5	2.0	11.8	12.0	162.1	13.0
30			9.0	7.9	5.9	10.3	19.2	12.6
31			3.1	5.2			4.0	5.0
Total	845.7	1437.0	1199.2	1290.9	1866.2	1495.5	265.8	166.7

TABLE F-2. (Continued)

Date	Daily suspended sediment load (Tons)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	2.9	3.7	1.2	1.4	0.1	0.1	0.1	0.0
2	2.8	3.2	0.3	1.3	0.1	0.1	0.2	0.0
3	1.6	2.9	0.8	1.2	0.2	0.1	0.1	0.0
4	1.5	2.6	1.9	1.1	0.2	0.1	0.1	0.0
5	0.8	2.4	1.0	1.0	0.1	0.1	0.1	0.0
6	0.7	2.3	0.9	0.9	0.0	0.1	0.1	0.0
7	1.1	2.1	0.9	0.9	0.3	0.1	0.1	0.0
8	1.4	2.0	0.4	0.8	0.1	0.1	0.0	0.0
9	0.7	1.2	0.4	0.7	0.0	0.1	0.1	0.0
10	1.0	2.1	0.3	0.6	0.0	0.0	0.0	0.0
11	0.7	2.8	0.2	0.6	0.0	0.2	0.0	0.0
12	0.9	2.3	0.7	0.5	0.1	0.3	0.0	0.0
13	57.9	18.8	0.5	0.5	0.1	0.2	0.0	0.0
14	467.4	111.2	0.4	0.4	0.1	0.1	0.0	0.0
15	13.0	37.9	0.3	0.4	0.1	0.1	0.0	0.0
16	7.0	8.6	0.3	0.4	0.1	0.0	0.1	0.0
17	5.4	4.7	0.4	0.3	0.1	0.1	0.0	0.0
18	7.3	4.4	0.5	0.3	0.0	0.1	0.0	0.0
19	3.8	3.6	0.1	0.3	0.1	0.1	0.2	0.1
20	2.4	3.1	0.3	0.4	0.1	0.0	0.2	0.3
21	1.2	2.8	0.4	0.4	0.3	0.0	0.1	0.1
22	0.5	2.7	0.4	0.3	0.2	0.1	0.1	0.0
23	0.8	2.6	0.3	0.3	0.2	0.1	0.0	0.0
24	2.7	3.0	0.3	0.2	0.1	0.0	0.1	0.0
25	1.5	3.2	0.1	0.2	0.1	0.0	0.0	0.0
26	0.7	2.1	0.3	0.2	0.0	0.0	0.1	0.0
27	0.4	1.8	0.1	0.1	0.0	0.0	0.1	0.0
28	0.9	1.7	0.7	25.8	0.0	0.0	0.0	0.0
29	0.8	1.8	0.2	33.2	0.1	0.0	0.2	0.0
30	1.0	1.6	0.1	3.4	0.0	0.0	0.1	0.0
31			0.1	0.2	0.0	0.0		
Total	590.8	245.2	14.8	78.3	2.9	2.3	2.2	0.5

TABLE F-3. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1977 water year

Date	Daily suspended sediment load (Tons)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
20	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
21	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.1	0.1			0.0	0.0	0.0	0.0
Total	1.1	0.3	0.8	0.0	0.0	0.0	0.0	0.0

TABLE F-3. (Continued)

Date	Daily suspended sediment load (Tons)							
	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0
2	0.0	0.0	0.0	0.0	0.8	1.2	0.0	0.0
3	0.0	0.0	0.0	0.1	0.4	0.8	0.0	0.1
4	0.0	0.0	0.2	0.2	0.4	0.7	0.2	0.3
5	0.0	0.0	0.6	0.3	0.7	0.6	0.3	1.7
6	0.0	0.0	0.3	0.4	0.3	0.2	0.2	0.8
7	0.0	0.0	0.2	0.2	0.2	0.1	0.0	0.1
8	0.0	0.0	0.3	0.2	0.2	0.1	0.0	0.0
9	0.0	0.0	0.2	0.1	0.2	0.1	0.0	0.0
10	0.0	0.0	0.3	0.2	0.2	0.1	0.0	0.0
11	0.0	0.0	2.7	0.5	0.1	0.1	0.0	0.0
12	0.0	0.0	4.2	1.1	0.1	0.1	0.0	0.0
13	0.0	0.0	0.3	0.5	0.1	0.3	0.0	0.0
14	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0
15	0.0	0.0	0.1	0.1	0.2	0.2	0.0	0.0
16	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.2
17	0.0	0.0	0.2	0.1	0.0	0.1	0.0	0.0
18	0.0	0.0	0.3	0.9	0.1	0.2	0.0	0.0
19	0.0	0.0	0.1	0.7	0.1	0.2	0.0	0.0
20	0.0	0.0	0.2	0.4	1.8	3.4	0.0	0.1
21	0.0	0.0	0.1	0.2	0.2	2.2	0.1	0.2
22	0.0	0.0	0.1	0.0	0.1	1.0	0.9	0.9
23	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.2
24	0.2	0.0	0.1	0.0	0.1	0.0	0.0	0.0
25	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
26	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0
27	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0
28	0.0	0.0	0.1	0.5	0.1	0.4	0.0	0.0
29			0.6	1.4	0.1	0.2	0.0	0.0
30			0.2	0.6	0.0	0.0	0.0	0.5
31			0.1	0.1			0.0	0.4
Total	0.2	0.0	12.4	9.4	7.4	12.8	1.8	5.5

TABLE F-3. (Continued)

	Daily suspended sediment load (Tons)							
Date	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.0	0.0	0.0	0.0	0.0	1.3	3.7	2.5
2	0.0	0.0	0.0	0.0	0.4	61.8	0.5	0.7
3	0.0	0.0	0.0	0.2	0.5	24.7	0.4	0.3
4	0.0	0.0	0.0	0.5	0.1	2.1	1.1	0.2
5	0.0	0.0	0.0	0.1	0.1	4.6	0.3	0.1
6	0.0	0.0	0.6	0.4	0.3	22.5	0.0	0.1
7	0.0	0.0	0.2	54.3	0.1	3.8	0.7	0.1
8	0.0	0.4	0.0	25.3	1.5	0.8	0.4	0.0
9	0.0	0.3	0.0	2.2	1.2	0.6	0.1	0.1
10	0.0	0.0	0.0	0.0	0.5	0.4	0.1	0.0
11	0.0	0.2	0.0	0.2	0.0	0.1	0.2	0.0
12	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
15	0.0	0.0	0.0	0.5	0.2	0.1	0.2	0.0
16	0.0	0.0	0.0	25.7	12.9	45.3	0.2	0.0
17	0.0	3.1	0.0	10.3	5.8	29.2	12.0	3.4
18	0.1	24.0	0.0	1.0	1.1	3.1	29.0	136.3
19	0.0	4.8	0.0	0.1	0.1	0.4	8.8	62.4
20	0.0	0.3	0.0	0.0	0.1	0.1	2.1	7.2
21	0.0	0.0	0.0	0.0	0.0	0.1	1.8	1.4
22	0.0	0.0	0.0	0.1	0.0	0.0	1.1	0.7
23	0.0	0.3	0.0	0.0	0.0	0.0	0.9	0.8
24	0.0	0.7	0.0	0.0	0.0	0.0	0.6	1.7
25	0.0	0.1	0.0	0.0	0.0	0.0	1.4	1.2
26	0.0	0.0	0.0	0.0	0.2	3.2	1.3	0.7
27	0.0	0.0	0.0	0.0	0.4	2.2	0.6	0.5
28	0.0	0.0	1.0	0.9	1.3	0.9	0.5	0.4
29	0.0	0.0	6.3	23.1	0.9	0.7	0.6	0.4
30	0.0	0.0	0.5	6.7	0.5	0.3	0.9	0.9
31			0.3	0.6	0.4	0.2		
Total	0.1	34.3	8.9	152.2	28.6	208.5	69.9	222.1

TABLE F-4. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1978 water year

Date	Daily suspended sediment load (Tons)							
	October		November		December		January	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.7	1.6	2.0	4.8	0.6	0.5	1.6	0.9
2	0.8	1.2	1.7	3.2	0.5	0.5	1.5	0.8
3	0.5	0.9	1.4	2.8	0.4	0.4	1.5	0.8
4	0.6	0.7	1.2	2.4	0.2	0.3	1.5	0.7
5	0.5	0.5	1.2	2.2	0.1	0.1	1.3	0.7
6	0.4	0.4	1.4	2.1	0.2	0.2	1.3	1.0
7	0.3	1.4	0.6	1.9	0.3	0.4	1.9	1.6
8	5.1	4.4	0.5	1.7	0.3	0.3	1.9	1.6
9	1.1	2.5	0.4	1.8	0.4	0.4	1.9	1.4
10	0.6	1.6	1.0	1.5	0.4	0.5	1.9	1.3
11	0.7	1.4	0.6	1.3	0.4	0.5	1.8	1.2
12	1.1	1.1	0.6	1.1	0.3	0.3	1.6	1.2
13	0.8	0.9	0.5	1.2	0.5	0.4	1.9	1.1
14	1.3	0.8	0.9	1.2	0.6	0.7	2.2	1.1
15	0.3	0.7	0.9	1.2	1.2	1.0	2.3	1.1
16	0.4	0.6	0.7	1.1	2.3	1.8	2.5	1.1
17	0.5	0.6	0.7	0.9	8.3	38.4	2.4	1.1
18	0.6	0.5	0.5	0.9	11.7	60.1	2.2	1.0
19	0.7	0.5	0.9	0.9	7.3	15.7	1.9	1.0
20	0.5	0.4	0.8	1.1	4.2	6.4	1.6	0.9
21	0.6	0.4	0.0	1.2	2.9	4.1	1.2	0.9
22	0.6	0.5	0.8	0.9	2.4	3.6	0.9	0.8
23	4.0	3.7	0.8	0.8	1.8	3.2	0.8	0.7
24	5.8	12.9	1.0	0.7	2.4	2.9	0.7	0.7
25	3.2	8.7	0.9	0.6	2.5	2.6	0.8	0.6
26	2.9	5.0	1.2	0.5	2.3	2.2	0.8	0.6
27	2.9	3.2	1.1	0.5	2.3	2.0	0.8	0.6
28	1.8	2.6	1.1	0.5	2.3	1.6	0.7	0.5
29	1.6	2.2	1.0	0.6	2.1	1.4	0.8	0.5
30	1.8	2.1	0.7	0.6	1.9	1.1	0.8	0.5
31	1.0	3.7			1.2	0.9	0.9	0.5
Total	43.7	67.7	27.1	42.2	64.3	154.5	45.9	28.5

TABLE E-4. (Continued)

Date	Daily suspended sediment load (Tons)							
	February		March		April		May	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	0.8	0.5	0.4	0.3	1.4	4.1	3.4	5.0
2	0.8	0.4	0.4	0.3	1.6	3.2	4.1	4.5
3	0.6	0.4	0.4	0.3	5.2	2.9	2.2	6.0
4	0.4	0.4	0.4	0.3	2.2	2.7	4.1	4.1
5	0.6	0.4	0.4	0.3	29.5	7.3	1.1	4.1
6	0.8	0.8	0.3	0.3	94.2	24.5	1.0	3.6
7	0.8	0.4	0.0	0.3	8.5	8.5	2.1	5.5
8	0.8	0.4	0.4	0.3	4.2	3.8	2.8	7.9
9	0.7	0.3	0.3	0.4	50.5	13.0	3.1	6.5
10	0.7	0.4	0.3	0.4	137.5	139.9	1.0	4.7
11	0.6	0.4	0.3	0.4	8.5	50.8	4.1	4.1
12	0.5	0.3	0.3	0.5	14.6	12.0	1.4	4.1
13	0.5	0.3	0.3	0.6	4.8	5.8	20.2	35.4
14	0.4	0.3	0.4	0.6	6.0	4.6	11.8	28.1
15	0.5	0.3	0.4	0.8	6.5	4.1	12.8	12.7
16	0.5	0.3	2.0	6.5	6.3	3.2	9.3	9.8
17	0.4	0.3	87.7	45.9	113.7	28.9	9.4	8.1
18	0.3	0.3	19.2	31.0	1321.5	660.4	8.6	7.0
19	0.4	0.3	122.9	101.1	64.6	327.1	7.4	6.5
20	0.5	0.3	201.6	198.0	25.5	53.7	7.3	6.0
21	0.6	0.3	197.9	116.8	15.6	24.6	5.4	5.5
22	0.7	0.3	78.5	37.4	11.8	18.5	6.3	8.8
23	0.6	0.3	16.0	17.6	12.5	18.6	4.1	7.2
24	0.6	0.3	5.2	6.6	7.5	13.4	1.8	4.7
25	0.6	0.3	4.3	4.6	7.7	10.3	1.1	4.1
26	0.6	9.3	3.9	4.5	8.2	8.6	0.1	4.1
27	0.5	0.3	1.0	6.0	7.9	7.0	2.2	13.0
28	0.4	0.3	0.5	6.5	7.7	7.0	3.9	31.2
29			2.3	5.5	7.2	6.5	4.1	11.6
30			2.8	5.0	6.1	6.0	2.1	5.5
31			2.0	5.5			1.9	4.6
Total	16.2	9.5	753.2	604.6	1999.0	1481.0	150.2	274.0

TABLE F-4. (Continued)

Date	Daily suspended sediment load (Tons)							
	June		July		August		September	
	Rec	Sim	Rec	Sim	Rec	Sim	Rec	Sim
1	46.0	10.4	2.5	2.5	1.4	0.5	1.0	0.3
2	4.5	3.9	2.0	2.3	1.1	0.4	0.6	0.3
3	4.3	3.2	1.6	2.0	1.2	0.4	0.3	0.3
4	4.3	2.8	1.8	1.8	0.9	0.3	0.3	0.2
5	3.4	2.3	1.9	1.6	1.5	0.3	0.3	0.2
6	2.6	2.1	2.6	1.9	0.9	0.3	0.4	0.2
7	3.1	1.9	2.9	3.9	0.5	0.3	0.4	0.2
8	2.0	1.6	1.6	3.2	0.1	0.2	0.4	0.1
9	2.1	1.3	2.0	1.7	0.2	0.2	0.6	0.2
10	1.7	1.0	4.6	1.3	0.2	0.2	0.5	0.1
11	1.2	0.9	1.4	1.1	0.2	0.2	0.4	0.1
12	1.8	0.7	1.3	1.2	0.2	0.2	0.9	0.3
13	0.9	0.4	2.2	1.2	0.2	0.1	2.9	10.0
14	0.3	0.5	0.3	0.9	0.2	0.1	44.1	87.2
15	80.2	27.3	1.7	0.9	0.3	0.1	44.2	55.7
16	3.6	23.7	1.5	0.8	0.4	0.1	1.6	6.3
17	1.9	3.0	1.6	0.9	0.4	0.2	1.1	1.9
18	1.0	0.8	2.0	1.2	0.4	0.1	2.3	2.9
19	0.6	0.3	5.8	8.6	0.4	0.1	2.2	4.4
20	286.8	30.6	3.2	5.2	0.3	0.1	72.0	38.9
21	14.6	18.1	2.0	1.8	0.3	0.2	24.7	22.6
22	4.6	6.5	4.1	1.4	0.3	0.6	11.1	11.2
23	3.8	4.6	1.9	1.2	0.3	0.2	7.9	8.1
24	3.2	4.1	1.2	1.0	0.8	0.1	5.6	6.0
25	2.9	3.6	1.2	0.9	0.5	0.1	5.5	5.0
26	2.3	3.1	2.6	0.9	5.7	2.1	4.3	4.1
27	4.4	2.7	2.6	0.8	27.4	264.8	4.4	3.6
28	14.6	4.8	1.5	0.6	4.0	136.3	3.5	3.0
29	5.8	7.3	0.9	0.6	1.5	12.7	3.6	2.9
30	3.0	3.6	0.8	0.5	0.8	1.4	3.7	2.8
31			0.2	0.5	0.6	0.4		
Total	511.5	177.1	63.5	54.4	53.2	423.3	250.8	279.1