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KINEROS, A Kinematic Runoff and Erosion Model

Documentation and User Manual

ABSTRACT

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The kinematic runoff and erosion model KINEROS is an event-oriented, physically based model describing the processes of interception, infiltration, surface runoff, and erosion from small agricultural and urban watersheds. The watershed is represented by a cascade of planes and channels; and the partial differential equations describing overland flow, channel flow and erosion, and sediment transport are solved by finite difference techniques. Spatial variability of rainfall and infiltration, runoff, and erosion parameters can be accommodated. KINEROS may be used to determine the effects of various artificial features such as urban developments, small detention reservoirs, or lined channels on flood hydrographs and sediment yield.

KEYWORDS: Erosion, infiltration, pond, reservoir, sedimentation, simulation, surface runoff

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PREFACE

This manual is designed to provide a brief description of the components of the kinematic runoff and erosion model KINEROS. It also describes the program structure and the data set required to represent a catchment and provides guidance for estimating model parameters. The FORTRAN program for KINEROS is included in the files KINHYD1.FOR, KINSED1.FOR, and KINTEM1.FOR on the enclosed diskette. Input and output files for the examples are also on the diskette. Instructions and any revisions are included in the file README.DOC.

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SYMBOLS

A = Cross sectional area of water in a channel $[L^2]$
a = Fitting parameter in infiltration recovery equation
B = $G(\theta_s - \theta_i)$ $[L]$
b = Trapezoidal channel dimension $[L]$
BW = Channel bottom width $[L]$
C = Chezy friction coefficient $[L^{1/2}T^{-1}]$
C_1 = Weir coefficient
c_2 = Weir equation exponent
C_D = Drag coefficient
c_f = Coefficient in splash erosion equation
c_g = Hydraulic erosion transfer rate coefficient $[T^{-1}]$
c_h = Damping coefficient for splash erosion
C_{mx} = Equilibrium sediment concentration
c_o = Parameter in Bagnold/Kilinc sediment transport equation
C_s = Sediment concentration
c_s = Parameter in tractive force equation
D = Diameter of circular conduit $[L]$
d = Particle diameter $[L]$
d_r = Raindrop diameter $[L]$
$D50$ = Median particle diameter

e = Rate of erosion of soil bed $[L^2T^{-1}]$

F = Amount of rain infiltrated $[L]$

f' = Infiltration rate $[LT^{-1}]$

$\underline{f}$ = Denotes functional relationship

f_c = Infiltration capacity $[LT^{-1}]$

f_{cl} = Fractional clay content

f_D = Darcy-Weisbach friction factor

F_p = Ponding depth $[L]$

G = Effective net capillary drive $[L]$

g = Acceleration of gravity $[LT^{-2}]$

g_h = Hydraulic erosion rate $[L^2T^{-1}]$

g_s = Splash erosion rate $[L^2T^{-1}]$

h = Depth of surface runoff $[L]$

h_D = Hydraulic depth of circular conduit $[L]$

h_r = Elevation of reservoir water surface $[L]$

h_z = Reservoir outflow structure notch elevation $[L]$

I = Interception depth $[L]$

k = Dimensionless parameter in laminar flow equation

$k(h)$ = Function describing reduction in splash erosion as water depth, h, increases

k_o = Dimensionless parameter without raindrop impact effect

K_s = Effective saturated hydraulic conductivity $[LT^{-1}]$

K_{usle} = Soil erodibility factor in USLE

$K(\psi)$ = Hydraulic conductivity function $[LT^{-1}]$

L = Length of plane or channel $[L]$

m = Exponent in relationship between runoff rate and storage per unit area

n = Manning's n

p = Channel wetted perimeter $[L]$

p_e = Effective channel wetted perimeter for infiltration $[L]$

P_r = Volume of rock in unit volume of soil

Q = Surface runoff discharge per unit width $[L^2T^{-1}]$ or channel discharge $[L^3T^{-1}]$

q = Lateral inflow rate to a plane (Rainfall rate minus infiltration rate.) $[LT^{-1}]$

q_c = Lateral inflow rate to channel $[L^2T^{-1}]$

q_I = Flow rate into a reservoir $[L^3T^{-1}]$

q_m = Sediment transport capacity per unit width-overland flow $[L^2T^{-1}]$

q_O = Flow rate out of a reservoir $[L^3T^{-1}]$

q_s = Rate of lateral sediment inflow $[L^2T^{-1}]$

R = Hydraulic radius $[L]$

r = Rainfall rate $[LT^{-1}]$

R_e = Reynolds number

R_n = Particle Reynolds number

R_r = Weight of rock per unit weight of soil

S = Slope of plane or channel

S_c = Relative saturation at field capacity

S_f = Friction slope

S_i = Initial relative saturation

S_{max} = Maximum relative saturation

S_r = Residual relative saturation

S_s = Particle specific gravity

t = Time [T]

t_e = Time to equilibrium for a plane [T]

t_p = Ponding time [T]

u = Local vertically averaged velocity $[LT^{-1}]$

u_* = Shear velocity $[LT^{-1}]$

V = Reservoir volume $[L^3]$

V_r = Relative volume of rock in soil

v_s = Particle fall velocity $[LT^{-1}]$

W = Width of plane [L]

x = Distance [L]

ZL = Side slope of left side of a trapezoidal channel

ZR = Side slope of right side of a trapezoidal channel

α = Coefficient in relationship between runoff rate and storage per unit area

β = Exponent in sediment transport relationship

γ = Exponent in sediment transport relationship

γ_w = Specific weight of water

δ = Exponent in sediment transport relationship

Δt = Finite difference time increment [T]

Δx = Finite difference length increment [L]

ϵ = Exponent in sediment transport relationship

η = Infiltration recovery rate factor

θ = Relative volumetric soil water content, dimensionless

θ_c = Intersection angle in conduits

θ_i = Initial soil water content, dimensionless

θ_s = Maximum soil water content under imbibition

θ_w = Weighting factor $0 \leq \theta_w \leq 1$

τ_c = Critical shear stress $[L^2/T]$

τ_o = Bed shear stress $[L^2/T]$

ν = Kinematic viscosity $[L^2T^{-1}]$

ρ_s = Sediment particle density $[ML^{-3}]$

ϕ = Porosity

ϕ_f = Factor to reduce K_{usle} for mulch, etc.

ϕ_r = Factor to reduce hydraulic erosion for mulch, etc.

ψ = Soil matric potential [L]

ω = Coefficient in sediment transport relationship

KINEROS, A KINEMATIC RUNOFF AND EROSION MODEL: DOCUMENTATION AND USER MANUAL

D.A. Woolhiser, R.E. Smith, and D.C. Goodrich

INTRODUCTION

Engineers and soil conservationists often need to estimate runoff rates and volumes from ungaged watersheds. Traditional formula methods are useful for some purposes, but for many objectives more precise knowledge is required about the hydrologic response of a watershed or model sensitivity to various physical factors or assumptions. For this purpose, physically based distributed models of runoff are becoming more widely used. This report describes such a model, called KINEROS.

Since about 1970, the kinematic wave approximation has become a widely used method to simulate the movement of rainfall excess water over the land surface and through small channels. Although this method requires simplifying assumptions compared to more complete theory, its hydraulic requirements are well established (Wooding 1965, Woolhiser and Liggett 1967). It has been extensively verified by experiment (Woolhiser et al. 1970, Morgali 1970, Schreiber 1970, Kibler and Woolhiser 1970, Rovey and Woolhiser 1977). This method was applied to an arbitrary network of planes and channels in a computer model called KINGEN by Rovey et al. (1977). This model employed a computer solution derived model for infiltration to simulate the production of runoff, and it was intended for rural or urban runoff studies using a design storm.

Since publication of that document (Rovey et al. 1977), the model has been modified--the most notable modifications being the inclusion of simulation of erosion and sediment transport, revision of the infiltration component, and inclusion of a pond element. The model, now called KINEROS, has attained some popularity and has been used by research and consulting groups. KINEROS simulates the response of a catchment, whose

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configuration is defined by the user, to the occurrence of a user-specified rainfall event. The intensity pattern of rainfall at one or more points on the watershed must be described. KINEROS is applicable to several kinds of small watersheds, including natural and disturbed rural watersheds and urban watersheds of arbitrary configuration. It is assumed that runoff is generated by the Hortonian mechanism, that is, rainfall rates exceed the infiltration capacity, so the model is not appropriate for catchments with significant subsurface flow components. The infiltration model is interactive with the surface water routing model, and realistic interrelations are modeled. The simulation of erosion is optional and is based on work done by Smith (1978, 1981).

This report consists of--

1. Brief explanation of the mathematical models of the processes included,

2. Explanation of the program structure and the data set required to represent a catchment,

3. Set of examples to help the user understand the various input options and the output information produced.

THEORY

Introduction

Mathematical models of several components of the hydrologic cycle are required to describe and predict Hortonian runoff from complex watersheds. Both spatial and temporal variabilities of the rainfall input and of model parameters substantially affect the runoff process and must be accounted for. Temporal and spatial scales vary from component to component, and the problem of identifying the appropriate modeling scales for each component is the subject of ongoing research. In this section we describe the theory involved in the processes of rainfall, interception, infiltration, overland flow, open channel flow, erosion, sediment transport, reservoir routing,and reservoir sedimentation as used in KINEROS. Because of space limitations, the treatment is brief. However, given the material in this section and in the references, the user should be able to recognize the strengths and limitations of the model.

KINEROS is a distributed, event-oriented, physically based model describing the processes of surface runoff and erosion from small agricultural and urban watersheds. It is a *distributed* model because the watershed surface and channel network are represented by a cascade of planes and channels. Each plane may be described by its unique parameters, initial conditions, and precipitation inputs; and each channel, by unique parameters. It is an *event-oriented* model because it does not have components describing evapotranspiration and soil water movement between storms and therefore cannot maintain a hydrologic water balance between storms. Given initial soil moisture conditions, it calculates surface runoff for a single event or surface runoff and erosion if the erosion option is selected. It is *physically based* because the mathematical models used to describe the components are based on such physical principles as conservation of mass and momentum. We appreciate that not all the required physical principles are included (or well known in some instances), and the geometry of the model system is only an approximation (frequently a very crude approximation) of the real watershed.

Because of its distributed nature and its physical basis, KINEROS may be useful in determining the effects of various artificial features such as urban developments, small detention reservoirs, or lined channels on flood hydrographs and sediment yield.

The overall modeling approach can best be described by considering an example. A contour map of a small watershed and a schematic drawing of the cascade of planes and channels used to represent it are shown in figures 1 and 2. The general approach is to divide the watershed into a branching system of channels with plane elements contributing lateral flow to the channels or to the upper end of first order channels. The rainfall input may be spatially varied, and infiltration and roughness characteristics may differ for each plane. Data on rainfall depth versus time can be provided for 1 to 20 sites within or near the basin. Program KINEROS then calculates the difference between rainfall rate and infiltration rate for 5 to 15 nodes for each overland flow plane. The surface runoff routing and infiltration components are interactive so that infiltration may continue when rainfall has stopped provided water remains on the plane. Runoff is routed over each plane and through the channel system (and reservoirs, if present) to the watershed outlet. Channels may also lose water through infiltration. If the erosion option is used, erosion, deposition, and sediment transport are calculated and sediment is routed through the system.

Interception

As rain falls on a vegetated surface, part of it is held on the foliage by surface tension forces. Because it does not reach the soil surface, it has no part in infiltration. Accordingly, an interception depth (I) is subtracted from the rainfall before

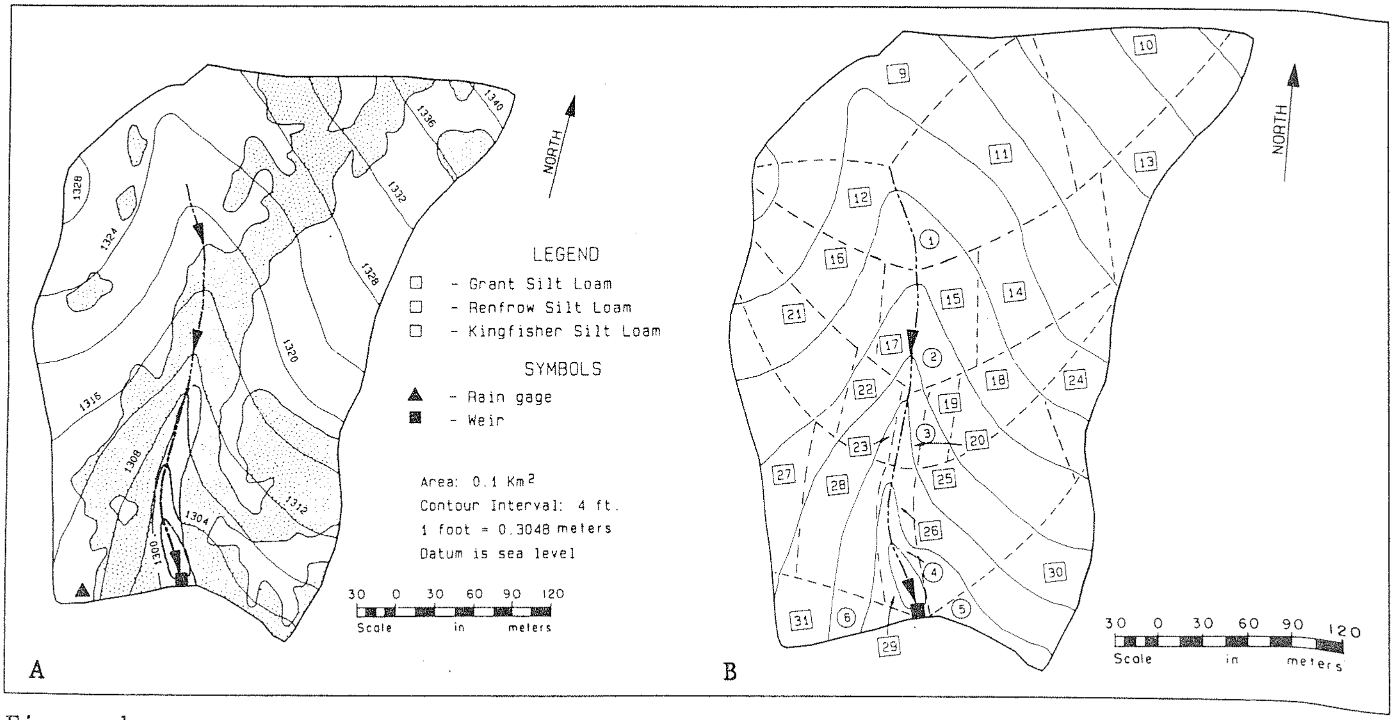


Figure 1.
R-5 catchment, Chickasha, OK: A, contour map; B, division into plane and channel elements.

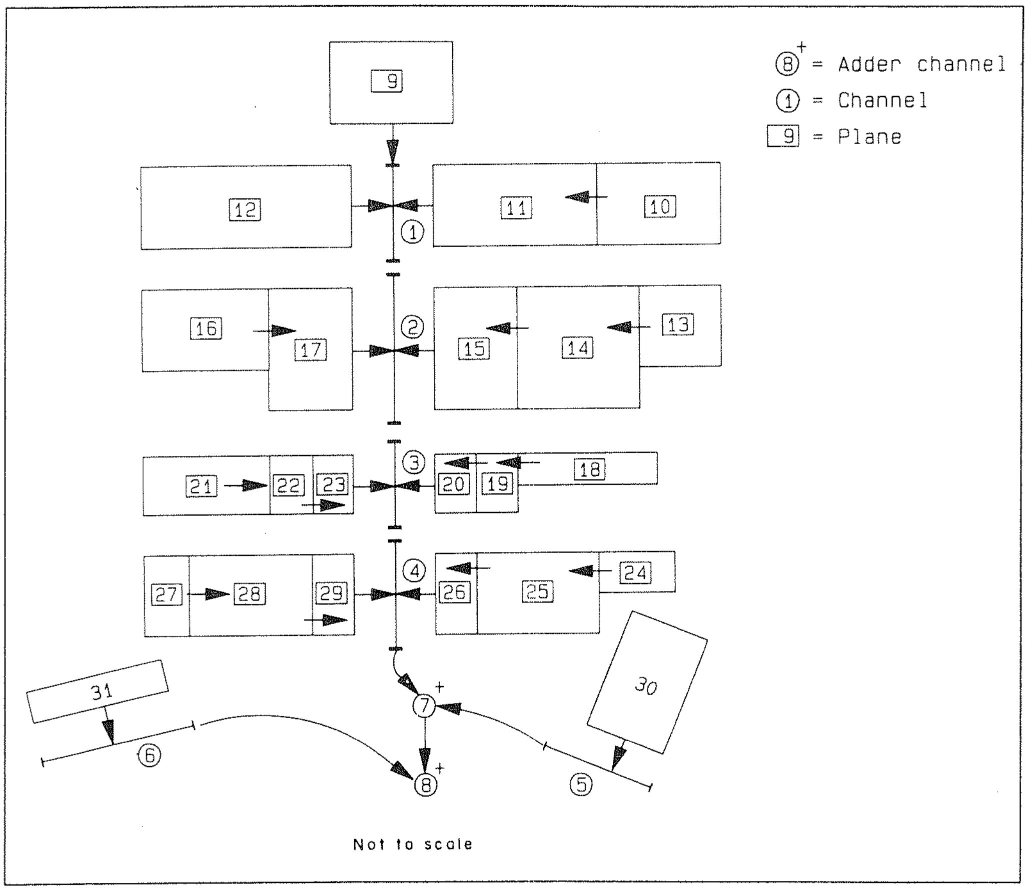


Figure 2.
Schematic of R-5 plane and channel configuration.

infiltration is calculated. In KINEROS, the rainfall rate is reduced until the interception depth (I) has been satisfied. If the total rain falling during the first time increment (Δt) is greater than I, the rainfall rate is reduced by $I/\Delta t$. If the depth is less than I, the rate is set to zero and the remainder of interception is removed from the rainfall in the following time increments.

Several researchers have reported appropriate values of interception for various types of vegetative cover. Some of these are summarized in table 1. Interception is affected by the species of vegetation, percentage of canopy cover, growth stage of vegetation, season of year, and wind velocity. Therefore, the values of I in table 1 should be adjusted for such conditions as growth stage and height. Horton's (1919) data reflect lower plant populations and fertility levels than found in current practice so are probably too low for corn. Although interception may be highly significant in the annual water balance, it is relatively unimportant for flood-producing storms.

Table 1.
Interception depths (I)

Vegetative cover	Height		I		Reference
	m	ft	mm	in	
Corn	1.82	6	0.76	[1]0.03	Horton (1919)
Tobacco	1.22	4	1.8	[1].07	Horton (1919)
Small grains	.91	3	4.1	[1].16	Horton (1919)
Meadow grass	.30	1	2.0	[1].08	Horton (1919)
Alfalfa	.30	1	2.8	[1].11	Horton (1919)
Grass (fescue)	--	--	1.0 - 1.2	.04 - .048	Burgy and Pomeroy (1958)
Mixed hardwoods	--	--	.5 - 1.8	.02 - .07	Horton (1919)
Apple	--	--	.5	.02	Calheiros de Miranda and Butler (1986)
Big bluestem grass	.6	2	2.3	.09	Clark (1940)
Bluegrass	--	--	1.0	.04	Haynes (1940)
Tarbush	--	--	3.0	[2].12	Tromble (1983)

[1] For 1-in (25.4-mm) storms.

[2] Depth of water per crown projected area.

Infiltration

During rainstorms the rate of rainfall changes continually, beginning and ending with a zero rate. Partly because of limitations in measuring equipment, we commonly approximate this rate change with a finite number of relatively short pulses. Each pulse is assumed to have a constant rate, but the rate changes from pulse to pulse. This sequence of rainfall pulses becomes the temporally and spatially distributed input to surface flow when it falls on impervious elements in the catchment. For land surfaces, however, there are always portions of the rain that (1) are intercepted by plants or surface litter or both and (2) enter the soil. The rate of input to surface runoff per unit area is called rainfall excess, and it is the difference between rainfall and infiltration rates plus interception rate. The infiltration rate is not constant; its pattern responds to the variation in rainfall rates and to the accumulated infiltration amount.

Rainfall Infiltration

At the beginning of a storm on an infiltrating watershed, there will always be an initial period within which the infiltration rate (f) is equal to the rainfall rate (r) and the rainfall excess (q) is zero. During this period, the soil can absorb water faster than the rain is supplying it and it may be called a rain limited infiltration period. The maximum rate at which water could enter the soil, called the infiltration capacity (f_c), can be described as a function ($\underline{f}$) of the initial water content (θ_i) and the amount of rain already absorbed into the soil (F):

$$f_c = \underline{f}(F, \theta_i) \qquad [1]$$

The initial water content (θ_i) is assumed constant over the depth of wetting but varies between storms. The relation $\underline{f}(F, \theta_i)$ is derived from simplifying assumptions allowing an analytic solution of the underlying Darcy flow equation and continuity of water across the surface (Smith 1983). Two parameters are key to the infiltration model. One is the effective saturated hydraulic conductivity (K_s); another is the effective net capillary drive (G):

$$G = \frac{1}{K_s} \int_{-\infty}^{0} K(\psi)\, d\psi \qquad [2]$$

in which ψ = soil matric potential [L]

$K(\psi)$ = hydraulic conductivity function [L/T]

Notice that G has units of length and can be thought of as a net or effective value of capillary head. G is conceptually a soil characteristic and does not incorporate the effect of initial water content, which is treated independently. Smith (1983) showed that the effect of the initial water content is not linear, in general, but can be considered linear for a large range of initial water contents.

Equation [2] allows G to be derived from basic hydraulic characteristics of the soil relating unsaturated hydraulic conductivity to θ and ψ. It can also be considered a parameter to be determined from field experiments with infiltrometers.

Rawls et al. (1982) compiled hydraulic data on a large number of soils over a range of textural classes, from which general estimates for values of G and K_s can be taken. These are presented in table 2. Cosby et al. (1984) presented regression equations for estimating log K_s and other parameters based on percent sand, silt, or clay.

Smith (1983) reported several similar expressions for describing infiltration rate responses to rainfall, which are derived from unsaturated soil physics. Each analytic expression employs the parameter G in tandem with the *saturation deficit* of the soil,

Table 2.
Soil hydraulic characteristics

Texture class	Total porosity (ϕ)	Residual saturation (S_r)	Maximum saturation (S_{max})	Mean K_s	
	cm^3/cm^3			cm/h	in/h
Sand	0.437 0.374 - 0.500	0.045	0.95	21.0	8.3
Loamy sand	.437 .368 - .506	.080	.92	6.1	2.4
Sandy loam	.453 .351 - .555	.09	.91	2.6	1.0
Loam	.463 .375 - .551	.06	.94	1.3	.52
Silt loam	.501 .420 - .582	.03	.97	.68	.27
Sandy clay loam	.398 .332 - .464	.17	.83	.43	.17
Clay loam	.464 .409 - .519	.16	.84	.23	.09
Silty clay loam	.471 .418 - .524	.08	.92	.15	.06
Sandy clay	.430 .370 - .490	.25	.75	.12	.05
Silty clay	.479 .425 - .533	.12	.88	.09	.04
Clay	.475 .427 - .523	.19	.81	.06	.02

[1] Obtained by analysis of data presented in Rawls et al. (1982).

[2] Arithmetic mean obtained from arithmetic means of soil characteristics in Rawls et al. Geometric mean is obtained by taking the antilog of the mean of the logarithms of the same data. Range shown below each value is approximately ± one standard deviation.

G^1			
Arithmetic	Geometric	Arithmetic	Geometric^2
cm	cm	in	in
10.1 2.2 - 20.7	4.6 1.0 - 27.1	4.0 0.86 - 8.2	1.8 0.34 - 10.7
14.7 4.1 - 32.3	6.3 2.3 - 31.7	5.8 1.6 - 12.7	2.5 .91 - 12.5
24.8 9.8 - 52.6	12.7 3.0 - 54.0	9.8 3.6 - 20.7	5.0 1.2 - 21.3
37.5 18.5 - 93.7	10.8 1.9 - 74.0	14.8 7.3 - 36.9	4.3 .75 - 29.1
48.5 22.0 - 104.3	20.3 4.3 - 118.0	19.1 8.7 - 41.7	8.0 1.7 - 46.5
61.7 22.0 - 107.0	26.3 6.0 - 132.0	20.1 8.7 - 42.1	10.4 2.5 - 52.0
53.3 25.0 - 117.4	25.9 6.7 - 116.0	21.0 9.8 - 46.2	10.2 2.6 - 45.6
72.0 37.0 - 147.0	34.5 8.5 - 168.0	28.3 14.6 - 57.9	13.6 3.3 - 66.1
76.8 37.3 - 173.0	30.2 5.6 - 178.0	30.2 14.7 - 68.1	11.9 2.2 - 70.1
81.2 43.0 - 170.0	37.5 9.3 - 182.0	32.0 16.9 - 66.9	14.8 3.7 - 71.7
89.0 46.0 - 183.0	40.7 8.8 - 204.0	35.0 18.1 - 72.0	16.0 3.5 - 80.3

which is the difference between the volumetric water-holding capacity of the soil and its initial water content. Calling this parameter B, we have

$$B = G\ (\theta_s - \theta_i) \qquad [3]$$

or

$$B = G\ \phi\ (S_{max} - S_i) \qquad [3a]$$

in which ϕ is soil porosity, θ_s and θ_i are saturated and initial water contents $[L^3/L^3]$, and S_{max} and S_i are maximum and initial values of *relative saturation*, defined as θ/ϕ. Parameter B has units of length like G and simply combines the parameter G with the time-dependent variable θ_i or S_i. In KINEROS we use the second of these two expressions, since conceptually relative saturation is easier to deal with as a value from 0 to 1. Actually S_i is limited on the lower end by the value of *residual saturation* (S_r). Values of S_r are presented in table 2 and relative saturation values at permanent wilting point and "field capacity" are shown in table 3 as an aid to judgment in selecting S_i.

Table 3.
Relative saturation at permanent wilting point and field capacity

	Relative saturation	
Texture class	Permanent wilting[1]	Field capacity[1]
Sand	0.08	0.21
Loamy sand	.13	.29
Sandy loam	.21	.46
Loam	.25	.58
Silt loam	.27	.66
Sandy clay loam	.37	.64
Clay loam	.42	.69
Silty clay loam	.44	.78
Sandy clay	.56	.79
Silty clay	.52	.81
Clay	.57	.83

[1] Derived from mean values of Table 2 in Rawls et al. (1982) using total porosity.

The infiltration expression used in KINEROS comes from Smith and Parlange (1978):

$$f_c = K_s \exp(F/B)/[\exp(F/B)-1] \qquad [4]$$

The parameter K_s acts somewhat as a scaling parameter for f_c as equation [4] indicates. For a short time interval after the beginning of rainfall or small values of F (generally when $F/B < 0.1$), equation [4] approaches the gravity-free infiltration relation

$$f_c = BK_s/F \qquad [5]$$

The infiltration process for uniform soils, therefore, consists of two parts, as illustrated in figure 3. Initially, infiltration is limited by the rain intensity, and F is accumulated at rainfall rate (r). The point at which f_c becomes limiting is called ponding, specifically as either ponding time (t_p) or ponding depth (F_p). After that point, equation [4] defines the infiltration rate (f), and f is limited by f_c. Thus f is always the lesser of r or f_c. The diagonal line on the logarithmic plot of figure 3, to which f_c is asymptotic at small values of F, is described by equation [5]. The asymptote at large F is $f = K_s$.

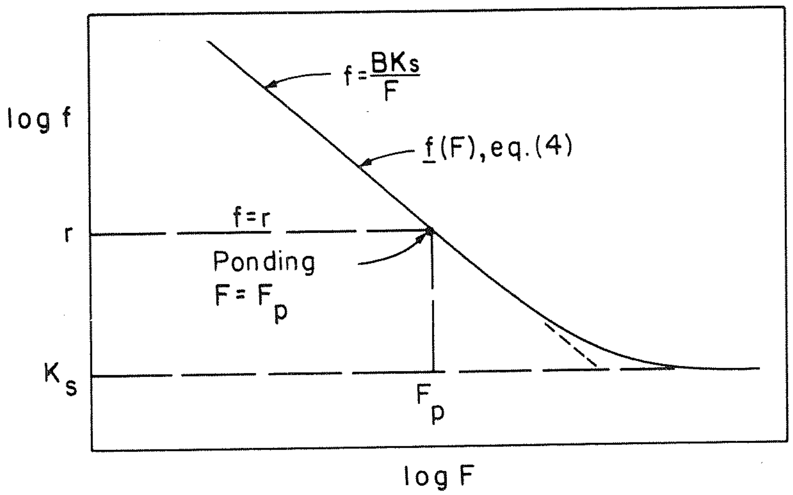


Figure 3.
Definition sketch for infiltration model.

Infiltration During Recession

When the rain ceases or falls to a rate below the infiltration capacity (f_c), infiltration continues from the rain and flowing water still on the soil surface until the water is locally depleted. Unlike rainfall, however, the supply of infiltrating water from flowing water cannot reasonably be assumed to be continuous over the surface. The kinematic treatment of the surface water flow does not require the assumption of "sheet" flow. On natural surfaces, flows are commonly confined to rivulets according to the geometry of the microtopography. As a result, infiltration of surface water during recession is limited by the fraction of the soil surface exposed to the surface water.

KINEROS provides a simple modification of infiltration during recession by describing the surface microtopography with a parameter RECS. This parameter represents, conceptually, the local maximum average depth of surface water flow for which the surface is essentially completely covered by the water. As average flowing water depth (h) is reduced below this depth, the surface covered by the flowing water is assumed to decline in direct proportion to the depth. Thus when the local mean depth is half of RECS, the soil surface is assumed to be half covered by the flowing water. A very low value of RECS represents a relatively smooth soil surface, with little topographic variation, such as a sod-covered plane; a large value of RECS represents a very rough or rilled surface, with flowing water confined to a small part of the surface. The ratio of h to RECS is used to reduce the net rate of loss of surface water by infiltration during recession conditions, as far as the surface water flow equations are concerned.

Recovery of Infiltration Capacity During Rainfall Hiatus

The theory represented in equations [2] through [4] applies in general when $r > K_s$. Often in real rainfall patterns there are one or more intervals during a storm in which $0 \le r < K_s$. As long as water remains on the surface to satisfy f_c, these intervals are still covered by this theory.

When a longer hiatus occurs, in which part or all of the surface is free of water, redistribution of soil water will occur and a subsequent rainfall will find a new and larger value of S_i. In KINEROS, the changes in relative saturation during such an interval are based on an analytic estimate of the water content that the soil would attain for a given $r < K_s$ if that rainfall continued indefinitely. This steady unsaturated flow relationship is based on a relation used by Brooks and Corey (1964) and others, between soil flux (equal to rain rate at a large time) and relative saturation at the steady rate, S(r):

$$S(r) = S_r + (S_{max} - S_r) \left[\frac{r}{K_s}\right]^p ; \quad (r < K_s) \qquad [6]$$

S_{max} and S_r are as defined previously, and p is an exponent on the order of 0.20. The long term S(r) is not achieved in the context of a typical changing pattern of r but is useful for estimating the direction of change of S_i. If rain rate increases from 0 to r_j ($r_j < K_s$), water content will increase toward $S(r_j)$ (equation [6]). Neglecting surface evaporation, the long term value of relative saturation for $r = 0$ is S_r.

KINEROS estimates the change of S_i during a hiatus by assuming this value moves asymptotically toward the value of S(r) as long as $r < K_s$:

$$S_i^j = S_i^{j-1} + \left[\min (S_j, S_c) - S_i^{j-1}\right] \left[1 - \exp(-\eta \Delta t)\right] \qquad [7]$$

in which j superscript or subscript represents time levels, and η is a rate factor which we wish to be a function of the depth of water previously infiltrated, and also a function of the amount of water still on the surface:

$$\eta = [1 - h/RECS]\exp(-2F)\sqrt{aK_s} \qquad [8]$$

S_c is the relative saturation at field capacity (-0.33 bars) as computed from a non-linear regression relationship derived from mean values of K_s versus water content at field capacity from Rawls et al. (1982). S_c is computed from the regression relationship using the input K_s so the user does not need to supply this quantity.

For a long hiatus equation [8] tends toward the initial relative (S_i^1) if $S_i^1 < S_c$ and tends toward relative field capacity (S_c) if $S_i^1 > S_c$.

This is a conceptual relation, but it has worked adequately based on experimental data from Walnut Gulch watershed in Arizona. The relationship provides that redistribution proceeds more slowly for large rains (F) or for tighter soils (low K_s), and more rapidly for small F or large K_s. "a" is a fitting parameter, and is currently set to 0.95. RECS was defined previously, and the first term in this expression provides for the reduced redistribution rate when water partly covers the surface during recessions.

Numerical Treatment

In the context of a simulation model, solution of many equations moves forward in time steps, and one needs to know the conditions during each step. In the case of infiltration, we need a value for the mean infiltration rate over the time step at every location along the flow path. When the solution must proceed in the time domain, an approach is required that varies from the straightforward application of the previous equations.

Recognizing that f = dF/dt, one may write dF/dt = $\underline{f}(F)$ and integrate this relation in steps:

$$\Delta t = \int_{F(t)}^{F(t+\Delta t)} \frac{dF}{\underline{f}(F)} \qquad [9]$$

The true mean value of f_c over an interval from time t to t + Δt (with f_c less than r) is obtained as

$$f(\Delta t) = \Delta F/\Delta t = [F(t+\Delta t) - F(t)]/(\Delta t) \qquad [10]$$

$F(t + \Delta t)$ is obtained numerically using equation [9] over the interval Δt divided into as many increments as desired. The infiltration rate ($\underline{f}(F)$) in equation [9] is taken along the line f = r for up to ponding depth and then follows $\underline{f}(F)$ from equation [4], as in figure 3.

Equation [4] is also used to calculate infiltration from trapezoidal channels. It is applied at each computational node over an area equal to the product of the effective wetted perimeter and the length increment (Δx), and becomes part of the lateral inflow term (see equation [23]).

Hortonian Overland Flow

When the rainfall rate exceeds the infiltration capacity and sufficient water ponds on the surface to overcome surface tension effects and fill small depressions, Hortonian overland flow begins. Viewed at a microscale, overland flow is an extremely complicated three-dimensional process. At a larger scale, however, it can be viewed as a one-dimensional flow process in which the flux is proportional to some power of the storage per unit area. That is:

$$Q = \alpha h^m \qquad [11]$$

where Q is the discharge per unit width, h is the storage of water per unit area (or depth if the surface is a plane), and α and m are parameters related to slope, surface roughness, and whether the flow is laminar or turbulent. Equation [11] is used in conjunction with the equation of continuity:

$$\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} = q(x,t) \qquad [12]$$

where t is time, x is the spatial coordinate, and q(x,t) is the lateral inflow rate. If equation [11] is substituted into equation [12] we get

$$\frac{\partial h}{\partial t} + \alpha m h^{m-1} \frac{\partial h}{\partial x} = q(x,t) \qquad [13]$$

A definition sketch of one-dimensional flow on a plane surface is shown in figure 4. It must be emphasized that the depicted overland flow on a plane surface is not the type of flow found in most field situations. Furthermore, the kinematic assumption requires only that discharge be some unique function of the amount of water stored per unit of area; it does not require sheet flow.

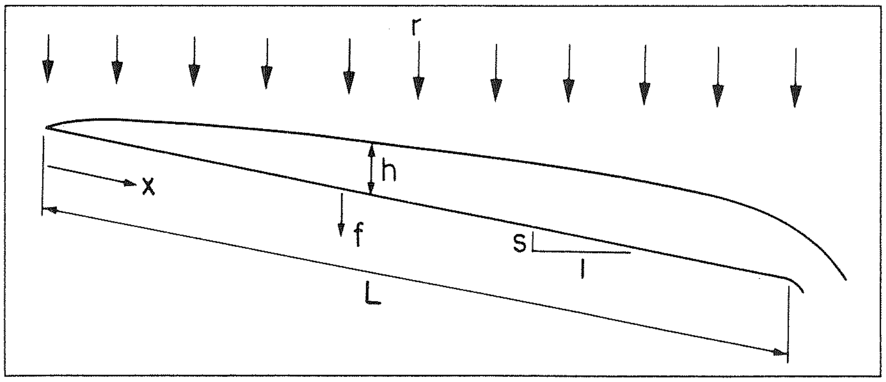


Figure 4.
Definition sketch of overland flow on a plane.

The kinematic wave equations are a simplification of the de Saint Venant equations and do not preserve all the properties of the more complex equations. Specifically, backwater cannot be accommodated and waves do not attenuate (unless they form shocks that do attenuate). It has been shown that the kinematic wave formulation is an excellent approximation for most overland flow conditions (Woolhiser and Liggett 1967, Morris and Woolhiser 1980).

The depth at the upstream boundary must be specified to solve the kinematic wave equations. If the plane is the uppermost one, the appropriate boundary condition is

$$h(0,t) = 0 \qquad [14]$$

If another plane is contributing runoff to the upper boundary of the plane in question, the boundary condition is

$$h(0,t) = \left[\alpha_u \, h_u(L,t)^{m_u} \, W_u / (\alpha \, W) \right]^{1/m} \qquad [15]$$

where $h_u(L,t)$ is the depth at the lower boundary of the contributing plane at time t, W_u is the width of the contributing plane, α_u is the slope-roughness parameter for the contributing plane, m_u is the exponent for the contributing plane, and α, m, and W refer to the lower or receiving plane.

In KINEROS the kinematic wave equations are solved numerically by a four-point implicit method. Notation for the finite-difference grid is shown in figure 5 and the finite-difference equation is

$$\begin{aligned} & h_{j+1}^{i+1} - h_{j+1}^{i} + h_{j}^{i+1} - h_{j}^{i} \\ & + \frac{2\Delta t}{\Delta x} \left\{ \theta_w \left[\alpha_{j+1}^{i+1} \left\langle h^m \right\rangle_{j+1}^{i+1} - \alpha_{j}^{i+1} \left\langle h^m \right\rangle_{j}^{i+1} \right] \right. \\ & \left. + (1-\theta_w) \left[\alpha_{j+1}^{i} \left\langle h^m \right\rangle_{j+1}^{i} - \alpha_{j}^{i} \left\langle h^m \right\rangle_{j}^{i} \right] \right\} \\ & - \Delta t \left(\bar{q}_{j+1} + \bar{q}_{j} \right) = 0 \end{aligned} \qquad [16]$$

where θ_w is a weighting parameter for the x derivatives at the advanced time step. Because this equation is nonlinear in the unknown $\left(h_{j+1}^{i+1}\right)$, a solution is obtained by Newton's method (sometimes referred to as the Newton-Raphson technique, cf. Pearson 1983, p. 11). This difference scheme is unconditionally stable from a linear stability analysis, but the accuracy is highly dependent on the size of the Δt and Δx increments used. The difference scheme is nominally of first order accuracy.

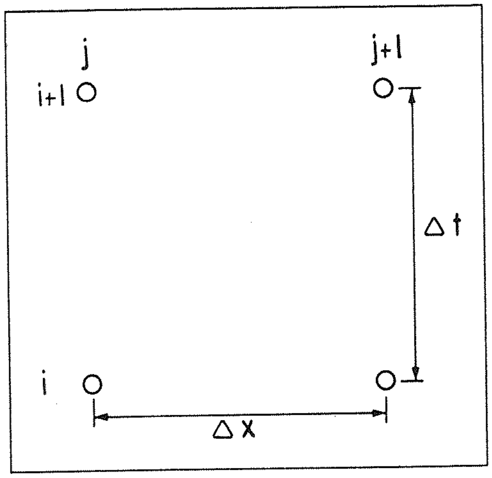


Figure 5.
Notation - finite difference grid.

Four options for α and m in equation [11] are provided in KINEROS:

1. The Manning hydraulic resistance law is used. In this option

$$\alpha = 1.49\ S^{1/2}/n \qquad \text{and} \qquad m = 5/3 \tag{17}$$

where S is the slope, n is Manning's roughness coefficient, and English units are used.

2. A laminar law is used until the Reynolds number ($R_e = Q/\nu$) exceeds a critical value (RCRIT), and then Manning's law is used. Thus if R_e is smaller than RCRIT,

$$\alpha = 8gS/(k\nu) \qquad \text{and} \qquad m = 3 \tag{18}$$

where ν is the kinematic viscosity, g is the acceleration of gravity, and k is a dimensionless parameter that has a theoretical value of 24 for a hydraulically smooth surface and may be on the order of 14,000 for turf (Morgali 1970). If R_e is greater than RCRIT, equation [17] is used.

3. A laminar law is used until the Reynolds number exceeds a critical value and then the Chezy law is used. Thus if R_e is smaller than RCRIT, equation [18] is used. If R_e is greater than RCRIT,

$$\alpha = C\ S^{1/2} \quad \text{and} \quad m = 3/2 \qquad [19]$$

where C is the Chezy friction coefficient.

4. The Chezy law, equation [19], is used for all values of R_e.

Overland flow response characteristics are controlled by the slope, slope length, and hydraulic resistance parameters as well as the rainfall intensity and infiltration characteristics. For example, if the Manning resistance law is used, the time to equilibrium (t_e) of a plane of length (L) and slope (S) with a constant rate of lateral inflow (q), is

$$t_e = \left[\frac{n\ L}{1.49 S^{1/2} q^{2/3}} \right]^{3/5} \qquad [20]$$

where n is the Manning resistance coefficient. Therefore, to maintain the time response characteristics of the catchment we must retain the slope, slope length, and hydraulic resistance in our simplified version of a complex catchment. The length, width, and slope of the plane elements can be determined from topographic maps. The hydraulic resistance (or parameter) is more difficult to determine. First, a decision must be made regarding the appropriate flow law. It is generally agreed that overland flow on a plane begins as laminar flow and eventually becomes turbulent at large Reynolds numbers. Values of the critical Reynolds number range from 100 to 1,000 (Chow 1959, Yu and McNown 1964, Morgali 1970). However, raindrops impacting on the water film generate local areas of turbulent flow and have an effect similar to increasing the viscosity of the fluid. For example, the relationship between the Darcy-Weisbach friction factor (f_D) and Reynolds number for laminar flow over a hydraulically smooth surface is

$$f_D = \frac{24}{R_e} \qquad [21]$$

Several laboratory experiments (cf. Glass and Smerdon 1967, Li 1972) have shown that with raindrop impact this relationship becomes

$$f_D = k/R_e; \qquad k > 24 \qquad [22]$$

$$k = k_o + \underline{f}(r) \qquad [22a]$$

where k_o is the appropriate value for a given surface geometry without raindrop impact and $\underline{f}(r)$ is some function of the rainfall rate. Although the effects of raindrop impact can be significant on hydraulically smooth surfaces such as laboratory catchments, they are not important for hydraulically rough surfaces usually found in the field. The laminar flow model in KINEROS does not include a relationship between k and rainfall rate. Ranges of k_o for various surfaces are presented in table 4.

Although the range of k_o for each surface is large, the time of equilibrium is proportional to $k_o^{1/3}$, so a 10 percent error in k_o will cause a smaller error in t_e. It should be noted that the relationship $R_e = Q/_\nu = uh/_\nu$ is used for all surfaces in KINEROS although, for example, the local depth (h) may not be the appropriate characteristic length to use in flow through dense sod.

In KINEROS it is not necessary to specify the critical Reynolds number; rather, the appropriate turbulent Manning's n or Chezy C is chosen. This choice will define the critical Reynolds number, which is then used in the program to change the friction law at the appropriate time. Ranges of Manning's n and Chezy C obtained from experiments reported in the literature are also shown in table 4, and values of Manning's n are shown for a wide range of surfaces in table 5. These values are generally representative of very small areas when correspondence exists between reality and the mathematical model of one-dimensional flow over a plane. If a plane is used to represent areas larger than about 2 acres (0.8 ha), these values should be adjusted (n downward, C upward) to reflect the greater number of rills on long slopes. Some guidance is available in the literature regarding appropriate roughness adjustments and geometric model simplification. Refer to Lane et al. (1975), Lane and Woolhiser (1977), Wu et al. (1978), and Goodrich et al. (1988) for background information.

Table 4.
Resistance parameters for overland flow

Surface	Laminar flow (k_o)	Turbulent flow Manning's n	 Chezy C
			$ft^{1/2}/s$
Concrete or asphalt	24 - 108	0.01 - 0.013	73 - 38
Bare sand	30 - 120	.01 - .016	65 - 33
Graveled surface	90 - 400	.012 - .03	38 - 18
Bare clay-loam soil (eroded)	100 - 500	.012 - .033	36 - 16
Sparse vegetation	1,000 - 4,000	.053 - .13	11 - 5
Short grass prairie	3,000 - 10,000	.10 - .20	6.5 - 3.6
Bluegrass sod	7,000 - 40,000	.17 - .48	4.2 - 1.8

Source: Woolhiser (1975).

We recommend that option 1, Manning's law, be used for KINEROS unless the watershed to be modeled is very small and hydraulically smooth, in which case option 2 (Laminar-Manning) is recommended. Options 3 and 4 are included for research applications.

Channel Routing

Unsteady, free surface flow in channels is also represented by the kinematic approximation to the equations of unsteady, gradually varied flow. Channel segments may receive uniformly distributed but time-varying lateral inflow from planes on either or both sides of the channel, or from one or two channels at the upstream boundary, or from a plane at the upstream boundary. The dimensions of planes are chosen to completely cover the watershed, so rainfall on the channel is not considered directly. The continuity equation for a channel with lateral inflow is

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c(x,t) \qquad [23]$$

where A is the cross-sectional area, Q is the channel discharge, and $q_c(x,t)$ is the net lateral inflow per unit length of channel. Under the kinematic assumption, Q can be expressed as a unique function of A and equation [23] can be written as

$$\frac{\partial A}{\partial t} + \frac{dQ}{dA}\frac{\partial A}{\partial x} = q_c(x,t) \qquad [24]$$

Table 5.
Recommended Manning's roughness coefficients for overland flow

Cover or treatment	Residue rate	Value recommended	Range
	tons/acre		
Concrete or asphalt		0.011	0.010 - 0.013
Bare sand		.01	.010 - .016
Graveled surface		.02	.012 - .03
Bare clay loam (eroded)		.02	.012 - .033
Fallow - no residue		.05	.006 - .16
Chisel plow	<1/4	.07	.006 - .17
	<1/4 - 1	.18	.07 - .34
	1 - 3	.30	.19 - .47
	>3	.40	.34 - .46
Disk/harrow	<1/4	.08	.008 - .41
	1/4 - 1	.16	.10 - .25
	1 - 3	.25	.14 - .53
	>3	.30	--
No till	<1/4	.04	.03 - .07
	1/4 - 1	.07	.01 - .13
	1 - 3	.30	.16 - .47
Moldboard plow (fall)		.06	.02 - .10
Colter		.10	.05 - .13
Range (natural)		.13	.01 - .32
Range (clipped)		.10	.02 - .24
Grass (bluegrass sod)		.45	.39 - .63
Short grass prairie		.15	.10 - .20
Dense grass[1]		.24	.17 - .30
Bermuda grass[1]		.41	.30 - .48

[1] Weeping lovegrass, bluegrass, buffalo grass, blue gramma grass, native grass mix (Okla.), alfalfa, lespedeza (from Palmer 1946).
Sources: Woolhiser (1975) and Engman (1986).

The kinematic assumption is embodied in the relationship between channel discharge and cross-sectional area.

$$Q = \alpha R^{m-1} A \qquad [25]$$

where R is the hydraulic radius. If the Chezy relationship is used, $\alpha = C\sqrt{S}$ and $m = 3/2$. If the Manning equation is used, $\alpha = 1.49S^{1/2}/n$ and $m = 5/3$. Channel cross sections may be approximated as trapezoidal or circular, as shown in figure 6. Equations for various functions of trapezoidal geometry are shown in table 6.

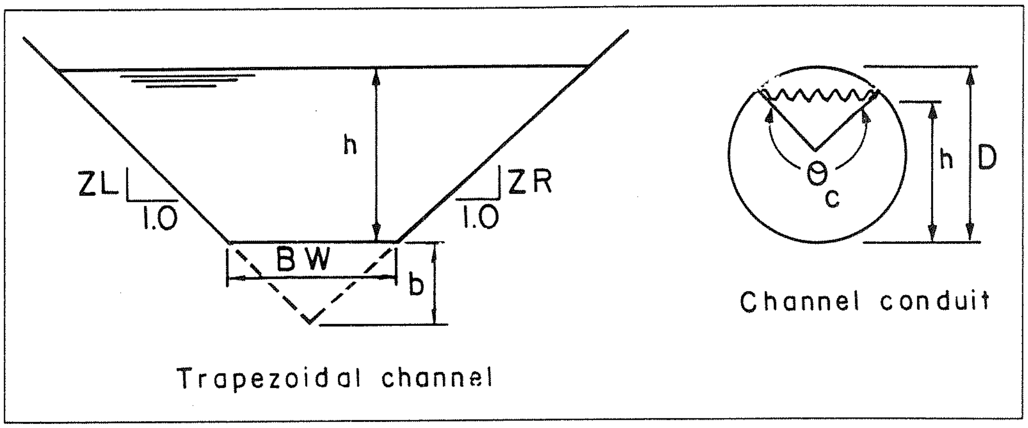


Figure 6.
Channel and conduit cross sections.

In an urban environment, circular conduits must be used to represent storm sewers. For the kinematic model to apply, there must be no backwater and the conduit is assumed to maintain free surface flow conditions at all times--there can be no pressurization. The continuity equation for a circular conduit is the same as equation [23] with $q_c = 0$. That is, there is no lateral inflow. The upper boundary condition is a specified discharge as a function of time. The most general discharge relationship and the one often used for flow in pipes is the Darcy-Weisbach formula:

$$S_f = \frac{f_D}{4R} \frac{u^2}{2g} \qquad [26]$$

where S_f is the friction slope, f_D is the Darcy-Weisbach friction factor, and u is the velocity (Q/A). Under the

Table 6.
Elements of a trapezoidal channel from geometry of figure 6

Geometric or hydraulic element	FORTRAN variable or function name	Mathematical relationship
Wetted perimeter at depth h	P	$b \cdot CO1 + H \cdot CO2$
	CO1	$1/ZL + 1/ZR$
	CO2	$\sqrt{1 + 1/ZL^2} + \sqrt{1+1/ZR^2}$
Discharge at depth h	GAF(H)	$\alpha(H \cdot CO1 \cdot (b+H/2))^N/(b \cdot CO1+H \cdot CO2)^{N-1}$
Area at depth h	AFH(H)	$H \cdot CO1 \cdot (b+H/2)$
	HF(H)	$(H \cdot CO1 \cdot (b+H/2))^{N-1}/(b \cdot CO1+H \cdot CO2)^N$
dQ/dh	DGH(H)	$\alpha\ HF(H) \cdot [CO1 \cdot (b+H) \cdot N \cdot (b \cdot CO1+H \cdot CO2)-(N-1) \cdot CO2 \cdot (H \cdot CO1 \cdot (b+H/2))]$
Depth at area A	HFA(A)	$-b+\sqrt{b^2 + (2 \cdot A/CO1)}$
dQ/dA	DGA(H)	$DGH(H)/(CO1 \cdot (b+H))$

kinematic assumption, S may be substituted for S_f in equation [26]; thus

$$u = 2\sqrt{\frac{2g}{f_D} RS} \qquad [27]$$

Discharge is computed by using equation [27] and

$$Q = \frac{\alpha A^m}{p^{m-1}} \qquad [28]$$

where p is the wetted perimeter, α is $[8gS/f_D]^{1/2}$, and $m = 3/2$. A schematic drawing of a partially full circular section is shown in figure 6, and geometric relationships are given in table 7.

Table 7.
Geometric elements of a partially full circular conduit from geometry of figure 6

Element	Relationship
Depth (h)	$D\left[1 - \cos\,(\theta_c/2)\right]/2$
Area (A)	$D^2\left(\theta_c - \sin\theta_c\right)/8$
Hydraulic radius (R)	$D\left(1 - \sin\theta_c/\theta_c\right)/4$
Wetted perimeter (p)	$D\left(\theta_c\right)/2$
Hydraulic depth (h_D)	$D\left(\dfrac{\theta_c - \sin\theta_c}{\sin\theta_c/2}\right)/8$

The kinematic equations for channels are solved by a four point implicit technique:

$$A^{i+1}_{j+1} - A^{i}_{j+1} + A^{i+1}_{j} - A^{i}_{j} + \frac{2\Delta t}{\Delta x}\left\{\theta_w\left[\frac{dQ}{dA}^{i+1}\left(A^{i+1}_{j+1} - A^{i+1}_{j}\right)\right] + (1-\theta_w)\left[\frac{dQ}{dA}^{i}\left(A^{i}_{j+1} - A^{i}_{j}\right)\right]\right\}$$

$$- 0.5\Delta t\left(q^{i+1}_{cj+1} + q^{i+1}_{cj} + q^{i}_{cj+1} + q^{i}_{cj}\right) = 0 \qquad [29]$$

where θ_w is a weighting factor for the space derivative. Newton's iterative technique is used to solve for the unknown area $\left(A^{i+1}_{j+1}\right)$. The finite difference equation for circular conduits is the same as equation [29] except that the lateral inflow terms (q_c) are zero.

The appropriate value of Manning's n or Chezy C to use for channels in KINEROS depends on (1) the channel material (that is, grassed waterway, gravel bedded stream, concrete-lined channel), (2) the degree to which the channel conforms to the idealized trapezoidal cross section, and (3) how straight the channel reach is. Because of these factors, choice of the appropriate parameters is highly subjective, except for artificial channels. Barnes (1967) estimated Manning's n for several streams and presented pictures of the stream reaches. These photographs are very useful in obtaining estimates for natural channels. Values of Manning's n or Chezy C for artificial channels can be obtained from several sources, including Chow (1959).

In arid and semiarid regions, infiltration into channel alluvium may significantly affect runoff volumes and peak discharge. If the channel infiltration option is selected, the integrated form of equation [4] is used to calculate accumulated infiltration at each computational node, beginning either when lateral inflow begins or when an advancing front has reached that computational node. Because the trapezoidal channel simplification introduces significant error in the area of channel covered by water at low flow rates (Unkrich and Osborn 1987), an empirical expression is used to estimate an "effective wetted perimeter." The equation used in KINEROS is

$$p_e = \min \left[h/(0.15\sqrt{BW}),\ 1.0 \right] p \qquad [30]$$

where p_e is the effective wetted perimeter for infiltration, h is the depth, BW is the bottom width, and p is the channel wetted perimeter at depth h. This equation states that p_e is smaller than p until a threshold depth is reached, and at depths greater than the threshold depth, p_e and p are identical. The channel loss rate is obtained by multiplying the infiltration rate by the effective wetted perimeter. Further experience may suggest changes in the form and parameters of equation [30].

Reservoir Routing

In addition to surface and channel elements, a watershed may contain up to three reservoir elements, which receive inflow from one or two channels and produce outflow from an uncontrolled outlet structure. Rain falling on the pond and infiltration from the pond are not considered. As long as outflow is solely a function of reservoir depth, the reservoir is well described by the mass balance and outflow equations:

$$\frac{dV}{dt} = q_I - q_O \qquad [31]$$

and

$$q_O = C_1(h_r - h_z)^{c_2} \tag{32}$$

in which $V = V(h_r)$ is reservoir volume $[L^3]$,

h_r = reservoir surface elevation [L],

q_I = inflow rate $[L^3/T]$,

q_O = outflow rate $[L^3/T]$,

h_z = reservoir outflow weir elevation [L], and

C_1 and c_2 = weir coefficients.

Reservoir surface elevation (h_r) is measured from some datum below the lowest pond elevation, and $V(h_r)$ is determined from the description of the reservoir geometry. Equation [31] is written in finite difference form over a time interval (Δt) and the stage at time $t + \Delta t$ is determined by the bisection method.

For purposes of water routing, the reservoir geometry may be described by a simple relation between V and h_r. However, one of the functions of reservoirs may be to trap sediment, so a more complete description is required by KINEROS. The reservoir is described as a survey would characterize it, with a series of cross sections using a common base elevation. An example is shown in figure 7. The cross sections are assumed to be normal to the flow of water through the reservoir, starting at the input end and ending at the outflow structure. Knowledge of flow cross-section changes along the flow path through the reservoir is important in routing the deposition of sediment in the pond. The description of the shape of the reservoir is converted within the program into a $V(h_r)$ relation for use in the previous equations.

Erosion and Sediment Transport

As an optional feature, KINEROS can simulate the movement of eroded soil along with the movement of surface water. KINEROS accounts separately for erosion caused by raindrop energy and erosion caused by flowing water. Similar procedures are used to describe transport of sediment within surface and channel elements. Transport of sediment through a reservoir element is handled very much like the analogous process in a settling pond.

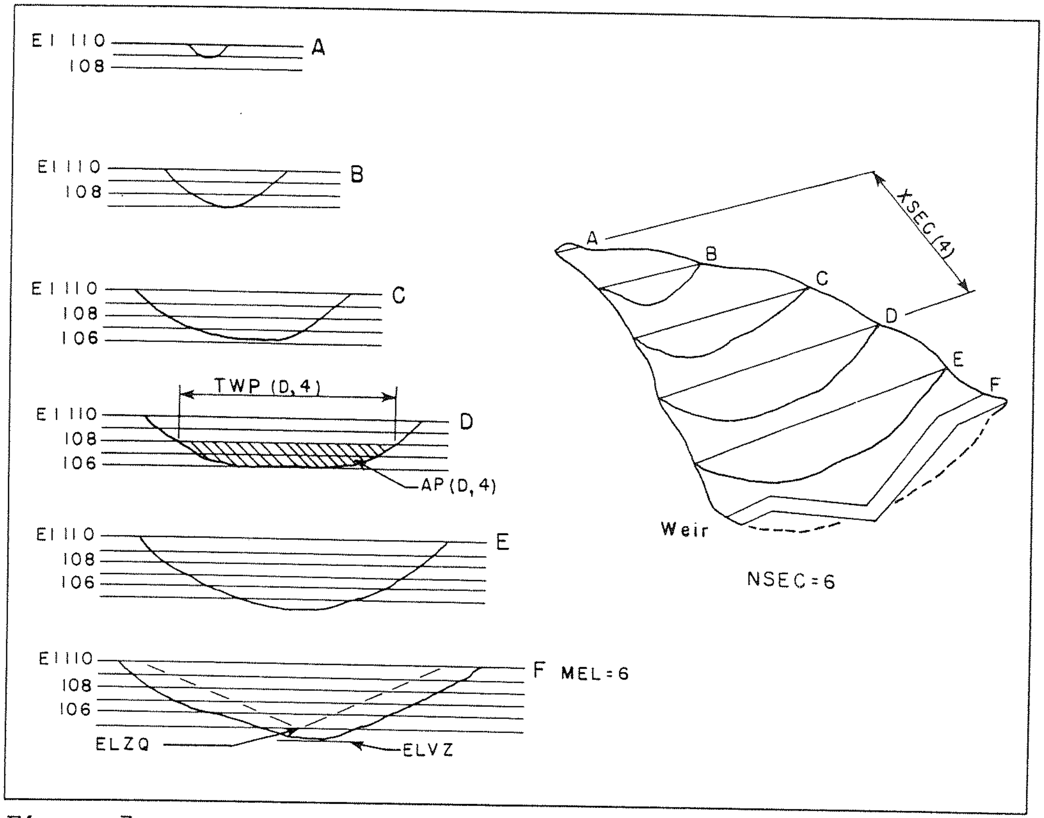


Figure 7.
Pond geometry for KINEROS.

Upland Erosion

The general equation used in KINEROS to describe the sediment dynamics at any point along a surface flow path is a mass balance equation similar to that for kinematic water flow (Bennett 1974):

$$\frac{\partial}{\partial t}(AC_s) + \frac{\partial}{\partial x}(QC_s) - e(x,t) = q_s(x,t) \qquad [33]$$

in which C_s = sediment concentration $[L^3/L^3]$,

A = cross sectional area of flow $[L^2]$,

e = rate of erosion of the soil bed $[L^2/T]$, and

q_s = rate of lateral sediment inflow for channels $[L^3/T/L]$.

For upland surfaces, e is assumed to be composed of two major components--production of eroded soil by splash of rainfall on bare soil and hydraulic erosion (or deposition) due to the interplay between shear force of water on the loose soil bed and the tendency of soil particles to settle under the force of gravity. Referring to splash erosion rate as g_s and hydraulic erosion rate as g_h, we have

$$e = g_s + g_h \qquad [34]$$

Based on limited experimental evidence, splash erosion rate can be approximated as a function of the square of the rainfall rate (Meyer and Wischmeier 1969). We have found that this relationship can lead to physically unrealistic concentrations at the upstream boundary, so in KINEROS we use the following relation:

$$g_s = c_f k(h) r q; \quad q > 0 \qquad [35]$$

$$= 0; \quad q < 0$$

in which c_f is a constant and k(h) is a reduction factor representing the reduction in splash erosion caused by increasing depth of water. It is 1.0 prior to runoff and its minimum is 0 for very deep flow. The function k(h) is given by the empirical expression

$$k(h) = \exp\,(-c_h h) \qquad [36]$$

Both c_f and k(h) are always positive, so g_s is always positive when there is rainfall and a positive rainfall excess (q). On the other hand, g_h represents the rate of exchange of sediment between the flowing water and the soil over which it flows, and may be either positive or negative. KINEROS assumes that for any given surface water flow condition (velocity, depth, slope, etc.), there is an equilibrium concentration of sediment that can be carried if that flow continues steadily. Hydraulic erosion rate (g_h) is estimated as being linearly dependent on the difference between the equilibrium concentration and the current sediment concentration. In other words, hydraulic erosion is modeled as a kinetic transfer process:

$$g_h = c_g (C_{mx} - C_s) A \qquad [37]$$

in which C_{mx} is the concentration at equilibrium transport capacity, $C_s = C_s(x,t)$ is the current local sediment concentration, and c_g is a transfer rate coeffficient $[T^{-1}]$. Clearly the transport capacity is important in determining hydraulic erosion, as is the selection of transfer rate coefficient. Conceptually, c_g would be very low for cohesive material and very high (realistically, less than 0.1 s^{-1}) for fine, totally noncohesive material. Foster et al. (1983) proposed a function to estimate c_g based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965 1978) soil erodibility factor plus information on the soil mulch and residue conditions. This method is applicable to cultivated soils and may be used in KINEROS.

Many transport capacity relations have been proposed in the literature, but most have been developed and tested for relatively deep, mildly sloping flow conditions, such as streams and flumes. In the absence of a clearly superior relation for shallow surface runoff, KINEROS provides the user a choice between several transport relationships: (1) A "tractive force" relation used by Meyer and Wischmeier (1969) and attributed to Laursen (1958), (2) the unit stream power relation of Yang (1973), (3) the Bagnold relationship (Kilinc and Richardson 1973), (4) the relation from Ackers and White (1973), (5) the transport relation of Yalin (1963), and (6) the transport relation of Engelund and Hansen (1967). These relations have been studied and compared by Alonso et al. (1981) and by Julien and Simons (1985), who showed that each could be represented by a generalized relation of the type

$$q_m = C_{mx}Q = \omega\, S^{\beta}\, Q^{\gamma}\, r^{\delta} \left[1 - \frac{\tau_c}{\tau_o} \right]^{\epsilon} \quad ; \; \tau_o \geq \tau_c \qquad [38]$$

in which q_m = transport capacity $[L^2T^{-1}]$,

τ_o = bed shear stress $[L^2/T]$,

τ_c = critical shear stress $[L^2/T]$, and

ω = a coefficient.

Exponents β, γ, and ϵ have values of either 0 or between 1 and 2, and δ varies from 0 to -2.24. The equations for each transport relationship are presented in the appendix.

Although not every transport relation selectable in KINEROS has non-zero values for all the exponents β, γ, and ϵ, all use such local hydraulic conditions as slope, velocity, or depth of flow. Some, in addition, use sediment specific gravity and the mean particle size of the soil rather than requiring selection of an empirical coefficient.

The hydraulic erosion parameter (c_g) has two interpretations. It represents erodibility as constrained by cohesiveness and related factors when C_{mx} is greater than C_s. Alternatively, c_g is a function of the relative fall velocity of the median size particles when deposition is occurring, that is, when C_s exceeds C_{mx}.

In local deposition, the value of c_g is calculated from particle size and density. Particle fall velocity (v_s) may be calculated from particle density and size, assuming the particles have drag characteristics and terminal fall velocities similar to those of spheres (Fair and Geyer 1954):

$$v_s^2 = \frac{4}{3} \frac{g(S_s - 1)d}{C_D} \qquad [39]$$

in which g = gravitational acceleration $[LT^{-2}]$,
S_s = particle specific gravity,
C_D = drag coefficient, and
d = particle diameter $[L]$.

The drag coefficient is a function of particle Reynolds number as follows:

$$C_D = \frac{24}{R_n} + \frac{3}{\sqrt{R_n}} + 0.34 \qquad [40]$$

in which R_n is the particle Reynolds number, defined as

$$R_n = v_s d/\nu \qquad [41]$$

where ν is kinematic viscosity of water $[L^2/T]$. Settling velocity of a particle is found by solving equations [39], [40], and [41] for v_s. The coefficient c_g in equation [37] is then

$$c_g \text{ (deposition)} = \frac{v_s}{h_D} \left[1 - \frac{C_{mx}}{C_s} \right] \qquad [42]$$

where h_D is the hydraulic depth.

In physical terms, this expression says that the particles in excess of the carrying capacity concentration (C_{mx}) will be removed at the settling velocity rate.

Numerical Solution

Equation [33] is solved numerically at each time step used by the surface water flow equations. A four-point implicit finite-difference scheme is used; however, iteration is not required if erosion is occurring since given current and immediate past values for A and Q and previous values for C_s, the finite-difference form of this equation can be solved for $C_{s\,j+1}^{\,i+1}$ as a function of $C_{s\,j}^{\,i}$, $C_{s\,j+1}^{\,i}$, and $C_{s\,j}^{\,i+1}$.

During deposition the values of C_{mx} and C_s in equation [42] are taken as $C_{mx\,j+1}^{\,i}$ and $C_{s\,j+1}^{\,i}$ so iteration is not required.

When runoff commences during a period when rainfall is creating splash erosion, the initial condition on the vector C_s should not be taken as zero. The initial sediment concentration at ponding ($C_s(t=t_p)$), can be found by simplifying equation [33] for conditions at that time. Variation with respect to x vanishes, and hydraulic erosion is zero. We may then state

$$\frac{\partial}{\partial t}(AC_s) = e(x,t) = c_f rq \qquad [43]$$

Here we have assumed k(h) = 1.0 since depth is zero. If we expand the derivative and note that A is zero at time of ponding and recognize that dA/dt is the rainfall excess rate (q), we find

$$C_s(t=t_p) = \frac{c_f\ r\ q}{(q+v_s)} \qquad [44]$$

The sediment concentration at the upper boundary of a single plane $C_s(0,t)$ is given by an expression identical to equation [44].

Channel Erosion and Sediment Transport

The general approach to sediment transport simulation for channels is nearly the same as that for upland areas. The major difference in the equations is that splash erosion (g_s) is neglected in channel flow, and the term q_s becomes important in representing lateral inflows. Equation [33] is equally applicable to either channel or distributed surface flow. The choice of transport capacity relation may be different for the two flow conditions. For upland areas, q_s will be zero, whereas for channels it will be the important addition that comes with lateral inflow from surface elements. The close similarity of the treatment of the two types of elements allows the program to use the same algorithms for both types of elements.

The computational scheme for any element uses the same time and space steps employed by the numerical solution of the surface water flow equations. In that context, equation [33] is solved for $C_s(x,t)$, starting at the first node below the upstream boundary, and from the upstream conditions for channel elements. If there is no inflow at the upper end of the channel the transport capacity at the upper node is zero and the deposition mode is in effect. The upper boundary condition is then

$$C_s(0,t) = \frac{q_s}{q_c + v_s \, BW} \qquad [45]$$

where BW is the channel bottom width.

Note that for a triangular channel the upper boundary concentration is equal to the concentration in the lateral inflow. A(x,t) and Q(x,t) are assumed known from the surface water solution.

Sediment Routing Through Reservoirs

For shallow rapid flow where erosion is generally more important than deposition, the use of a mean particle diameter can usually be justified for simulation purposes. When reservoirs are important elements in the catchment, however, KINEROS asks the user to specify a particle size distribution, because deposition is the only sedimentation process, and settling velocity is very sensitive to particle size. The distribution is characterized by a mean and a standard deviation and is assumed pseudonormally distributed into particle size classes as specified by the user.

As indicated, the approach for pond sedimentation in KINEROS is similar to that for tank sedimentation, and particle fall velocities and flow-through velocities are used to find the trajectories that intersect the reservoir bottom. The input reservoir cross sections describe its shape (see fig. 7) successively from the inlet to outlet ends of the reservoir. Particle fall velocities are calculated for each particle size class using equations [39] - [41]. Particles are assumed distributed uniformly through the reservoir depth in the first section at the inlet end, and the relative fall versus lateral velocities from that point forward determine the proportion of each particle size class that deposits between successive cross sections. At successive sections, each particle size class will have a conceptual depth from the surface to the top of the area still containing sediment of that size.

Suspended and slowly falling particles are subject to molecular diffusion and dispersion, which can sometimes modify the time distribution of outflow concentrations. KINEROS simulates this modification using an effective dispersion coefficient, which is supplied by the user. Typical values suggested are from 10^{-5} to 10^{-4} ft^2/s. In many cases, dispersion is unimportant and can be neglected, such as for very short flow-through situations or for large particles.

If a pond is located within a watershed, the mean particle diameter of the outflow will be smaller than that of the inflow. KINEROS cannot account for this phenomona.

Since the time necessary for a reservoir outflow to approach zero may be significantly longer than that for a channel input hydrograph to return to zero, the user may need to specify a much longer simulation time if a pond or ponds are included in the catchment geometry.

Program Description

A FORTRAN77 program has been written to implement the KINEROS model. The code is structured, with 42 subroutines or functions, each performing specific model functions. Table 8 lists the subroutines and defines their tasks.

KINEROS is run interactively, with the program prompting the user for names of input and output files. When files are used repetitively (for example, on initial runs where parameters are varied for purposes of "calibration"), the user has the option to reuse files without having to reenter the names.

Two input files (or additional files for PONDS) are required to run KINEROS and two output files are always written. Detailed file descriptions follow. It is suggested that the user follow a file-naming convention to simplify KINEROS usage. The developers typically call input parameter files by a name that describes the location and watershed with the extension .PAR, for example, LUCKY103.PAR for Lucky Hills Watershed 103 parameter file. Similarly, LUCKY103.PRE would be the precipitation file for that location. Some users incorporate the rain dates in the file names. LUCKY103.DAT would be the standard hydrologic output, and LUCKY103.AUX is the auxiliary detailed output. *KINEROS makes no demands of the user so far as file names are concerned.* A naming convention is recommended simply for easy use.

The developers have experienced the frustrations of handling input files consisting of matrices of unidentified numbers, where one changes the watershed area when intending to change a channel length. Because FORTRAN77 does not support the handy NAMELIST function, KINEROS input files have been constructed as templates, with each variable's name appearing above the space where the value should be entered and with some guidance as to line duplication requirements where necessary. Sample template files are illustrated with run examples in the next section and are included on the program diskette.

Table 8.
KINEROS program and subroutines

PROGRAM MAIN:	Calls subroutines INTSEL, READER, PLANE, CHANNL, POND, CONVERT and HYDRITE
SUBROUTINES:	
ADD:	Adds specified discharges (lateral flow, channel junctions) and computes upstream boundary values (depth, area, or intersection angle θ_c in conduits). Called from CHANNL and POND. Calls ERROR, ITER, and GOTOER.
BISECT:	Locates the minimum of an external one-dimensional function using the bisection method. Called from ITER. Calls FCT.
CAPACY:	Calculates erosion transport capacity for local suspended sediment concentration (equation [37]). Called from SEDCOM. Calls SHIELDF.
CHANINF:	Calculates an index accumulated infiltration depth at each node using the integrated form of equation [4]. Called from IMPLCT.
CHANNL:	Implicit finite difference solution for unsteady flow in channels with trapezoidal or circular cross sections. Called from MAIN. Calls IMPLCT, SEDCOM, ADD, RESLAW, CHGLAW, and VSETL.
CHGLAW:	Changes the hydraulic resistance laws at the transition Reynolds number if Laminar-Turbulent option has been selected. Called from IMPLCT, CHANNL and PLANE.
CONVERT:	Converts units of time and length in input data to units used internally and reconverts to desired units in output. Called from MAIN and READER.
DEFAULT:	Sets default values for parameters. Called from PAREAD.
ERROR:	Prints appropriate execution error messages. Called from READER, PONDRD, ADD, PLANE, IMPLCT, and IMPAUB. Calls GOTOER.
FCP:	Finds flux capacity as a function of water in soil profile. Called from FINTG and XPLINF.
FINTG:	Integrates infiltration equation [4]. Called from XPLINF. Utilizes functions QCP, FCP, and FOF.
FOF:	Returns the cumulative infiltration depth. Called from FINTG.

Table 8--Continued.
KINEROS program and subroutines

GOTOER:	Escape routine called when arguments are incorrect in a computed "GO TO" statement. Called from INSPEC, ERROR, ADD, RESLAW, PLANE, and IMPLCT.
HOFV:	Calculates pond surface elevation given surface area or volume by log interpolation. Called from POND.
HYDRITE:	Writes hydrograph for selected element (plane or channel). Called from MAIN.
IMPAUB:	Calculates an error function for an assumed area in the iterative solution for the upper boundary area of a trapezoidal channel, given an upstream discharge. Called from ADD through ITER. Calls ERROR.
IMPCHA:	Calculates an error function for an assumed area in the iterative solution for cross sectional area in a trapezoidal channel. Called from IMPLCT through ITER.
IMPCIR:	Calculates an error function for assumed value of the independent variable θ_c in the iterative solution for cross sectional area in a circular channel. Called from IMPLCT through ITER.
IMPLCT:	Four point implicit finite difference scheme. Called from subroutines PLANE and CHANNL. Calls ITER, CHGLAW, GOTOER, ERROR, and CHANINF.
IMPOCF:	Calculates an error function for an assumed depth h in the iterative solution of depth along a plane. Called from IMPLCT through ITER.
IMTHUB:	Calculates an error function for an assumed value of the independent variable θ_c in the iterative solution of upper boundary area of a circular conduit, given an upstream discharge Q from ADD. Called from ADD through ITER.
INSPEC:	Inspects input data for errors and prints out an error message if one is detected. Called from READER and PAREAD. Calls ERROR.
INTSEL:	Interactive file selection routine. Called from MAIN.
ITER:	Newton-Raphson iteration scheme to solve general nonlinear equations of the form F(x) = 0. Called from ADD and IMPLCT. Calls variable functions FCT (passed to ITER in the call statement as IMTHUB, IMPOCF, IMPCHA, IMPCIR, and IMPAUB) and BISECT.

Table 8--Continued.
KINEROS program and subroutines

PAREAD:	Reads data from file IREAD. Called from READER. Calls READTM, INSPEC, DEFAULT, and PONDRD.
PLANE:	Finite difference solution for overland flow on a plane. A four point implicit method is used. Called from MAIN. Calls IMPLCT, RESLAW, ERROR, CHGLAW, XPLINF, SEDCOM, UNIF, GOTOER, and VSETL.
POND:	Routes flow through a storage element and calculates selective particle sedimentation if required. Called from MAIN. Calls VOLCAL, SEDIV, HOFV, VOFH, ADD and VSETL.
PONDRD:	Reads pond data input such as cross-sectional areas, top widths, and other necessary pond data. Called from PAREAD. Calls READTM and ERROR.
QCP:	Finds water storage in profile as a function of flux. Called from FINTG.
READER:	Reads in model parameters, watershed geometry data and rainfall data. Called from MAIN. Calls READTM, INSPEC, PAREAD, and CONVERT.
READTM:	Reads N records from input file INUN. Used to skip over nondata records in the input templates. Called from READER and PAREAD.
RESLAW:	Calculates the parameters for the hydraulic resistance law selected in the input. Called from PLANE and CHANNL. Calls GOTOER.
SEDCOM:	Calculates sediment concentrations and deposition depths given values for local depth, slope, and velocity (equation [33]) using transport capacity calculated by CAPACY and rain splash detachment rate calculated by SPLASH. Called from PLANE and CHANNL. Calls CAPACY and SPLASH.
SEDIV:	Calculates the mean particle size for each of n equal class intervals for a sediment with a given median particle size and standard deviation of particle diameters. Called from POND. Calls URAN.
SHIELDF:	Computes the dimensionless critical tractive force for particle movement. Called from CAPACY.
SPLASH:	Determines rain splash erosion rate by an empirical function of rain intensity modified by local water mean depth. (See equations [35] and [36]) Called from SEDCOM.

Table 8--Continued.
KINEROS program and subroutines

UNIF:	Uses linear interpolation to convert a list of discharge values at irregular time increments into a list with regular time increments. Called from PLANE.
URAN:	Calculates uniform random variable. Called from SEDIV.
VOFH:	Calculates elevation dependent variable (volume or area) by log interpolation given depth. Called from POND.
VOLCAL:	Calculates volume-stage and surface area-stage table. Called from POND.
VSETL:	Computes a particle settling velocity. Called from POND, CHANNL, and PLANE.
XPLINF:	Computes infiltration rates. Called from PLANE. Calls FINTG and FCP.

Creation of Input Files

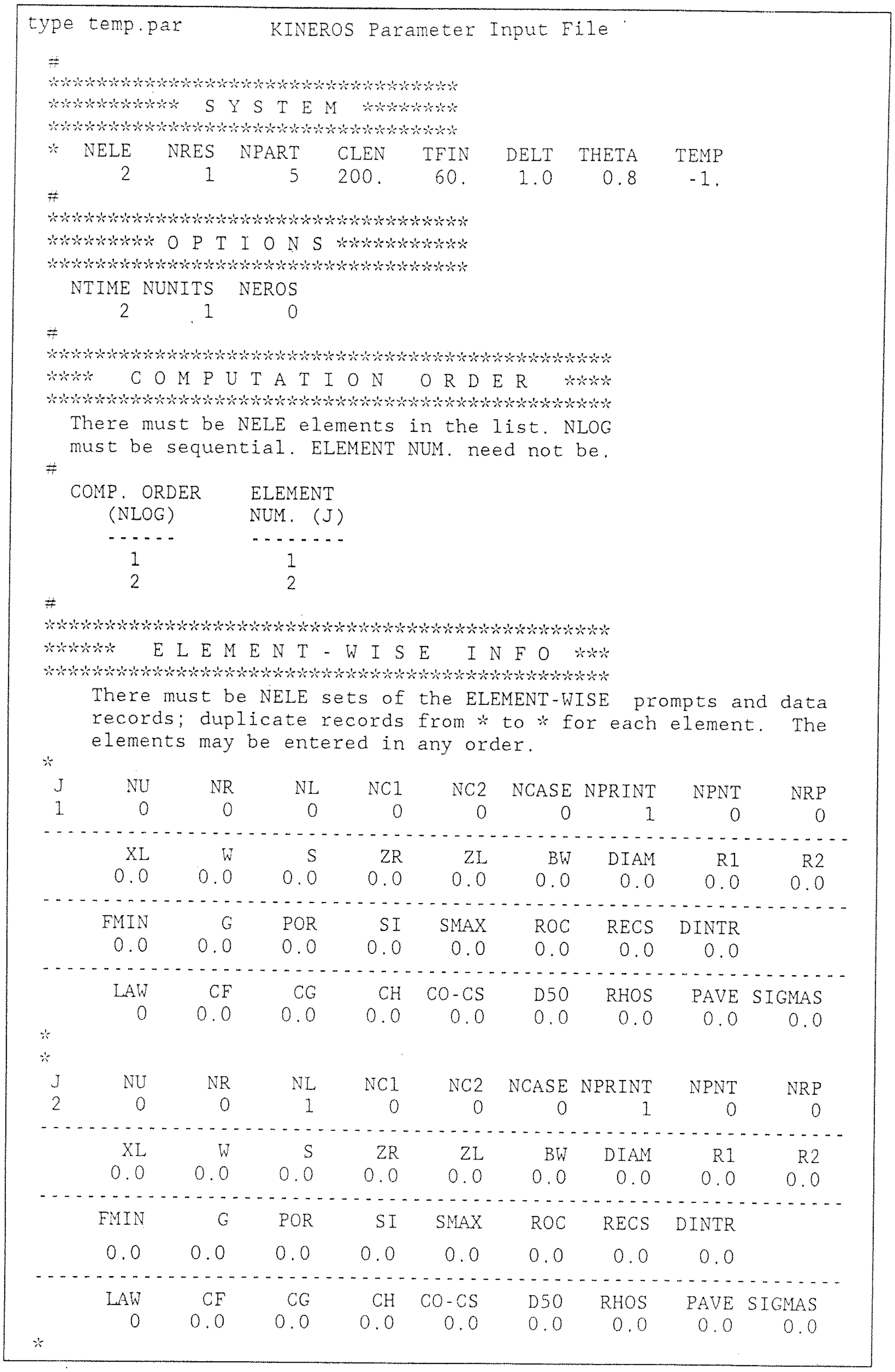
KINEROS reads input data from three input files. The names of these files are supplied by the user during execution of the program. One file contains rainfall data for all the raingages on or near the watershed that are used in the simulation. The second file has data describing the hydrologic features of the surfaces and channels of the watershed. In this file are data describing the network of planes and channels, their size and slope, hydraulic roughness of each, and infiltration and erosion parameters of each element. The third file contains data describing hydrologic features of any ponds that are part of the watershed.

Templates, which are preformatted files into which the user may enter data, are supplied with the program. Figures 8 - 10 illustrate three template files of sample data. Table 9 contains names, definitions, and units of all input data contained in all three files. All data are read using unformatted READ statements, so the exact position of each entry is not crucial. However, there must be at least one space or a comma between entries, and data must be entered for each item. *The user should be careful not to add or delete heading lines.* In this section, we briefly discuss estimation guidelines, when they exist, for the more difficult parameters.

The user has several operational choices in KINEROS, including units for input and output and detail of output for any element in the network. Choices of many of the hydrologic parameters are necessarily subjective and depend partly on the user's hydrologic experience as well as knowledge of the watershed for which simulation is being performed. In the following sections we attempt to give as much guidance as practical in selecting parameters that are at least reasonable for the conditions treated.

Watershed Geometry - Selection of Planes and Channels

The objective is to select a set of planes and channels and the flow linkage that will preserve the most significant spatial variations of topography, soils, cover, and rainfall. Although there is no objective method for selecting the network of planes and channels, Lane et al. (1975) provided some guidelines and insights regarding the effects of geometric simplification on parameter values and hydrograph simulation.

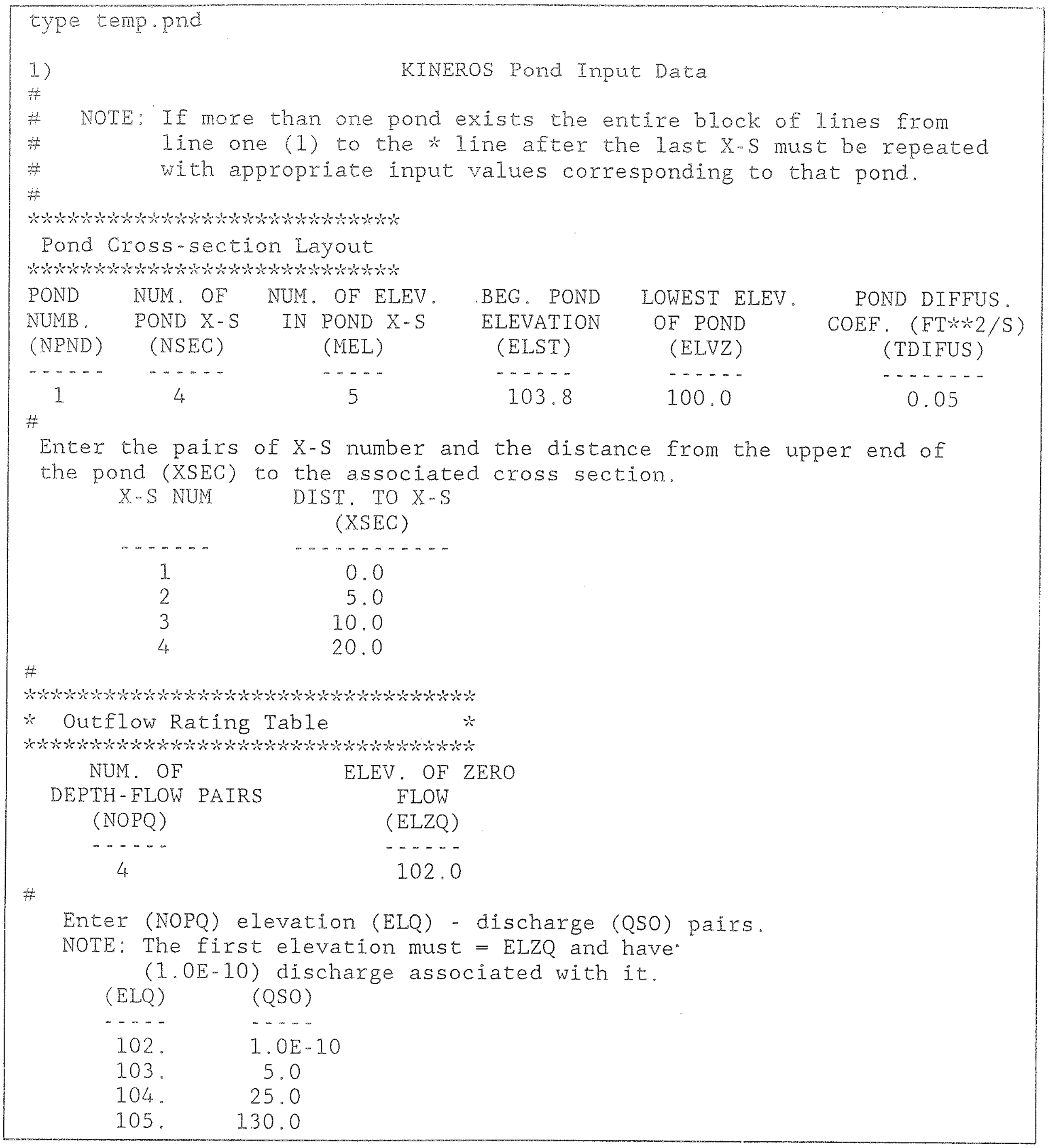


```
type temp.par        KINEROS Parameter Input File
 #
 ************************************
 ***********  S Y S T E M  ********
 ************************************
 *  NELE    NRES   NPART    CLEN    TFIN    DELT   THETA    TEMP
       2       1       5    200.     60.     1.0     0.8     -1.
 #
 *************************************
 ********* O P T I O N S ***********
 *************************************
   NTIME NUNITS  NEROS
       2      1      0
 #
 **************************************************
 ****   C O M P U T A T I O N   O R D E R   ****
 **************************************************
   There must be NELE elements in the list. NLOG
   must be sequential. ELEMENT NUM. need not be.
 #
   COMP. ORDER    ELEMENT
      (NLOG)      NUM. (J)
      ------      --------
        1            1
        2            2
 #
 **************************************************
 ******   E L E M E N T - W I S E   I N F O  ***
 **************************************************
     There must be NELE sets of the ELEMENT-WISE  prompts and data
     records; duplicate records from * to * for each element.  The
     elements may be entered in any order.
 *
  J       NU       NR       NL      NC1      NC2   NCASE NPRINT    NPNT      NRP
  1        0        0        0        0        0       0      1       0        0
 -------------------------------------------------------------------------------
          XL        W        S       ZR       ZL      BW    DIAM      R1       R2
         0.0      0.0      0.0      0.0      0.0     0.0     0.0     0.0      0.0
 -------------------------------------------------------------------------------
        FMIN        G      POR       SI     SMAX     ROC    RECS   DINTR
         0.0      0.0      0.0      0.0      0.0     0.0     0.0     0.0
 -------------------------------------------------------------------------------
         LAW       CF       CG       CH    CO-CS     D50    RHOS    PAVE SIGMAS
           0      0.0      0.0      0.0      0.0     0.0     0.0     0.0     0.0
 *
 *
  J       NU       NR       NL      NC1      NC2   NCASE NPRINT    NPNT      NRP
  2        0        0        1        0        0       0      1       0        0
 -------------------------------------------------------------------------------
          XL        W        S       ZR       ZL      BW    DIAM      R1       R2
         0.0      0.0      0.0      0.0      0.0     0.0     0.0     0.0      0.0
 -------------------------------------------------------------------------------
        FMIN        G      POR       SI     SMAX     ROC    RECS   DINTR

         0.0      0.0      0.0      0.0      0.0     0.0     0.0     0.0
 -------------------------------------------------------------------------------
         LAW       CF       CG       CH    CO-CS     D50    RHOS    PAVE SIGMAS
           0      0.0      0.0      0.0      0.0     0.0     0.0     0.0     0.0
 *
```

Figure 8.
Template for parameter input.

```
 type temp.pre

                              KINEROS   Rainfall Input Data
#
****************************
      Gage Network Data
****************************
#
  NUM. OF RAINGAGES    MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
      (NGAGES)             (MAXND)
      --------             -------
        1                    6
#
 There must be NELE  pairs of (GAGE  WEIGHT) data
*
 ELE. NUM. (J)     RAINGAGE     WEIGHT
 -------------     --------     ------
       1              1           1.0
       2              1           1.0
#
*****************************
       Rainfall Data
*****************************
 There must be NGAGES sets of rainfall data. Repeat lines from * to *
 for each gage inserting a variable number of TIME-DEPTH data pairs
 (see example in User Manual).
#
* ALPHA-NUMERIC GAGE ID: WALNUT GULCH GAGE #5 = GAGE NUM. 1
#
  GAGE NUM.     NUM. OF DATA PAIRS (ND)
  ---------     -----------------------
     1                    6
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time).
#
   TIME     ACCUM. DEPTH
  ------    ------------
    0.0         0.00
    5.0         0.16
    8.0         0.17
   13.0         0.40
   15.0         0.42
  100.0         0.42
*
```

Figure 9.
Template for rainfall input.



```
type temp.pnd

1)                          KINEROS Pond Input Data
#
#   NOTE: If more than one pond exists the entire block of lines from
#         line one (1) to the * line after the last X-S must be repeated
#         with appropriate input values corresponding to that pond.
#
****************************
 Pond Cross-section Layout
****************************
POND    NUM. OF   NUM. OF ELEV.   BEG. POND   LOWEST ELEV.    POND DIFFUS.
NUMB.   POND X-S   IN POND X-S    ELEVATION    OF POND      COEF. (FT**2/S)
(NPND)   (NSEC)       (MEL)        (ELST)       (ELVZ)          (TDIFUS)
------   ------       -----        ------       ------          --------
  1        4            5           103.8       100.0             0.05
#
 Enter the pairs of X-S number and the distance from the upper end of
 the pond (XSEC) to the associated cross section.
       X-S NUM      DIST. TO X-S
                       (XSEC)
       -------      ------------
          1             0.0
          2             5.0
          3            10.0
          4            20.0
#
**********************************
*  Outflow Rating Table          *
**********************************
     NUM. OF              ELEV. OF ZERO
  DEPTH-FLOW PAIRS            FLOW
     (NOPQ)                  (ELZQ)
     ------                  ------
       4                      102.0
#
   Enter (NOPQ) elevation (ELQ) - discharge (QSO) pairs.
   NOTE: The first elevation must = ELZQ and have
         (1.0E-10) discharge associated with it.
      (ELQ)      (QSO)
      -----      -----
       102.      1.0E-10
       103.       5.0
       104.      25.0
       105.     130.0
```

Figure 10.
Template for pond geometry.

```
#
************************************
   Specific Cross-section Data
************************************
   There must be (NSEC) sets of cross-section records with (MEL) elevations
   per X-S with X-S area (A) and top width (TWP). For each cross-section
   repeat lines from * to * inserting the appropriate num. of elev. (MEL).
   ****
   NOTE: The pond cross section information must be defined to the "same"
   ****  elev. as the highest elev. in the elevation-discharge table.
   *
      X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                   (EL)          (A)            (TWP)
      -------      -----       --------     -------------
         1         101.0          0.0            0.0
         1         102.0          0.0            0.0
         1         103.0          1.0            3.15
         1         104.0          6.23           7.33
         1         105.0         10.30           9.58
   *
   *
      X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                   (EL)          (A)            (TWP)
      -------      -----       --------     -------------
         2         101.0          0.0            0.0
         2         102.0          0.46           2.11
         2         103.0          6.51           8.41
         2         104.0         16.20          11.31
         2         105.0         28.80          15.49
   *
   *
      X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                   (EL)          (A)            (TWP)
      -------      -----       --------     -------------
         3         101.0          1.52           3.05
         3         102.0          7.49           9.24
         3         103.0         21.10          14.30
         3         104.0         36.30          17.70
         3         105.0         52.75          22.45
   *
   *
      X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                   (EL)          (A)            (TWP)
      -------      -----       --------     -------------
         4         101.0          1.71           4.22
         4         102.0          7.30           6.57
         4         103.0         15.20          10.70
         4         104.0         30.50          21.10
         4         105.0         44.30          27.70
   *
```

Figure 10--Continued.
Template for pond geometry.

Table 9.
Definitions of input variables and parameters

Name	Definition
A	Area of pond cross section below a given elevation (EL) - ft^2 or m^2.
BW	Channel bottom width - ft or m.
CF	Rainsplash parameter equation [35].
CG	Hydraulic erosion transfer coefficient rate - equation [37].
CH	Rainsplash erosion damping parameter - equation [36] - in or mm.
CLEN	Characteristic length of overland or channel flow. Use maximum of sum of lengths of cascading planes or longest channel - ft or m.
CO	Parameter in Kilinc and Richardson erosion relationship - equation [A.3].
CS	Parameter in tractive force erosion equation [A.1].
D	Accumulated rainfall depth at time (T) - in or mm.
D50	Median sediment particle diameter - ft or μm. Required for all laws.
DELT	Time increment to be used in calculations - estimate using equations [48] or [49].
DIAM	Conduit diameter - ft or m.
DINTR	Interception depth - in or mm.
EL	Elevation of plane for pond cross section - ft or m.
ELQ	Elevation for pond discharge rating table - ft or m.
ELST	Pond water surface elevation at beginning of event - ft or m.
ELVZ	Elevation of lowest point of pond bottom - ft or m.
ELZQ	Zero flow elevation for pond outlet - ft or m.
FMIN	Saturated hydraulic conductivity. Note: If obtained for soil matrix, it should be corrected for volume of rock. $FMIN = K_s\ (1 - V_r)$. English - in/h. Metric - mm/h.

Table 9--Continued.
Definitions of input variables and parameters

G	Effective net capillary drive - in or mm. Note: If obtained from infiltrometer data it should be corrected by dividing by $(1-V_r)$.
GAGE	Rain gage (1 - 20) for input to watershed element.
J	Element number.
LAW	Code for erosion law. 1 Tractive force - equation [A.1]. 2 Unit stream power - equation [A.2]. 3 Bagnold/Kilinc - equation [A.3]. 4 Ackers and White - equation [A.4]. 5 Yalin - equation [A.12]. 6 Engelund and Hansen - equation [A.13].
MAXND	Maximum number of rainfall time-depth pairs - MAXND $\le$ 100.
MEL	Number of elevations in pond cross section input - 2 $\le$ MEL $\le$ 10.
NCASE	Code for channel type: 1 Trapezoidal. 2 Circular.
NC1	Element number of first channel contributing at upstream boundary.
NC2	Element number of second channel contributing at upstream boundary.
ND	Number of rainfall time-depth pairs for specific rain gage - ND $\le$ MAXND.
NELE	Number of plane, channel, and pond elements - NELE $\le$ 60.
NEROS	Code for erosion option: 0, 1 No erosion calculation. 2 Erosion option.
NGAGES	Number of rain gages - 1 $\le$ NGAGES $\le$ 20.
NL	Element number of plane contributing to left side of channel.
NLOG(1)	Denotes order of calculation. Element corresponding to NLOG(1) will be calculated first, NLOG(2) will be calculated second, etc.
NOPQ	Number of pond stage-discharge pairs - 2 $\le$ NOPQ $\le$ 20.
NPART	Number of sediment size classes for pond settling algorithm - NPART $\le$ 7.

Table 9--Continued.
Definitions of input variables and parameters

NPND	Number of the pond in the pond input file.
NPNT	Pond code: 0 Plane or channel. 1 Pond.
NPRINT	code for detailed printout in auxiliary output file: 1 Do not print. 2 Print.
NR	Element number of plane contributing inflow to right side of channel.
NRES	Resistance law code: 1 Manning's Law. 2 Laminar - Manning. 3 Laminar - Chezy. 4 Chezy.
NRP	Code for printout of rainfall and intermediate runoff rates in the primary output file: 0 No print. 1 Print rainfall rates for this element. 2 Print intermediate runoff rates. 3 Print both rainfall and runoff rates.
NSEC	Number of pond cross sections - $2 \leq$ NSEC ≤ 10.
NTIME	Code for time units: 1 Seconds. 2 Minutes.
NU	Element number of plane contributing to upstream boundary.
NUNITS	Code for units: 1 English. 2 Metric.
PAVE	Proportion of surface area covered with gravel. PAVE = 1 denotes a paved surface.
POR	Soil porosity.
QSO	Discharge from pond when elevation is ELQ - ft^3/s or m^3/s.
R1	Manning's n for NRES = 1 or 2. Chezy C for NRES = 3 or 4.

Table 9--Continued.
Definitions of input variables and parameters

R2	Laminar "k" for NRES = 2 or 3. Not required for NRES = 1 or 4.
RECS	Infiltration recession factor - in or mm.
RHOS	Specific gravity of sediment particles.
ROC	Volumetric rock content of soil - dimensionless.
S	Slope.
SI	Relative soil saturation - dimensionless $S_r < SI < SMAX$.
SIGMAS	Standard deviation of sediment diameter - ft or μm.
SMAX	Maximum relative saturation under imbibition - $SI < SMAX < 1.0$.
T	Time for rainfall depth (D) - s or min.
TDIFUS	Pond diffusivity coefficient - ft^2/s.
TEMP	Temperature. If in English units, Fahrenheit; in metric, centigrade. Default value is 65°F if TEMP = -1.
TFIN	Duration of runoff computations.
THETA	Weighting factor in finite difference equations - $0.5 < THETA \leq 1.0$.
TWP	Top width of pond section at given elevation - ft or m.
W	Width of plane. If channel, W = 0 - ft or m.
WEIGHT	Multiplication factor to be applied to rainfall depths for GAGE to obtain rainfall pattern for specific element.
XL	Length of plane or channel - ft or m. If zero for a channel, the outflow will be the sum of the channel inflows.
XSEC	Distance from upper end of pond to a given cross section - ft or m.
ZL	Side slope of left side of trapezoidal channel.
ZR	Side slope of right side of trapezoidal channel.

First, topographic and soils maps of the watershed should be obtained and a working map prepared. The channel network should be subdivided into reaches so that the channel cross section in each reach can be represented by a characteristic trapezoidal channel or circular conduit. Flow lines should then be drawn perpendicular to the contour lines from the ends of each channel segment to the drainage divides. Within each of the areas so defined, subareas of different soil texture and land use that may affect infiltration rates as well as changes in land slope should be identified. Finally, these subareas should be approximated by rectangular planes. In selecting the length and width of the planes, it is best to duplicate the average length of flow as closely as possible. Note that the width of an upstream plane contributing to a lower plane or channel need not equal the width of the lower plane or the length of the channel, respectively. The sum of the areas of plane elements contributing to a reach of stream should equal the contributing area as measured on the map.

It may be convenient to sketch planes on the working map. Slopes can be estimated by dividing the vertical drop of a plane by its length. Channel lengths can be scaled from the map. Channel cross sections may be obtained by fitting a trapezoidal section to cross sections taken from the map or from field surveys. For circular conduits, only the length (XL) and diameter (DIAM) are required.

Estimation of Hydraulic Resistance Parameters

First, a decision must be made concerning the resistance law, (NRES) to be used. Options 2 or 3 (laminar-turbulent) are recommended only for very small watersheds with relatively smooth and plane surfaces, such as parking lots and streets. Appropriate values of Manning's n or Chezy C and R1 or the laminar flow constant (k_o) R2 can be taken from tables 4 or 5.

For large watersheds where considerable distortion is introduced by the geometric representation or where surfaces are hydraulically rough, either option 1, the Manning law, or option 4, the Chezy law, is recommended. Manning's law is used most frequently for both planes and channels. Ranges of Manning's n or Chezy C are also given in tables 4 and 5. Hydraulic resistance for overland flow has also been reported by other authors (Emmett 1970, Ree et al. 1977, Rovey et al. 1977, Podmore and Huggins 1980). It should be noted that there is an interaction between values of n or C, the geometric complexity of the model, and the degree of rilling or channeling on the natural surface represented by a plane in the model. In general, n should be reduced or C increased as concentration of flow increases.

Infiltration Parameter Estimation

The infiltration model requires knowledge of one variable--initial relative saturation (SI)--and two parameters discussed previously--G and FMIN. In addition, maximum relative saturation (SMAX) can be estimated from table 2 based on soil texture. KINEROS uses relative saturation values, which are water contents relative to porosity, rather than absolute water contents. Thus, an initial water content (θ_i) of 0.2 for a soil with a porosity of 0.4 would be a saturation (SI) = 0.2/0.4 = 0.5. This value depends on the rainfall history of a catchment prior to the event of interest, as well as soil and vegetation status of the catchment and relative environmental evaporative energy.

In the KINEROS code, AL is used for the expression $G\phi(S_{max}-S_i)$, and FMIN is used to represent K_s. These parameters can be estimated in several ways. Infiltrometer data can be analyzed to obtain fitted values, or natural runoff events can be studied to identify best fit values of these infiltration parameters using a surface water routing model such as KINEROS. This is a difficult procedure, because (1) measurement errors can be crippling and (2) the two parameters exhibit a certain interaction in terms of total runoff from a given storm (Wisheropp 1982).

The parameters can also be determined from unsaturated soil hydraulic characteristics, but these data are most often unavailable. If the textural class of the soil is known--for example, clay loam, silt loam, sandy clay loam--the parameters may be estimated based on the tabulations of Rawls et al. (1982). Table 2 is taken from that report and gives approximate values of hydraulic characteristics to be expected for several soils. Data are considerably scattered, as would be expected, and both geometric mean and arithmetic mean sample values for G are presented, as well as values representing one standard deviation away from the mean. The values of G in table 2 were calculated from the data in Rawls et al. (1982), based on the unsaturated hydraulic characteristic relation of capillary potential to unsaturated K. Values for K_s are also widely scattered, and Rawls et al. (1982) do not provide standard deviations.

Cosby et al. (1984) present regression equations relating the mean log of K_s to percent sand and the standard deviation of log K_s to percent silt. The variable S_r in table 2 represents a relative saturation at which the permeability approaches zero and should be used as a lower bound for S_i unless a lower value can be justified from field data. Initial saturations should be between S_r and S_{max}. Values of S_r and S_{max} in table 2 are sample means from the Rawls et al. (1982) data, and each, of course, varies from soil to soil. This table should be used only as a guideline and careful note taken of the range of values reported.

One additional parameter is required for the infiltration model in KINEROS. ROC is the fraction of surface soil occupied by rocks. It is given as a volume ratio from 0 to 1.0 and represents conceptually the relative volume not acting as a porous medium. It reduces the effective cross-sectional area of vertical flow and decreases the net average value of FMIN in the infiltration model. It is an important parameter in very rocky soils but not in most cultivated field soils.

If parameters FMIN and G are both estimated from infiltrometer data, they both include the effects of rock and the parameter ROC should be set to 0.0. If FMIN is estimated from infiltrometer data and G from soil textural information, G will be corrected for rock within the program, so ROC should be set at its estimated value. If K_s and G are both estimated from soil textural data, FMIN is obtained from the relationship FMIN $= K_s(1 - \text{ROC})$ and G will be corrected within the program.

The method used to determine infiltration parameters depends on the amount and type of data available for a given application and the individual experience of the user of KINEROS.

Erosion Parameters

If erosion is simulated for any element, it should be simulated for all elements. One should not simulate erosion for a channel while not simulating erosion for the plane elements or other channels flowing into that element, unless they are nonerodible surfaces. The KINEROS option flag for erosion thus applies to all elements. A nonerodible surface within the catchment is specified by setting PAVE equal to one.

For each element, there are some parameters that must be chosen depending on the erosion option used. Most of the parameters of the erosion-transport model have already been discussed. In addition, option flags should be set.

Choosing a Sediment Transport Relation

Six sediment transport relations are available to estimate the transport capacity of the flow in channels or on a plane element. They are presented in the appendix. Most were developed and/or validated based on data for flow of noncohesive particles in small laboratory flumes or natural channels. This may indicate how little is actually known about upland sediment transport where flows are very shallow, slopes are often high, and where cohesive forces of soils are significant in resisting erosion. Nevertheless, some of these relations have been applicable to upland erosion (Smith 1978, Foster 1982).

Even for conditions under which they were developed, these different equations often give widely varying results. In this section, we discuss some of their features. The user is encouraged to consult the references for additional information. Comparative features of these equations can be found in Alonso et al. (1981) and Julien and Simons (1984, 1985).

Table 10 lists the six sediment transport relations or laws available in KINEROS and the parameters required for each. Options 1 and 3 are rather simple conceptual relations that employ a coefficient with a function of local hydraulic characteristics. Option 3, the "Bagnold" equation, is a function of local depth and hydraulic bed shear, and option 1 is a function of local flow velocity. Relations 2 and 4-6 are dimensionless equations, which estimate transport capacity from functions of particle size and specific gravity and from water viscosity rather than utilizing an empirical coefficient. Hydraulic conditions of the flowing water are part of current information from the hydraulic model.

Table 10.
Parameters needed by sediment transport relations or laws

Transport capacity relation		Parameter				
No.	Name/Reference	ρ_s	D50	c_s	c_0	ν
1	Tractive force (Meyer and Wischmeier 1969)	*[1]	*	x		*
2	Unit stream power (Yang 1973)	x	x			x
3	Bagnold/Kilinc (Kilinc and Richardson 1973)	*	*		x	*
4	Ackers and White (1973)	x	x			x
5	Yalin (1963)	x	x			x
6	Engelund and Hansen (1967)	x	x			x

[1] Parameters denoted by an *, although not required by the transport relation, are required to calculate deposition rates.

It is important for the user to understand the significance of the effective particle size parameter (D50) in KINEROS. It represents an effective mean value for the element, and the transport and deposition relations are often rather sensitive to its value. Also, it strictly can represent only the value for particles eroded from that element. Sediment carried in from an upstream element is transported as if it were of the particle size specified for the present element. This means that with KINEROS one cannot reasonably simulate erosion from a catchment when subcatchments have widely differing particle sizes.

Estimated ranges for mean particle size (D50) for various soil textures are given in table 11. These values were estimated using the USDA textural classification based on elementary particle composition (USDA 1975). The particle size would be considerably increased and effective particle density decreased for aggregates that are often an important part of transported sediment.

Table 11.
Estimated range of mean particle size for various soil textures

Soil texture	Sand	Silt	Clay	Expected[1] D50
	Percent	Percent	Percent	µm
Clay	0 - 45	0 - 40	55 - 100	1 - 45
Silty clay	.20	40 - 60	40 - 60	2 - 45
Silty clay loam	.20	40 - 73	27 - 40	3 - 46
Silt loam	0 - 50	50 - 87	0 - 27	3 - 50
Silt	0 - 20	80 - 100	0 - 13	8 - 30
Loam	23 - 52	28 - 50	7 - 27	9 - 60
Clay loam	20 - 45	15 - 53	27 - 40	5 - 30
Sandy loam	43 - 85	0 - 50	0 - 20	35 - 160
Loamy sand	70 - 90	0 - 30	0 - 15	90 - 180
Sandy clay	45 - 65	0 - 20	35 - 55	2 - 130
Sandy clay loam	45 - 80	0 - 28	20 - 35	21 - 160
Sand	85 - 100	0 - 15	0 - 10	140 - 200+

[1] From USDA texture triangle (USDA 1975), using assumed mean values of 2 µm for clay, 10 µm for silt, and 200 µm for sand.

The differences among the transport relations may be illustrated by simulating erosion from a simple catchment using transport laws 2 and 4-6. The catchment consists of a single plane with an eroding surface contributing runoff to a nonerodible channel described later as part of example 1 (see fig. 16). The particle size of soil (D50) was varied over an appropriate range for each transport law.

Figure 11 shows the range of results that may be expected from the various equations. For this example, rainfall splash erosion was occurring equally for all relations. Even for insignificant transport capacities, some sediment was predicted because of the continual suspension by rainsplash. This is best shown in figure 11 for the Ackers-White (A-W), Yang, and Yalin relations when the particle size approached 0.004. For all larger particle sizes, erosion would be constant and be production controlled rather than transport controlled.

The Yang Unit Stream Power relation shows the greatest sensitivity to particle size and may be excessively sensitive in this respect. The Engelund-Hansen (E-H) relation has been shown elsewhere (Alonso 1978, pers. commun.) to be robust and relatively accurate for a useful range of particle sizes and hydraulic conditions. The Ackers-White (A-W) relation is only good for particle sizes greater than 0.04 mm (0.00013 ft), and this limiting behavior is shown in figure 11. The Yang relation also has a lower limit of applicability of D50 = 0.062 mm (0.0002 ft).

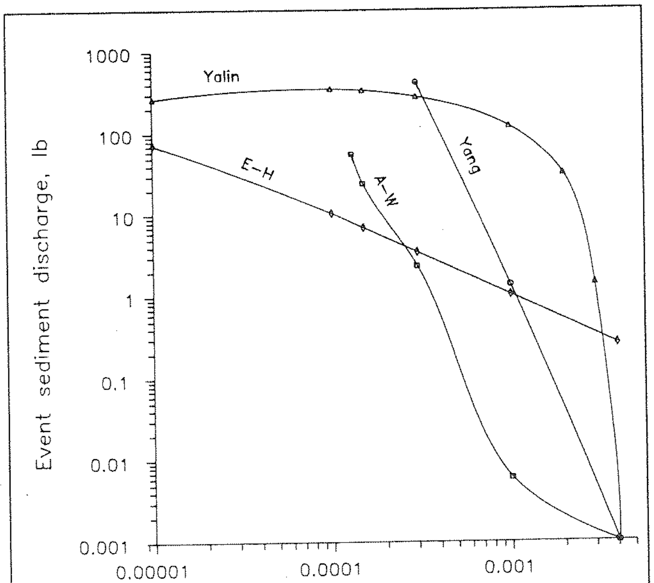


Figure 11. Sediment discharge as function of D50 for four transport capacity relations or laws.

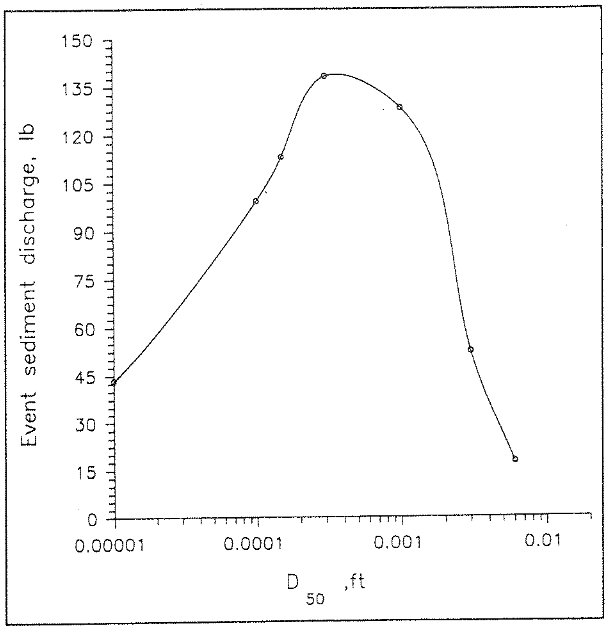


Figure 12. Sediment discharge as function of D50, Yalin relation.

The Yalin relation gives relatively high results for this test, but it has been favored by others (Foster and Meyer 1972) for reproducing transport at relatively shallow depths. Nevertheless, the Yalin equation has some peculiar characteristics at certain ratios of depth to particle size (Alonso 1978, pers. commun.), in which it will predict a reduction of transport capacity with a reduction in particle size, contrary to reasonable expectations. This is related to the complex relation of particle size and shear velocity (increasing with depth) within the function.

Figure 12 shows such behavior, using the same geometry, but simulating erosion in the channel rather than the plane as in figure 11. This relation should be restricted to the range of conditions under which it was tested (Yalin 1963). As with other transport relations, its accuracy for the very shallow flows of plane elements is uncertain.

The tractive force (TF) relation 1 (table 10) has the appeal of simplicity, presuming transport concentration capacity to be a function of velocity to the power 4 and inversely proportional to depth. Meyer and Wischmeier (1969) cited Laursen (1958) as the source for this relationship. Its single parameter (c_s) accounts for variation in particle size, particle density, and any other hydraulic or physical factors not included in the equation. Clearly in this equation, transport capacity is directly related to c_s, and its estimation is best guided by

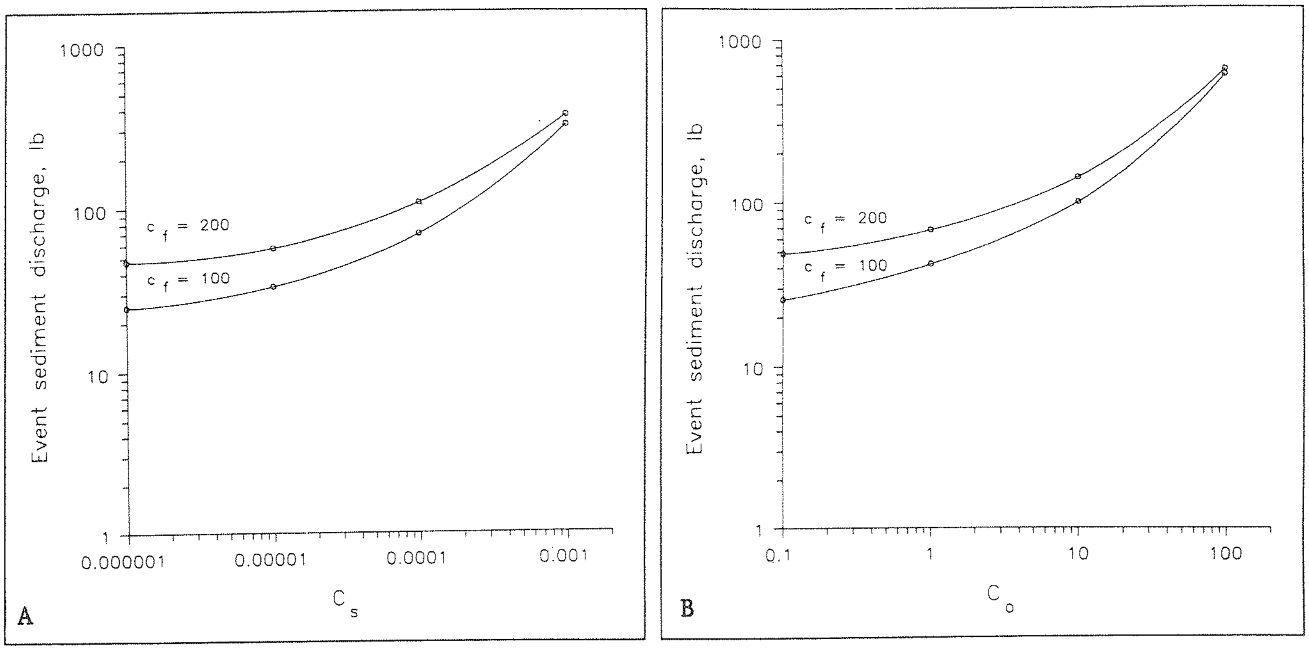


Figure 13.
Sediment discharge predicted A, by the tractive force relation or law as function of parameter c_s and B, by the Kilinc and Richardson relation as fuction of parameter c_o.

comparing results of a range of values with a simple plane example. Figure 13A shows the relation between sediment production for a simple catchment and value of c_s. The catchment consists of the single plane with a nonerodible channel from example 1. The particle diameter (D50) was taken as 0.00001 ft, $c_h = 0.0$ and $c_g = 0.003$. By comparing the results of figures 11 and 13A, one could choose c_s to represent a given particle size so that the results are similar to those given by a more complex relation.

Similarly, parameter c_o in the relation from Kilinc and Richardson (1973), attributed to Bagnold, directly determines relative transport capacity. Unlike the TF relation, however, factors of bed slope are also included as part of the shear terms. The critical shear limit is another difference between this relation and the TF relation, so for flows with low bed shear, erosion will be insensitive to values of c_o. Like c_s, c_o can be selected to represent a range of conditions and particle sizes. Figure 13B illustrates the effect of c_o on sediment production for the example 1 catchment and with other erosion parameters the same as for figure 13A.

Figure 13 also illustrates the three general behavior ranges that may be exhibited in erosion and sediment transport on a runoff surface. These ranges are determined by the relative values of splash erosion, transport capacity, erosion rate, and settling velocity. At very low values of transport capacity relative to splash erosion rate, there is a minimum sediment production from the plane determined by the ratio of production to deposition. For this example, that value is about 25 lb of sediment for the storm. This occurs although there is no transport capacity. The next range of behavior is the middle zone, where any increase in transport capacity is utilized because of the continuing excess of splash erosion rate over transport rate. Finally, as transport capacity increases further relative to the other factors, splash rate becomes less significant; and in the extreme, the rate of sediment off the end of the surface is governed by the rate of hydraulic erosion, which depends jointly on c_g and transport capacity.

Estimating Rainsplash Erosion Parameters

Parameters c_f and c_h (equations [35] and [36]) are important in controlling the rate at which rainfall energy produces loose, transportable particles from the soil surface. Often erosion is limited more by this rate of production than by the ability of the flowing surface water to transport the sediment. On the other hand, with flowing water and a rate of rainsplash erosion that exceeds the rate of settling, sediment will move off the catchment even with no transport capacity.

The value of c_f is clearly highest for loose, noncohesive, unprotected soils. Its value has been related to cropping and slope factors by Foster et al. (1983), and their value for relatively unprotected soil is related to the soil erodibility factor in the Universal Soil Loss Equation (Wischmeier and Smith 1978). This value may be expressed in KINEROS units (feet and seconds) for estimation as follows:

$$c_f = 422K_{usle}(\phi_f) \qquad [46]$$

The USLE handbook can be consulted for estimating values of the soil erodibility factor (K_{usle}) which are on the order of 0.1 to 0.5. Since English-metric conversions are not attempted for parameter c_f, the metric and English input values should be identical. The factor ϕ_f represents reductions due to mulch, erosion pavement, vegetal cover, and other factors mitigating splash erosion. A more complete discussion of the estimation of ϕ_f is found in Foster et al. (1983). The model user's judgment will ultimately be required to estimate the amount of reduction appropriate for the conditions of simulation.

The parameter c_h controls the effect of surface water depth on raindrop detachment. After surface water forms, it reduces splash erosion by absorbing kinetic energy from the raindrops; and the extent of reduction varies directly with depth of the surface water (Mutchler and Larson 1971, Schultz et al. 1985). KINEROS employs a conservative estimate for this damping, expressed in equation [36]. With depths expressed in feet, as used internally in KINEROS, and representing raindrop diameter by d_r, using a value of $2/d_r$ for c_h will reduce splash erosion by roughly 50 percent for a water depth of one-third drop diameter; this is in general agreement with published experimental results. It represents a value of 203 for c_h when mean drop diameter is 3 mm. Since soil surfaces are never uniform, both shallower and deeper water cover will be present at any time.

Estimating the Hydraulic Erosion Coefficient

The hydraulic erosion coefficient (c_g) represents the relative rate of erosion by flowing water when the hydraulic conditions for the selected transport capacity relation indicate a larger transport capacity than the local concentration (equation [37]). This parameter is larger for loose, noncohesive soils than for cohesive soils that resist erosion. Foster and Smith (1984) estimated this parameter to be related to K_{usle} and fractional clay content (f_{cl}) in the following manner:

$$c_g = 5.6\, K_{usle}\, \phi_r / a_T \qquad [47]$$

$$\text{with } a_T = 188 - 468 f_{cl} + 907 f_{cl}^2; \qquad f_{cl} \le 0.22;$$

$$\text{or } a_T = 130; \qquad f_{cl} > 0.22$$

This set of equations estimates c_g values (ft^{-1}) on the order of 0.001 to 0.02. K_{usle} is assumed to be in English units as reported by Wischmeier and Smith (1978). The factor ϕ_r (dimensionless, 0-1.0) accounts for erosion resistance due to mulches or other management practices.

Partially "Paved" Catchments

A parameter PAVE is included in KINEROS to represent the part of a "plane" element that is nonerodible because of pavement or other resistant cover. PAVE = 0 represents completely soil covered surfaces, and PAVE = 1.0 halts erosion completely as for a parking lot. This parameter can be used to account for desert pavement or rock mulch.

Describing the Geometry and Characteristics of a Pond

A pond is described for use in KINEROS by specifying a set of cross sections that lie normal to the path of flow through the pond. Water is assumed to enter the pond at one end and to exit through an outlet, with a known relation between discharge and depth of overfall, such as a weir or outlet orifice.

Description of the geometry of the pond requires preliminary interpretation of ordinary survey data. Sets of data pairs of cross-sectional area below the waterline and bank-to-bank width are required for sections in order, as described previously. In addition, these data are required at a fixed set of elevations. In other words, if one imagines the pond to be intersected by a set of level planes of fixed elevation, the data at each cross section must be given for conditions as if the water level were at each of those elevations.

The user is asked to describe the pond geometry by specifying MEL (2-10) elevations, at which data will be supplied at several (NSEC) sections that are normal to the flow path. At each section and each elevation at that section, the user must specify the bank-to-bank width (TWP) and cross sectional area of water intersected by the section. Thus for section J and elevation I, one would describe AP(J,I) and TWP(J,I). See figure 7.

Other pond information required includes the distance along the flow path to each section (XSEC), the beginning water surface elevation (ELST), and the elevation of the lowest point on the pond bottom (ELVZ). The outflow rating is given by a table of NOPQ pairs of elevation ELQ and corresponding discharge QSO. When sediment is to be routed through the pond, the user should supply the number of particle size classes into which the sediment, with median particle size (D50), is to be subdivided. The particle sizes of the various classes are determined by the standard deviation (SIGMAS) from the erosion data for the element just above the pond. In addition, to account for dispersion, short circuiting, and diffusion, an effective diffusivity coefficient (TDIFUS) may be specified for the dispersal of sediment during its travel through the pond.

Values of TDIFUS on the order of 0.00001 to 0.0001 ft^2/s are suggested.

Program Output

Two output files are always created by the program. The type and amount of detailed information in each are determined by switches in the parameter file for each element. The basic output file is the hydrologic output. A second file containing detailed computation results can be written for debugging or detailed analysis.

The basic hydrologic output file always contains identifying information, the names of input files read for the run, and hydrologic summary information. Optionally, it may contain detailed rainfall and runoff data. Sediment information is also contained in this file if the sediment option is selected. The amount of data output to this file is a function of each element's parameter NRP:

NRP = 0 Summary information only.

NRP = 1 Precipitation rate pattern written for this element if a plane; if element is the last channel, precipitation data for last raingage read is output.

NRP = 2 Runoff hydrograph written for the element.

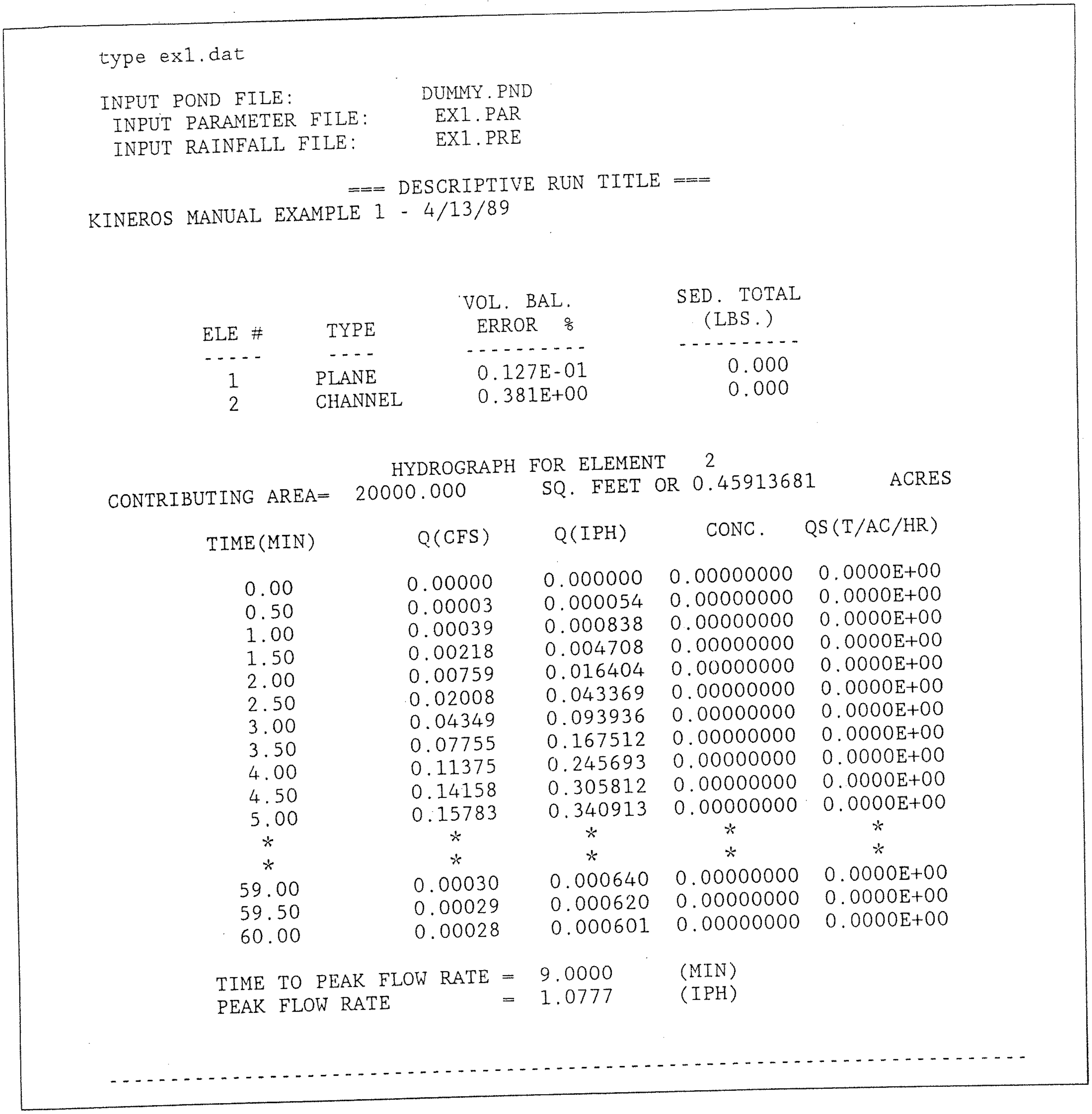
NRP = 3 Both precipitation rates and runoff hydrograph written.

The auxiliary output file contains identifying information and a summary of calculations in the order of calculation. This output is determined by the value of the element's parameter NPRINT:

NPRINT = 1 No detailed output written for the element.

NPRINT = 2 Calculation results written. <u>CAUTION</u>: Depending on the length of simulation, time step, and number of elements for which this option is chosen, the output can be voluminous.

The most useful outputs will normally reside in the output hydrograph file and in the rainfall and runoff plot files if requested. A sample output is shown in figure 14. The time increments for the output hydrograph and sediment concentration will be equal to the parameter DELT. The other columns are self-explanatory.



```
type ex1.dat

INPUT POND FILE:            DUMMY.PND
 INPUT PARAMETER FILE:       EX1.PAR
 INPUT RAINFALL FILE:        EX1.PRE

                   === DESCRIPTIVE RUN TITLE ===
KINEROS MANUAL EXAMPLE 1 - 4/13/89


                               VOL. BAL.         SED. TOTAL
        ELE #      TYPE        ERROR  %            (LBS.)
        -----      ----       ----------         ----------
          1        PLANE       0.127E-01            0.000
          2        CHANNEL     0.381E+00            0.000


                   HYDROGRAPH FOR ELEMENT    2
  CONTRIBUTING AREA=  20000.000     SQ. FEET OR 0.45913681      ACRES

        TIME(MIN)         Q(CFS)      Q(IPH)        CONC.    QS(T/AC/HR)

          0.00           0.00000     0.000000   0.00000000  0.0000E+00
          0.50           0.00003     0.000054   0.00000000  0.0000E+00
          1.00           0.00039     0.000838   0.00000000  0.0000E+00
          1.50           0.00218     0.004708   0.00000000  0.0000E+00
          2.00           0.00759     0.016404   0.00000000  0.0000E+00
          2.50           0.02008     0.043369   0.00000000  0.0000E+00
          3.00           0.04349     0.093936   0.00000000  0.0000E+00
          3.50           0.07755     0.167512   0.00000000  0.0000E+00
          4.00           0.11375     0.245693   0.00000000  0.0000E+00
          4.50           0.14158     0.305812   0.00000000  0.0000E+00
          5.00           0.15783     0.340913   0.00000000  0.0000E+00
           *                *            *            *            *
           *                *            *            *            *
         59.00           0.00030     0.000640   0.00000000  0.0000E+00
         59.50           0.00029     0.000620   0.00000000  0.0000E+00
         60.00           0.00028     0.000601   0.00000000  0.0000E+00

        TIME TO PEAK FLOW RATE =   9.0000       (MIN)
        PEAK FLOW RATE         =   1.0777       (IPH)

    ----------------------------------------------------------------
```

Figure 14.
Sample summary output file.

```
                         **** EVENT SUMMARY ****
                         ----- -------

                         GLOBAL VOLUME BALANCE
              VALUES ARE IN UNITS OF LENGTH (VOL./BASIN AREA)

                    BASIN AREA =     20000.000      (FT**2)
            TOTAL RAINFALL DEPTH =    0.200 (IN)


 STORAGE REMAINING ON ALL PLANES            =    0.00016 (IN)
 STORAGE REMAINING IN CHANNELS+CONDUITS     =    0.00011 (IN)
 STORAGE REMAINING IN PONDS                 =    0.00000 (IN)
 TOTAL INFILTRATION FROM ALL PLANES         =    0.00000 (IN)
 TOTAL INFILTRATION FROM ALL CHANNELS       =    0.00000 (IN)
 TOTAL BASIN RUNOFF                         =    0.19894 (IN)        331.6 CU.FT.

                                                ---------
 TOTAL OF STOR., INFIL. AND RUNOFF TERMS =       0.19922 (IN)


            *** GLOBAL VOL. ERROR  =      0.3925 PERCENT ***
```

Figure 14--Continued.
Sample summary output file.

The detailed output is useful primarily for diagnostic purposes. An example is shown in figure 15. For those elements when NPRINT = 2, the results of the finite difference computations will be printed out for each time step. QL(IPH) is the net rate of lateral inflow, INFIL is the infiltration rate, SUP(I=1,NK) is the sediment supply rate and H2(I=1,NK) is the depth of flow (in feet) at each of the NK node points. CMX(I=1,NK) is the equilibrium sediment transport concentration at each node, and CT(I=1,NK) is the sediment concentration. DELH(I=1,NK) represents the amount of erosion (-) or deposition (+) at each node (in feet).

INFLOW, OUTFLOW, and STOR are volume balance terms in cubic feet for the entire plane. INFLOW is the sum of the rainfall plus inflow from a contributing plane (RO FROM UPSTREAM) since time (t) = 0. OUTFLOW is the sum of infiltration (INFIL) at each node plus the discharge from the lower boundary of the plane (RO OUT). STOR is the amount of water stored on the plane at time (t). A positive ERROR indicates loss of water and negative an apparent gain. Although errors are usually less than 1 percent, they may be somewhat larger when an upper plane contributes runoff to a lower plane where ponding has not yet occurred. These errors are due to kinematic shocks occurring under these circumstances, and the numerical methods used in KINEROS do not account for them explicitly. Errors greater than 1 percent may also occur when only five nodes are used for a channel with no upstream inflow.

```
type ex1.aux

INPUT POND FILE:            DUMMY.PND
 INPUT PARAMETER FILE:       EX1.PAR
 INPUT RAINFALL FILE:        EX1.PRE
                      === DESCRIPTIVE RUN TITLE ===
   KINEROS MANUAL EXAMPLE 1 - 4/13/89

          *** PLANE NO.    1 DIAGNOSTIC INFORMATION ***

            THE RAIN GAGE FOR PLANE  1 IS GAGE NO.  1
         PPCT. WEIGHT IS 1.00   INTERCEPTION IS 0.01  (IN)

       GEOM. PARAMETERS ARE  L=  100.0  W=  200.0  S= 0.0500
       ROUGHNESS COEF. IS MANNINGS N=0.013
       IMPERVIOUS PLANE

               **** WATER BALANCE AT END OF PLANE ****
           <INFLOW BASED ON (PPT*GAGE WT) - INTER. + RUNON>
   INFLOW= 0.333E+03 OUTFLOW= 0.333E+03 STOR.= 0.268E+00 ERROR= 0.127E-01 %

    -----------------------------------------------------------------

          ** CHANNEL NO    2 DIAGNOSTIC INFORMATION **

   T(  2)= 0.3000E+02   Q(  2)= 0.2508E-04   QL(  2)= 0.2543E-04
   A2(K=1,NK)=  0.0000  0.0004  0.0004  0.0004  0.0004  0.0004  0.0004  0.0004
    0.0004  0.0004  0.0004  0.0004  0.0004  0.0004  0.0004
     UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.763E-01  INFIL. OUTFLOW= 0.000E+00
     CHAN. OUTFLOW= 0.376E-03      STORAGE= 0.736E-01            ERROR= 0.308E+01 %
     *                             *                                    *
     *                             *                                    *
   T( 60)= 0.1770E+04   Q( 60)= 0.8666E-02   QL( 60)= 0.2539E-04
   A2(K=1,NK)=  0.0000  0.0020  0.0031  0.0041  0.0051  0.0059  0.0067  0.0075
    0.0083  0.0091  0.0098  0.0106  0.0113  0.0120  0.0128
     UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.331E+03  INFIL. OUTFLOW= 0.000E+00
     CHAN. OUTFLOW= 0.328E+03      STORAGE= 0.146E+01            ERROR= 0.389E+00 %
     *                             *                                    *
     *                             *                                    *
   T(121)= 0.3600E+04   Q(121)= 0.2783E-03   QL(121)= 0.8230E-06
   A2(K=1,NK)=  0.0000  0.0002  0.0004  0.0005  0.0006  0.0008  0.0009  0.0010
    0.0011  0.0012  0.0012  0.0013  0.0014  0.0015  0.0016
     UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.333E+03  INFIL. OUTFLOW= 0.000E+00
     CHAN. OUTFLOW= 0.332E+03      STORAGE= 0.185E+00            ERROR= 0.381E+00 %

       GEOM. PARAMETERS ARE  L=  200.0  S= 0.0300
       TRAP. X-S  LEFT SLOPE= 1.000 RIGHT SLOPE= 1.000 BOTT. WID.=   2.00
       ROUGHNESS COEF. IS MANNINGS N= 0.013
       IMPERVIOUS CHANNEL
       CONTRIB. CHANNEL NUMBERS: NC1=   0 NC2=   0
       CONTRIB. PLANE NUMBERS:  LEFT=   1  RIGHT=   0  UPPER=   0

               *** WATER BALANCE AT END OF CHANNEL ***

             <INFLOW BASED ON RUNIN + LATERAL INFLOW>
  INFLOW= 0.333E+03 OUTFLOW= 0.332E+03 STOR.= 0.185E+00 ERROR= 0.381E+00 %
```

Figure 15.
Sample auxiliary output file.

EXAMPLES USING HYPOTHETICAL WATERSHEDS

Three examples using hypothetical watersheds have been developed to demonstrate features of KINEROS and the preparation of input data files.

Example 1

We will describe procedures to create input files for the hypothetical watershed shown in figure 16. In this example, the plane, element 1, contributes lateral inflow to a trapezoidal channel, element 2. We name the input parameter file EX1.PAR and start by copying the template file TEMP.PAR to EX1.PAR. We use an editor to fill in input values below the parameter names.

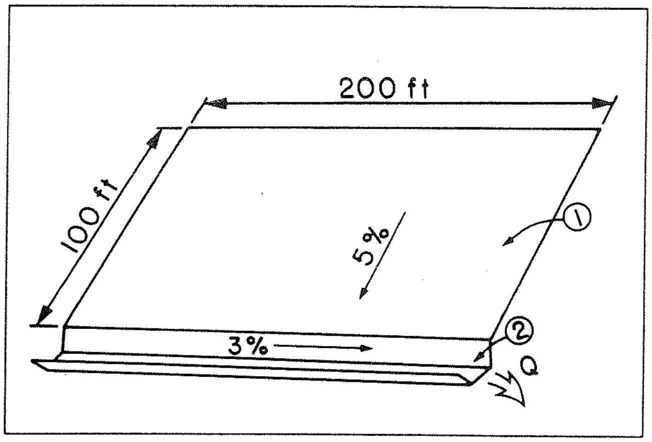
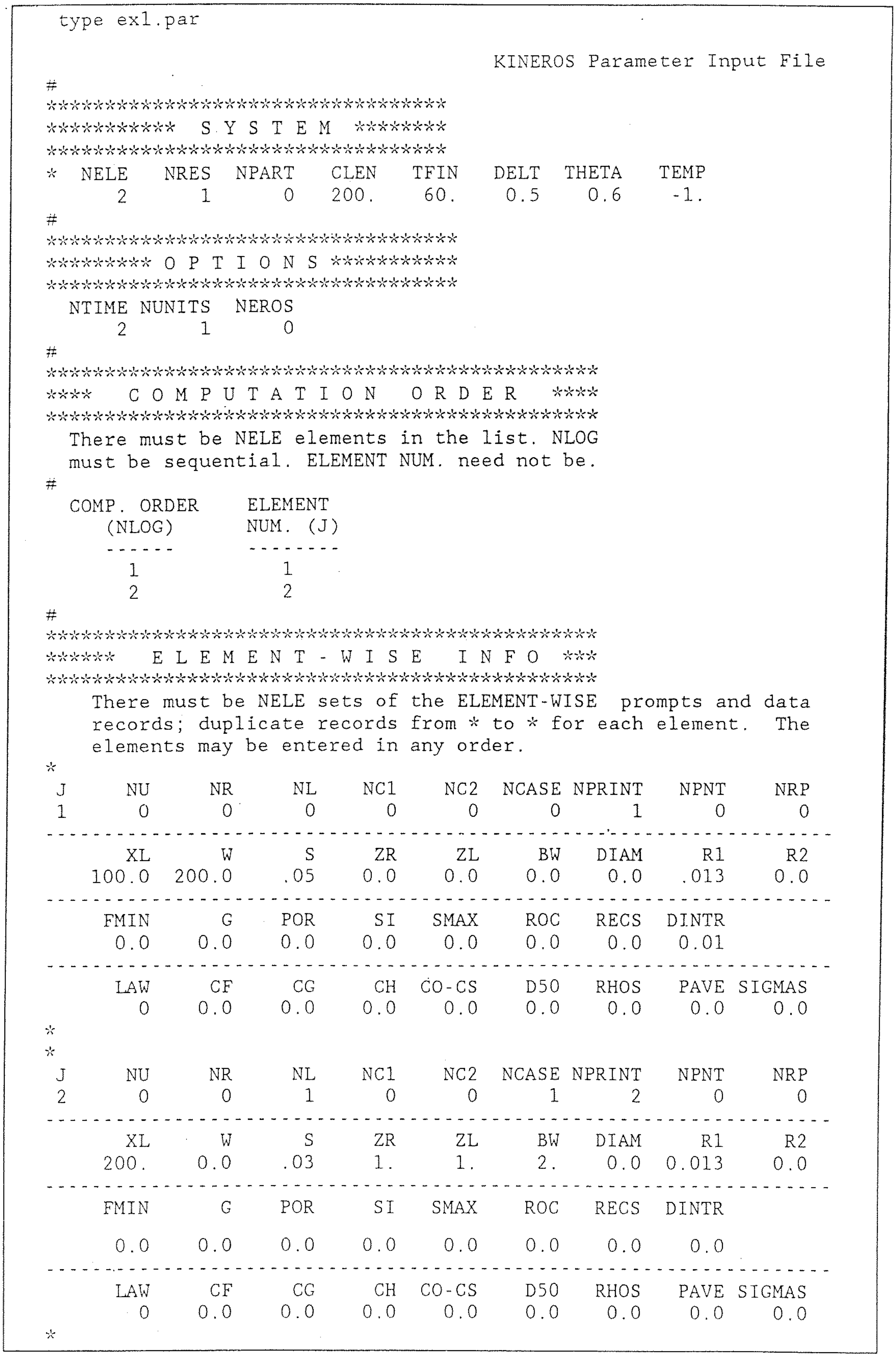


Figure 16.
Hypothetical watershed.

A printout of the completed file EX1.PAR is shown in figure 17. There are eight parameters under the heading "SYSTEM." NELE refers to the number of watershed elements (planes, channels, and ponds), so we enter 2. NRES refers to the resistance law to be used. We use NRES=1, which is Manning's law. NPART is needed only for pond elements. CLEN is a characteristic length that is used within the program to choose the length of Δx increments in the finite difference solutions. It should normally be set equal to the sum of the lengths of the longest cascade of planes in the system or the longest single channel whichever is greater. For this example, the channel length controls and CLEN = 200 ft.

TFIN is the desired maximum duration for runoff computations. It is based on the length of the rainfall event and the watershed response time. Assume that for this example we wish the program to stop after it has computed a runoff hydrograph with a duration of 60 minutes from the beginning of the rain. Therefore TFIN = 60.



```
 type ex1.par

                                         KINEROS Parameter Input File
#
**********************************
*********** S Y S T E M ********
**********************************
*  NELE   NRES  NPART   CLEN   TFIN   DELT  THETA   TEMP
      2      1      0   200.    60.    0.5    0.6    -1.
#
***********************************
********* O P T I O N S ***********
***********************************
  NTIME NUNITS  NEROS
      2      1      0
#
***********************************************
****   C O M P U T A T I O N   O R D E R   ****
***********************************************
  There must be NELE elements in the list. NLOG
  must be sequential. ELEMENT NUM. need not be.
#
  COMP. ORDER    ELEMENT
     (NLOG)      NUM. (J)
     ------      --------
       1            1
       2            2
#
***********************************************
******   E L E M E N T - W I S E   I N F O ***
***********************************************
    There must be NELE sets of the ELEMENT-WISE  prompts and data
    records; duplicate records from * to * for each element.  The
    elements may be entered in any order.
*
 J     NU     NR     NL    NC1    NC2  NCASE NPRINT   NPNT    NRP
 1      0      0      0      0      0      0      1      0      0
------------------------------------------------------------------
       XL      W      S     ZR     ZL     BW   DIAM     R1     R2
    100.0  200.0    .05    0.0    0.0    0.0    0.0   .013    0.0
------------------------------------------------------------------
     FMIN      G    POR     SI   SMAX    ROC   RECS  DINTR
      0.0    0.0    0.0    0.0    0.0    0.0    0.0   0.01
------------------------------------------------------------------
      LAW     CF     CG     CH  CO-CS    D50   RHOS   PAVE SIGMAS
        0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
*
*
 J     NU     NR     NL    NC1    NC2  NCASE NPRINT   NPNT    NRP
 2      0      0      1      0      0      1      2      0      0
------------------------------------------------------------------
       XL      W      S     ZR     ZL     BW   DIAM     R1     R2
     200.    0.0    .03     1.     1.     2.    0.0  0.013    0.0
------------------------------------------------------------------
     FMIN      G    POR     SI   SMAX    ROC   RECS  DINTR

      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
------------------------------------------------------------------
      LAW     CF     CG     CH  CO-CS    D50   RHOS   PAVE SIGMAS
        0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
*
```

Figure 17.
Parameter file for example 1.

DELT is the time increment for computations and printout of the hydrograph. For this example we use DELT = 0.5 min.

THETA is the weighting factor in the implicit numerical solution. It must be between 0.5 and 1. As THETA approaches 1.0, more numerical dispersion is introduced into the solution. In this example there will be no kinematic shocks, so we select THETA = 0.6. (If kinematic shocks are likely to occur, THETA = 0.8 is recommended.)

TEMP is the temperature in degrees Fahrenheit (for English unit input). It is used to calculate the kinematic viscosity of water. If TEMP is set to -1, a default temperature of 65°F is used. We will use the default value.

There are three parameters under the heading "OPTIONS." NTIME refers to the use of seconds or minutes as units of time for input data and time variables DELT and TFIN. Since we use NTIME = 2, input will be in minutes. We use NUNITS = 1, so all input is in English units. We do not use the erosion option in this example, so NEROS = 0.

The next heading is "COMPUTATION ORDER" with column headings NLOG and ELEMENT NUM.(J). These integer variables control the order of computations. Entries under NLOG are consecutive integers starting with 1 and ending with NELE. Under ELEMENT NUM.(J), we enter 1 and 2. This means that the computations will be completed first for element 1 (the plane) and then for element 2 (the channel). The entries under ELEMENT NUM.(J) need not be consecutive integers; however, the outflow hydrographs of all elements contributing upstream inflow or lateral inflow to the element J must be computed before the computations can proceed for element J.

Under the heading "ELEMENT-WISE INFO," we enter the geometric description of each plane and channel and the infiltration and erosion parameters if required. The elements can be entered in any order, but it is most convenient to enter them in order, beginning with element 1.

The variable J refers to the element number, so we enter 1 for the plane and 2 for the channel. There are no planes contributing to the upper boundary of plane 1, so NU = 0. NR through NCASE are valid only for channels, so we enter a zero in each column. We do not wish a diagnostic printout, so NPRINT = 1. This is not a pond, so NPNT = 0. We do not wish to print out rainfall or runoff data for this element, so NRP = 0. The length (100 ft), width (200), and slope (0.05) are entered under XL, W, and S, respectively. ZR through DIAM apply only for channels, so zeros are entered. Because we have selected NRES =

1, R1 refers to the Manning's n value. If we assume that plane 1 has an asphalt surface, an appropriate value for R1 is 0.013. With NRES = 1, R2 is inoperative, so we enter a zero. The plane is impervious, so FMIN = 0.0. With the options chosen, zeros can be entered for all other parameters except the interception DINTR, which we assume is 0.01 in.

For the channel (element 2), NU = 0 since no plane contributes to the upper boundary. Plane 1 contributes lateral inflow to the left side of the channel, so NL = 1. NR = 0 because there is no contribution to the right side. Similarly NC1 and NC2 are zero because no channels contribute to the upper boundary of channel 2. The channel is trapezoidal, so NCASE = 1. We select the detailed printout option, so NPRINT = 2. As discussed before, NPNT and NRP are both zero. We enter the channel length (200) under XL and a zero under W. *W = 0 indicates a channel.* The channel slope (S) = 0.03. For a trapezoidal channel with a 2-ft bottom width and 1:1 side slopes, ZR = 1., ZL = 1., and BW = 2. For Manning's n we again select R1 = 0.013. All other parameters can be set to zero.

The parameter and geometry file is now complete, so we create the precipitation input file. We begin by copying the template file TEMP.PRE to the file EX1.PRE. The completed precipitation input file is shown in figure 18. Under the heading "Gage Network Data," we have two parameters. NGAGES is the number of raingages. In this example NGAGES = 1. MAXND refers to the maximum number of time-depth pairs in the rainfall data. Let us assume that the cumulative rainfall and the intensity histogram are as shown in figure 19. We will need five time-depth pairs to represent the rainfall pattern since *rainfall must be defined past TFIN*. Therefore MAXND = 5. The next data, ELE. NUM.(J), RAINGAGE, and WEIGHT, provide a means of weighting the rainfall at a given gage by a multiplier, WEIGHT, to get the correct rainfall for ELEMENT(J). We have only one gage, which we will call gage 1, and its weight will be 1 for elements 1 and 2. Under the heading "Rainfall Data," we enter the parameter ND, which is the number of time depth pairs for the specific gage, starting with gage 1. In this case ND = 5. The time (TIME) and accumulated rainfall depth pairs (ACCUM. DEPTH) are entered next.

Part of the output hydrograph file is shown in figure 14 and part of the detailed or auxiliary output file is shown in figure 15.

The standard output file (fig. 14) shows the names of the input parameter file and rainfall file, the volume balance errors and total erosion for each element, the contributing area, the outflow hydrograph and sedigraph, peak flow rate statistics, and totals of input and output.

```
type exl.pre
                                   KINEROS   Rainfall Input Data
#
*****************************
      Gage Network Data
*****************************
#
  NUM. OF RAINGAGES    MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
       (NGAGES)            (MAXND)
       --------            -------
          1                   5
#
 There must be NELE  pairs of (GAGE  WEIGHT) data
*
 ELE. NUM. (J)     RAINGAGE     WEIGHT
 -------------     --------     ------
       1               1          1.0
       2               1          1.0
#
******************************
        Rainfall Data
******************************
 There must be NGAGES sets of rainfall data. Repeat lines from * to *
 for each gage inserting a variable number of TIME-DEPTH data pairs
 (see example in User Manual).
#
* ALPHA-NUMERIC GAGE ID: EXAMPLE 1 - GAGE 1 = GAGE 1.
#
  GAGE NUM.     NUM. OF DATA PAIRS (ND)
  ---------     -----------------------
      1                    5
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time)
#
   TIME     ACCUM. DEPTH
  ------    ------------
    0.0        0.00
    5.0        0.04
   10.0        0.13
   20.0        0.21
   65.0        0.21
*
```

Figure 18.
Precipitation input file for example 1.

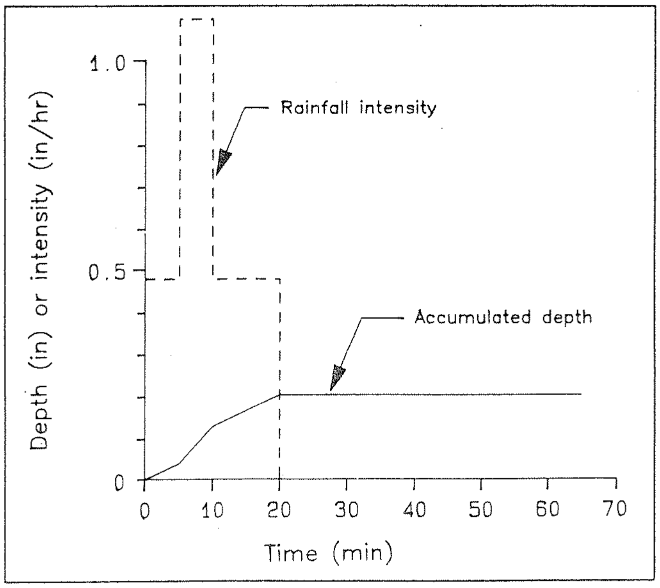


Figure 19.
Rainfall intensity pattern for example 1.

The auxiliary file, figure 15, includes a summary of parameter, geometry, and water balance information for each element and allows detailed printouts to be made for any element where NPRINT = 2. For example 1, NPRINT = 2 for the channel, element 2, and results of computations for each time step are printed out. T is the time in seconds, Q is the discharge at the downstream boundary of the element in cubic feet per second, QL is the lateral inflow in cubic feet per second per foot and A2(K=1,NK) is the cross sectional area in square feet at each node for that time. In this case, there were 15 nodes (NK = 15). The auxiliary file is useful primarily for program debugging and for checking input parameter files. It is always wise to scan the water balance information in this file and to determine the reason for any error greater than 2-3 percent.

Example 2

In this example, we demonstrate the following features: Infiltration, erosion, branching channels, circular conduit, and multiple raingages. The seven-element watershed geometry is shown in figure 20. Elements 1 and 2 are identical to those in example 1. Any changes in input data from example 1 for these elements are discussed. We assume that erosion occurs only on infiltrating planes and trapezoidal channels. The circular conduit is nonerodible, although deposition and subsequent erosion of that deposited material are possible. The input parameter file EX2.PAR is shown in figure 21. NELE is now 7. NRES is 2 signifying that the resistance option 2, Laminar-Manning, will be used. CLEN is 300 ft, the sum of the lengths of planes 4 and 7. DELT has been increased from 0.5 to 1.0 min., reflecting the increase in CLEN. TFIN has been increased to 90 minutes to reflect the slower response time of this watershed compared with that in example 1. THETA has been increased to 0.8 because we have cascading planes. Under "OPTIONS" note that NEROS = 2, signifying that we are electing the erosion option. The computational order is 1, 2, 3, 7, 4, 5, 6. Note that the following orders are also feasible: 3, 7, 4, 5, 1, 2, 6 and 7, 4, 3, 5, 1, 2, 6.

Input for element 1 is identical to that for example 1 except that we have entered 80 under R2 for the Laminar "k" value. Under LAW we enter 1, the code for the tractive force erosion law. We have entered values for CG (0.011), CS (0.001), D50 (0.0005), RHOS (2.65), POR (0.40), and PAVE (1.0) as required for the tractive force law. Note, however, that PAVE = 1 halts erosion detachment. CF = 0 also halts rainsplash erosion.

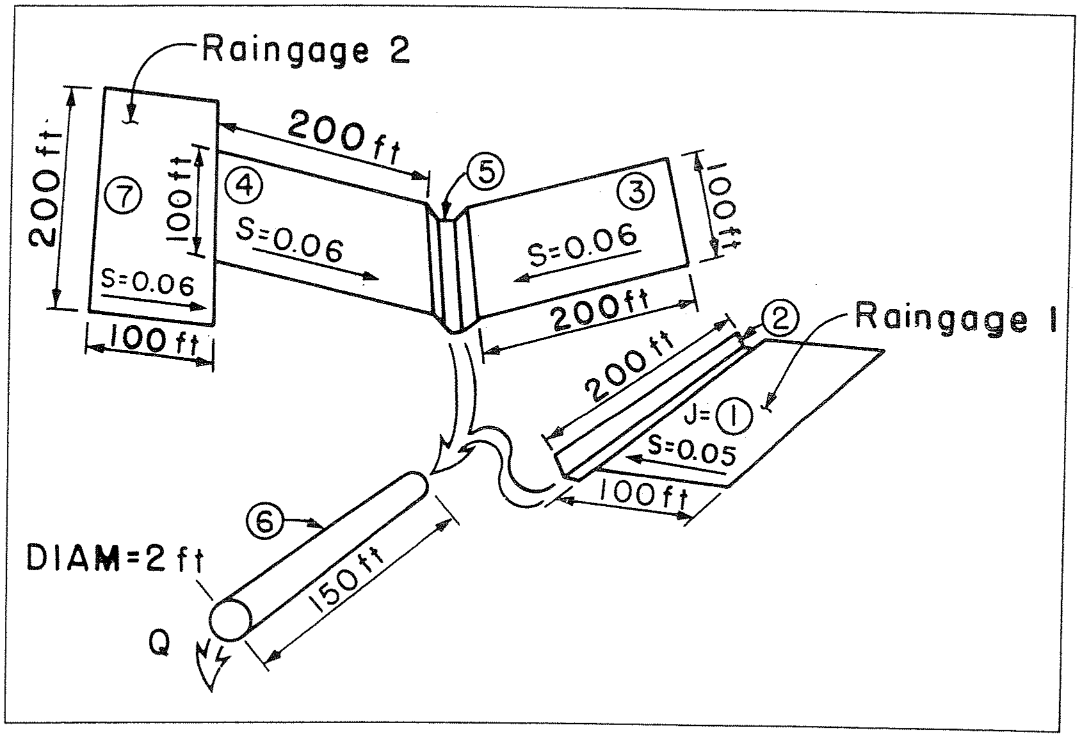


Figure 20.
Elements used in example 2.

For channel element 2 the input is identical to that in example 1 except that LAW = 2, which specifies the unit stream power relation with CG = 0.011, D50 (0.0005), RHOS (2.65), POR (0.40), and PAVE (1.0), which prevents erosion. We have also suppressed the detailed printout by setting NPRINT = 1. Elements 1 and 2 correspond to a paved parking lot drained by a paved channel.

For plane element 3 we have chosen values of RI and R2 to represent a sparsely vegetated rangeland watershed (see table 4). SMAX = 0.83, FMIN = 0.068 in/h, POR = 0.40, and G = 10.4 in represent a sandy clay loam soil (see table 2). Note that we have approximated K_s under imbibition by dividing the tabulated

K_s by 2. The effect of rock is estimated by multiplying K_s by (1. - ROC). The initial saturation (SI) is 0.25. The soil has 20 percent rock by volume. RECS = 0.2 in, so the water depth during recession must be greater than this depth for the entire wetted area to contribute to infiltration. The interception (DINTR) = 0.03 in.

```
type ex2.par
                                       KINEROS Parameter Input File
 #
 **********************************
 ***********  S Y S T E M  ********
 **********************************
 *  NELE   NRES  NPART   CLEN   TFIN   DELT  THETA   TEMP
       7      2      0   300.    90.    1.0    0.8    -1.
 #
 ***********************************
 ********* O P T I O N S ***********
 ***********************************
   NTIME NUNITS  NEROS
       2      1      2
 #
 ***********************************************
 ****   C O M P U T A T I O N   O R D E R   ****
 ***********************************************
   There must be NELE elements in the list. NLOG
   must be sequential. ELEMENT NUM. need not be.
 #
   COMP. ORDER    ELEMENT
      (NLOG)      NUM. (J)
      ------      --------
        1            1
        2            2
        3            3
        4            7
        5            4
        6            5
        7            6
 #
 ***********************************************
 ******   E L E M E N T - W I S E   I N F O  ***
 ***********************************************
     There must be NELE sets of the ELEMENT-WISE  prompts and data
     records; duplicate records from * to * for each element.  The
     elements may be entered in any order.
 *
  J     NU     NR     NL    NC1    NC2  NCASE NPRINT   NPNT    NRP
  1      0      0      0      0      0      0      1      0      0
 -------------------------------------------------------------------
        XL      W      S     ZR     ZL     BW   DIAM     R1     R2
     100.0  200.0   0.05    0.0    0.0    0.0    0.0  0.013   80.0
 -------------------------------------------------------------------
      FMIN      G    POR     SI   SMAX    ROC   RECS  DINTR
       0.0    0.0    0.4    0.0    0.0    0.0    0.0   0.01
 -------------------------------------------------------------------
       LAW     CF     CG     CH  CO-CS    D50   RHOS   PAVE SIGMAS
         1    0.0  0.011    0.0  0.001 0.0005   2.65    1.0    0.0
 *
 *
  J     NU     NR     NL    NC1    NC2  NCASE NPRINT   NPNT    NRP
  2      0      0      1      0      0      1      1      0      0
```

Figure 21.
Input parameter file for example 2.

```
------------------------------------------------------------------------------
      XL       W       S      ZR      ZL      BW    DIAM      R1      R2
   200.0     0.0    0.03     1.0     1.0     2.0     0.0   0.013     0.0
------------------------------------------------------------------------------
    FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.0     0.0     0.4     0.0     0.0     0.0     0.0     0.0
------------------------------------------------------------------------------
     LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
       2     0.0   0.011     0.0     0.0  0.0005    2.65     1.0     0.0
*
*
 J    NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 3     0       0       0       0       0       0       1       0       1
------------------------------------------------------------------------------
      XL       W       S      ZR      ZL      BW    DIAM      R1      R2
   200.0   100.0    0.06     0.0     0.0     0.0     0.0     0.1  1000.O
------------------------------------------------------------------------------
    FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
   0.068    10.4     0.4    0.25    0.83     0.2     0.2    0.03
------------------------------------------------------------------------------
     LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
       1   100.0   0.011   300.0   0.001  0.0005    2.65     0.1     0.0
*
*
 J    NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 4     7       0       0       0       0       0       2       0       2
------------------------------------------------------------------------------
      XL       W       S      ZR      ZL      BW    DIAM      R1      R2
   200.0   100.0    0.06     0.0     0.0     0.0     0.0     0.1  1000.0
------------------------------------------------------------------------------
    FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
   0.068    10.4     0.4    0.25    0.83     0.2     0.2    0.03
------------------------------------------------------------------------------
     LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
       1   100.0   0.011   300.0   0.001  0.0005    2.65     0.1     0.0
*
*
 J    NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 5     0       4       3       0       0       1       2       0       0
------------------------------------------------------------------------------
      XL       W       S      ZR      ZL      BW    DIAM      R1      R2
   100.0     0.0    0.04     2.0     2.0     0.5     0.0    0.02     0.0
------------------------------------------------------------------------------
    FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
------------------------------------------------------------------------------
     LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
       2     0.0   0.011     0.0     0.0  0.0005    2.65     1.0     0.0
*
*
 J    NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 6     0       0       0       2       5       2       1       0       0
------------------------------------------------------------------------------
      XL       W       S      ZR      ZL      BW    DIAM      R1      R2
   150.0     0.0    0.02     0.0     0.0     0.0     2.0   0.012     0.0
```

Figure 21--Continued.
Input parameter file for example 2.

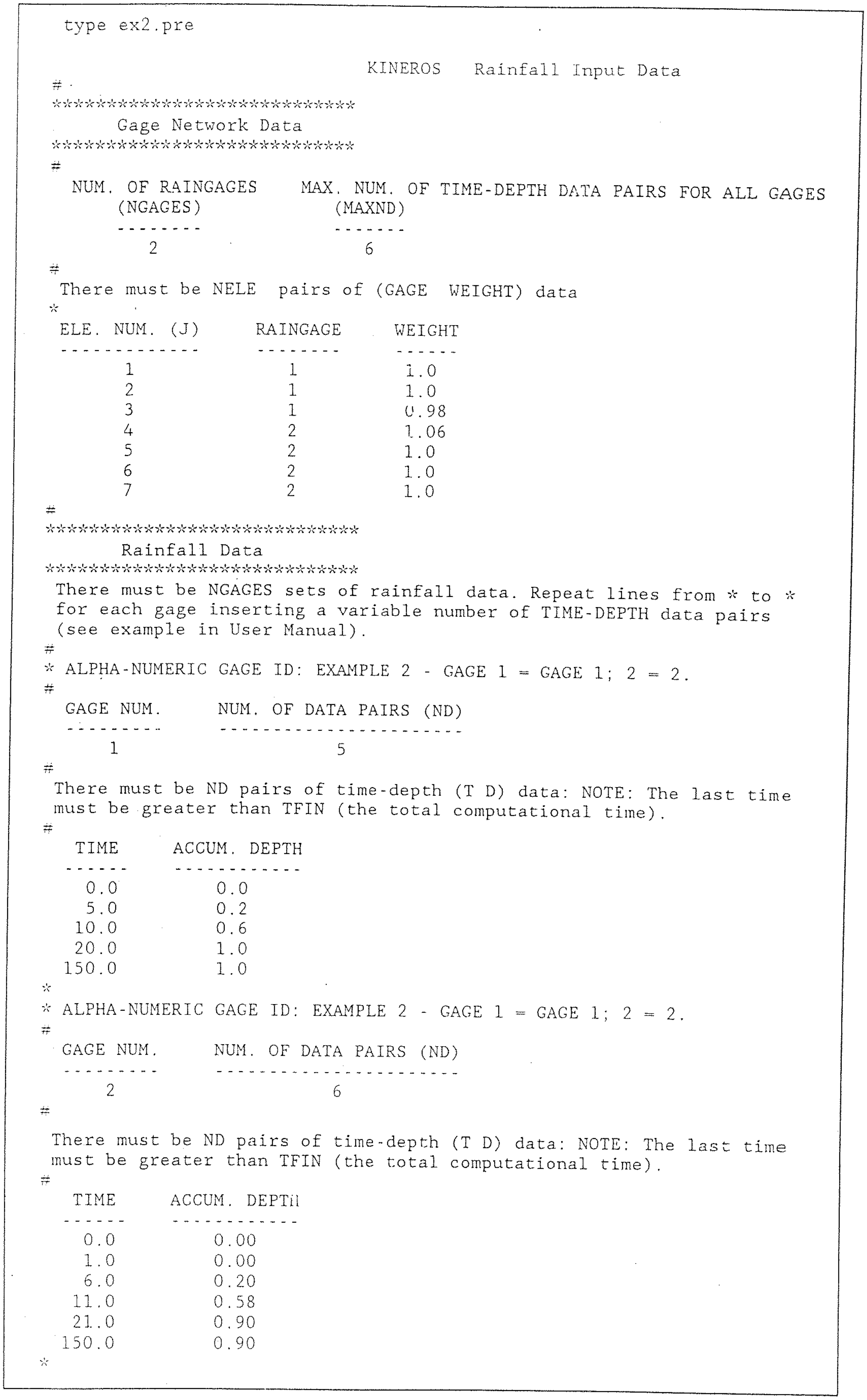
```
 --------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
 --------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         2     0.0   0.011     0.0     0.0  0.0005    2.65     1.0     0.0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 7       0       0       0       0       0       0       1       0       3
 --------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
     100.0   200.0    0.01     0.0     0.0     0.0     0.0   0.012   100.0
 --------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
 --------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         1     0.0   0.011     0.0     0.0  0.0005    2.65     1.0     0.0
*
```

Figure 21--Continued.
Input parameter file for example 2.

Plane 3 will be subject to erosion using the tractive force erosion law. The raindrop splash erosion parameters (CF and CH) are 100 and 300, respectively. The hydraulic erosion coefficient (CG) = 0.011 and the parameter (CS) = 0.001. The median diameter (D50) = 0.0005 ft. The particle specific gravity (RHOS) = 2.65, and the surface has 10 percent rock cover (PAVE = 0.10). NRP = 1, so the rainfall rates will be printed for this element. The remaining data are self-explanatory.

Note that plane 7 is impervious and contributes runoff to plane 4, which is pervious and erodible. Channels 5 and 6 are impervious and nonerodible. Hydrograph data and the detailed finite difference solution will be printed for element 4 (NRP = 2 and NPRINT = 2), and both rainfall and runoff rates will be printed for element 7 (NRP = 3). Note that values for D50 and RHOS have been included for all elements.

The rainfall data file EX2.PRE is shown in figure 22. Because there are two raingages, NGAGES = 2. There are six time-depth pairs for raingage 2, so MAXND = 6. We will assume that planes 1 and 3 are nearest to gage 1 and planes 4 and 7 are nearest to gage 2. We must assign values of RAINGAGE and WEIGHT to the channel elements, but the actual values put in are irrelevant because they are not used. The WEIGHT values would normally be estimated from an isohyetal map of the storm. We will assume that the storm depth at plane 4 was 0.95 in, so WEIGHT = 0.95/0.90 = 1.06. If the depth at plane 3 was 0.98 in, then WEIGHT = 0.98/1.00 = 0.98. Note that rain started 1 minute later at gage 2 than at gage 1, so it is possible to simulate storm movement.



```
 type ex2.pre

                                   KINEROS   Rainfall Input Data
 #
 ******************************
       Gage Network Data
 ******************************
 #
   NUM. OF RAINGAGES    MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
       (NGAGES)            (MAXND)
       --------            -------
          2                   6
 #
  There must be NELE  pairs of (GAGE  WEIGHT) data
 *
  ELE. NUM. (J)      RAINGAGE     WEIGHT
  -------------      --------     ------
        1               1          1.0
        2               1          1.0
        3               1          0.98
        4               2          1.06
        5               2          1.0
        6               2          1.0
        7               2          1.0
 #
 ******************************
       Rainfall Data
 ******************************
  There must be NGAGES sets of rainfall data. Repeat lines from * to *
  for each gage inserting a variable number of TIME-DEPTH data pairs
  (see example in User Manual).
 #
 * ALPHA-NUMERIC GAGE ID: EXAMPLE 2 - GAGE 1 = GAGE 1; 2 = 2.
 #
   GAGE NUM.      NUM. OF DATA PAIRS (ND)
   ---------      -----------------------
       1                    5
 #
  There must be ND pairs of time-depth (T D) data: NOTE: The last time
  must be greater than TFIN (the total computational time).
 #
    TIME      ACCUM. DEPTH
   ------     ------------
     0.0          0.0
     5.0          0.2
    10.0          0.6
    20.0          1.0
   150.0          1.0
 *
 * ALPHA-NUMERIC GAGE ID: EXAMPLE 2 - GAGE 1 = GAGE 1; 2 = 2.
 #
   GAGE NUM.      NUM. OF DATA PAIRS (ND)
   ---------      -----------------------
       2                    6
 #

  There must be ND pairs of time-depth (T D) data: NOTE: The last time
  must be greater than TFIN (the total computational time).
 #
    TIME      ACCUM. DEPTH
   ------     ------------
     0.0          0.00
     1.0          0.00
     6.0          0.20
    11.0          0.58
    21.0          0.90
   150.0          0.90
 *
```

Figure 22.
Rainfall input data for example 2.

Parts of the summary output file are shown in figure 23. The element number, type of element (plane or channel), volume balance error, and sediment transport output are shown for each element in computational order. The hydrograph for plane 7 is shown because NRP = 3 for that element. The hydrograph, sediment concentration, and sediment transport are always shown for the last element (in this example, channel 6). Finally the peak discharge rate, time to peak, total rainfall, water remaining in storage, total infiltration, total runoff and global volume balance error are given. The total rainfall will be the total for the storm given in the rainfall input file weighted by the area of each plane element. The total runoff will be the integral of the hydrograph up to time TFIN.

Part of the auxiliary output file is shown in figure 24. Diagnostic information is provided for each element in computational order. The rainfall hyetograph is printed out for plane 3 because NRP = 1, and for plane 7 because NRP = 3. For plane 4 (NPRINT = 2), the detailed printout shows the finite-difference solutions for the net sediment supply rate (SUP(I)), depth (H2(I)), sediment transport capacity (CMX(I)), and local sediment concentration (CT(I)), along with the lateral inflow rate (QL), infiltration rate (INFIL), and the accumulated change in bed elevation (DELH(I)) at four selected times.

At TIME = 0.0, rainfall has not yet started so all variables are set equal to zero. At TIME = 180 s, ponding has occurred at all nodes and inflow from impervious plane 7 is evidenced by increased depths at nodes 1 and 2. The flow depths at all nodes except node 1 are too small to provide sediment transport capacity (CMX); however, rain splash provides some erosion so the sediment concentrations (CT) are greater than zero except at node 1 where clear water is advected from nonerodible plane 7. The message NO POSITIVE ROOT AT J = 2 indicates a numerical problem associated with kinematic shock. This shock initiates perturbations in the depth that cause perturbations in the sediment transport capacity. This variation in CMX is reflected in the sediment supply term SUP alternating between erosion (+) and deposition (-).

At TIME = 480 s, the rainfall is at the maximum intensity and erosion is occurring at all nodes except node 8. The greatest amount of erosion (DELH) has occurred at node 1. The greatest depth and transport capacity is at node 2. The concentration profile reflects the upstream boundary condition (CT=0) and has a maximum at node 4.

At TIME = 1380 s, the rainfall rate has been zero for 60 s. Lateral inflow is equal to the negative of the infiltration rate. Erosion is occurring at the upper 5 nodes and deposition is taking place at the lower 5 nodes. All nodes show accumulated erosion, but perturbations introduced while the shock traversed plane 4 persist.

```
 type ex2.dat

 INPUT POND FILE:           DUMMY.PND
  INPUT PARAMETER FILE:      EX2.PAR
  INPUT RAINFALL FILE:       EX2.PRE

                    === DESCRIPTIVE RUN TITLE ===
KINEROS MANUAL EXAMPLE 2 - 4/13/89



                               VOL. BAL.         SED. TOTAL
        ELE #      TYPE         ERROR  %           (LBS.)
        -----      ----        ----------        ----------
          1       PLANE         0.990E+00           0.000
          2       CHANNEL       0.641E+00           0.000
          3       PLANE        -0.600E-01          50.237
          7       PLANE        -0.395E+00           0.000


                     HYDROGRAPH FOR ELEMENT    7
 CONTRIBUTING AREA=  20000.000       SQ. FEET OR 0.45913681      ACRES

        TIME(MIN)          Q(CFS)      Q(IPH)       CONC.    QS(T/AC/HR)

           0.00           0.00000    0.000000  0.00000000  0.0000E+00
           1.00           0.00000    0.000000  0.00000000  0.0000E+00
           2.00           0.01687    0.036449  0.00000000  0.0000E+00
           3.00           0.13499    0.291589  0.00000000  0.0000E+00
           4.00           0.45561    0.984113  0.00000000  0.0000E+00
           5.00           0.91709    1.980918  0.00000000  0.0000E+00
            *               *           *          *           *
     *              *          *          *          *
          86.00           0.00305    0.006582  0.00000000  0.0000E+00
          87.00           0.00298    0.006432  0.00000000  0.0000E+00
          88.00           0.00291    0.006288  0.00000000  0.0000E+00
          89.00           0.00285    0.006148  0.00000000  0.0000E+00
          90.00           0.00278    0.006014  0.00000000  0.0000E+00

        TIME TO PEAK FLOW RATE =  10.000      (MIN)
        PEAK FLOW RATE         =  4.5603      (IPH)


-----------------------------------------------------------------------


                               VOL. BAL.         SED. TOTAL
        ELE #      TYPE         ERROR  %           (LBS.)
        -----      ----        ----------        ----------
          5       CHANNEL       0.208E+01         345.061
          6       C.COND.      -0.106E-01         345.060
```

Figure 23.
Parts of summary output file for example 2.

```
                    HYDROGRAPH FOR ELEMENT    6
 CONTRIBUTING AREA=  80000.000      SQ. FEET OR  1.8365473      ACRES
       TIME(MIN)        Q(CFS)     Q(IPH)       CONC.    QS(T/AC/HR)

         0.00          0.00000    0.000000  0.00000000  0.0000E+00
         1.00          0.00040    0.000216  0.00000000  0.0000E+00
         2.00          0.07016    0.037888  0.00000000  0.0000E+00
         3.00          0.43391    0.234311  0.00000000  0.0000E+00
         4.00          0.85646    0.462490  0.00000000  0.0000E+00
         5.00          1.02774    0.554980  0.00000000  0.1181E-09
          *               *           *          *           *
          *               *           *          *           *
        86.00          0.00272    0.001467  0.00000000  0.4730E-10
        87.00          0.00261    0.001408  0.00000000  0.3765E-10
        88.00          0.00250    0.001351  0.00000000  0.2889E-10
        89.00          0.00240    0.001298  0.00000000  0.2125E-10
        90.00          0.00231    0.001248  0.00000000  0.1530E-10

       TIME TO PEAK FLOW RATE =  13.000     (MIN)
       PEAK FLOW RATE         =  2.9247     (IPH)

-----------------------------------------------------------------------


                    **** EVENT SUMMARY ****
                         ----- -------

                       GLOBAL VOLUME BALANCE
           VALUES ARE IN UNITS OF LENGTH (VOL./BASIN AREA)

              BASIN AREA =     80000.000      (FT**2)


              TOTAL RAINFALL DEPTH =   0.941 (IN)



  STORAGE REMAINING ON ALL PLANES           =   0.01245 (IN)
  STORAGE REMAINING IN CHANNELS+CONDUITS    =   0.00016 (IN)
  STORAGE REMAINING IN PONDS                =   0.00000 (IN)
  TOTAL INFILTRATION FROM ALL PLANES        =   0.19913 (IN)
  TOTAL INFILTRATION FROM ALL CHANNELS      =   0.00000 (IN)
  TOTAL BASIN RUNOFF                        =   0.71686 (IN)        4779.1 CU.FT.
                                              ---------
  TOTAL OF STOR., INFIL. AND RUNOFF TERMS   =   0.92859 (IN)

            *** GLOBAL VOL. ERROR  =      1.3185 PERCENT ***
```

Figure 23--Continued.
Parts of summary output file for example 2.

```
 type ex2.aux

 INPUT POND FILE:          DUMMY.PND
  INPUT PARAMETER FILE:     EX2.PAR
  INPUT RAINFALL FILE:      EX2.PRE

                    === DESCRIPTIVE RUN TITLE ===
KINEROS MANUAL EXAMPLE 2 - 4/13/89

        *** PLANE NO.    1 DIAGNOSTIC INFORMATION ***

          THE RAIN GAGE FOR PLANE  1 IS GAGE NO.  1
       PPCT. WEIGHT IS 1.00   INTERCEPTION IS 0.01  (IN)

     GEOM. PARAMETERS ARE  L=  100.0  W=  200.0  S= 0.0500
     ROUGHNESS COEF. ARE MANNINGS N=0.013  LAMINAR K=    80.0
     IMPERVIOUS PLANE
     EROSION PARAMETERS ARE ---
       LAW=  1 CF=0.000E+00 CG=0.110E-01 CH= 200.     CO=0.100E-02
       CS=0.100E-02 D50=0.500E-03 RHOS=  2.65 POR=  0.40 PAVE.FAC.= 1.000
     ACCUMUL. SURFACE DEPOSIT. OR EROSION (NEG.) AT EACH NODE (FT.)
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

                **** WATER BALANCE AT END OF PLANE ****
            <INFLOW BASED ON (PPT*GAGE WT) - INTER. + RUNON>
  INFLOW= 0.165E+04 OUTFLOW= 0.162E+04 STOR.= 0.905E+01 ERROR= 0.990E+00 %

-------------------------------------------------------------------------

        ** CHANNEL NO    2 DIAGNOSTIC INFORMATION **


     GEOM. PARAMETERS ARE  L=  200.0  S= 0.0300
     TRAP. X-S  LEFT SLOPE= 1.000 RIGHT SLOPE= 1.000 BOTT. WID.=   2.00
     ROUGHNESS COEF. IS MANNINGS N= 0.013
     IMPERVIOUS CHANNEL
     CONTRIB. CHANNEL NUMBERS: NC1=   0 NC2=   0
     CONTRIB. PLANE NUMBERS:  LEFT=   1  RIGHT=   0  UPPER=   0
     EROSION PARAMETERS ARE ---
       LAW=  2 CG=0.110E-01 CO=0.000E+00 CS=0.000E+00
       D50=0.500E-03 RHOS=  2.65 SURF.POR.=  0.40 PAVE. FAC.= 1.000
     ACCUMUL. CHAN. BOTTOM DEPOSIT. OR EROSION (NEG.)AT EACH NODE (SQ.FT.)
  0.000000  0.000000  0.000000  0.000000  0.000000  0.000000  0.000000  0.000000

0.000000  0.000000

               *** WATER BALANCE AT END OF CHANNEL ***
              <INFLOW BASED ON RUNIN + LATERAL INFLOW>
  INFLOW= 0.162E+04 OUTFLOW= 0.161E+04 STOR.= 0.475E+00 ERROR= 0.641E+00 %
-------------------------------------------------------------------------

        *** PLANE NO.    3 DIAGNOSTIC INFORMATION ***

              RAINFALL HYETOGRAPH FOR PLANE NO.   3
                 (AFTER INTERCEPTION REMOVED)
```

Figure 24.
Auxiliary output file for example 2.

```
                TIME (MIN)     INTENSITY(IN/HR)
                  0.0                1.99
                  5.0                4.70
                 10.0                2.35
                 20.0                0.00
                150.0                0.00
                150.1                0.00

           THE RAIN GAGE FOR PLANE  3 IS GAGE NO.  1
         PPCT. WEIGHT IS 0.98   INTERCEPTION IS 0.03  (IN)

       GEOM. PARAMETERS ARE  L=  200.0  W=  100.0  S= 0.0600
       ROUGHNESS COEF. ARE MANNINGS N=0.100  LAMINAR K=  1000.0
       INFILT. PARAMETERS ARE FMIN= 0.06800  G=  10.400  SI=    0.25
         POR=   0.400  SMAX=    0.83   ROC=    0.20  RECS=   0.200
       EROSION PARAMETERS ARE ---
         LAW=  1 CF= 100.     CG=0.110E-01 CH= 300.      CO=0.100E-02
         CS=0.100E-02 D50=0.500E-03 RHOS=  2.65 POR=  0.40 PAVE.FAC.= 0.100
       ACCUMUL. SURFACE DEPOSIT. OR EROSION (NEG.) AT EACH NODE (FT.)
  -0.44567E-05 -0.11217E-03 -0.33075E-04 -0.83216E-05 -0.41094E-04 -0.21475E-04
   0.50459E-04 -0.31442E-04 -0.59458E-04 -0.38744E-04

                **** WATER BALANCE AT END OF PLANE ****
            <INFLOW BASED ON (PPT*GAGE WT) - INTER. + RUNON>
    INFLOW= 0.158E+04 OUTFLOW= 0.157E+04 STOR.= 0.147E+02 ERROR=-0.600E-01 %

-----------------------------------------------------------------------------

         *** PLANE NO.    7 DIAGNOSTIC INFORMATION ***

              RAINFALL HYETOGRAPH FOR PLANE NO.    7
                 (AFTER INTERCEPTION REMOVED)
                TIME (MIN)     INTENSITY(IN/HR)
                  0.0                0.00
                  1.0                2.40
                  6.0                4.56
                 11.0                1.92
                 21.0                0.00
                150.0                0.00

           THE RAIN GAGE FOR PLANE  7 IS GAGE NO.  2
         PPCT. WEIGHT IS 1.00   INTERCEPTION IS 0.00  (IN)

       GEOM. PARAMETERS ARE  L=  100.0  W=  200.0  S= 0.0100
       ROUGHNESS COEF. ARE MANNINGS N=0.012  LAMINAR K=   100.0
       IMPERVIOUS PLANE
       EROSION PARAMETERS ARE ---
         LAW=  1 CF=0.000E+00 CG=0.110E-01 CH= 200.      CO=0.000E+00
         CS=0.000E+00 D50=0.500E-03 RHOS=  2.65 POR=  0.40 PAVE.FAC.= 1.000
       ACCUMUL. SURFACE DEPOSIT. OR EROSION (NEG.) AT EACH NODE (FT.)
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

                **** WATER BALANCE AT END OF PLANE ****
            <INFLOW BASED ON (PPT*GAGE WT) - INTER. + RUNON>
    INFLOW= 0.150E+04 OUTFLOW= 0.148E+04 STOR.= 0.227E+02 ERROR=-0.395E+00 %
```

Figure 24--Continued.
Auxiliary output file for example 2.

```
-------------------------------------------------------------------------

       *** PLANE NO.    4 DIAGNOSTIC INFORMATION ***

         THE RAIN GAGE FOR PLANE  4 IS GAGE NO.  2
      PPCT. WEIGHT IS 1.06   INTERCEPTION IS 0.03  (IN)
  PARTICLE SETTLING VELOCITY IS 0.053276 FT. PER SEC.
    TIME IS   60.00000 SEC., RAIN RATE IS        0.00000 IPH******************
QL(IPH)=   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   0.00000   0.00000
INFIL=   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   0.00000   0.00000
SUP(I=1,NK)= 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
H2(I=1,NK)=   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   0.00000   0.00000
CMX(I=1,NK)= 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000 0.0000000
CT(I=1,NK)= 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000 0.0000000
DELH(I=1,NK)= 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
RAIN= 0.000E+00 RO FROM UPSTREAM= 0.000E+00 INFIL= 0.000E+00 RO OUT= 0.000E+00
INFLOW= 0.000E+00 OUTFLOW= 0.000E+00 STOR. = 0.000E+00 ERROR= 0.000E+00 %
  *                              *                               *
  *                              *                               *
    TIME IS  180.00000 SEC., RAIN RATE IS        2.18400 IPH******************
QL(IPH)=  -0.05629   0.05659   0.05659   0.05659   0.05659   0.05659
  0.05659   0.05659   0.05659   0.05659
INFIL=   2.24029   2.12741   2.12741   2.12741   2.12741   2.12741
  2.12741   2.12741   2.12741   2.12741
   NO POSITIVE ROOT AT J=    2
         H2(J+1)=H1(J+1)+(QL)(DT)
SUP(I=1,NK)= 0.30439E-08 -0.30541E-08  0.30570E-08 -0.30564E-08  0.30570E-08
-0.30564E-08  0.30570E-08 -0.30564E-08  0.30570E-08 -0.30564E-08
H2(I=1,NK)=   0.00996   0.00103   0.00008   0.00008   0.00008   0.00008
  0.00008   0.00008   0.00008   0.00008
CMX(I=1,NK)= 0.0000339 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000 0.0000000 0.0000000 0.0000000
CT(I=1,NK)= 0.0000000 0.0000001 0.0000000 0.0000002 0.0000001 0.0000002
0.0000001 0.0000002 0.0000001 0.0000002
DELH(I=1,NK)=-0.15350E-06  0.15271E-06 -0.15285E-06  0.15282E-06 -0.15285E-06
 0.15282E-06 -0.15285E-06  0.15282E-06 -0.15285E-06  0.15282E-06
RAIN= 0.121E+03 RO FROM UPSTREAM= 0.506E+01 INFIL= 0.120E+03 RO OUT= 0.199E-05
INFLOW= 0.126E+03 OUTFLOW= 0.120E+03 STOR. = 0.147E+02 ERROR=-0.649E+01 %
  *                              *                               *
  *                              *                               *
    TIME IS  480.00000 SEC., RAIN RATE IS        4.83360 IPH******************
QL(IPH)=   3.98584   3.97608   3.97595   3.97599   3.97601   3.97594
  3.97596   3.97596   3.97594   3.97595
INFIL=   0.84776   0.85752   0.85765   0.85761   0.85759   0.85766
  0.85764   0.85764   0.85766   0.85765
SUP(I=1,NK)= 0.42398E-06  0.29801E-06  0.22410E-06  0.19083E-06  0.10873E-06
 0.54401E-07  0.17737E-08 -0.59984E-07  0.22685E-07  0.12297E-07
H2(I=1,NK)=   0.04400   0.04462   0.04407   0.04236   0.03828   0.03095
```

Figure 24--Continued.
Auxiliary output file for example 2.

```
  0.02290   0.01804   0.01584   0.01392
CMX(I=1,NK)= 0.0009732 0.0009959 0.0009755 0.0009135 0.0007717 0.0005415
0.0003278 0.0002203 0.0001772 0.0001430
CT(I=1,NK)= 0.0000000 0.0003212 0.0004618 0.0005040 0.0004848 0.0003818
0.0003212 0.0002247 0.0000692 0.0001401
DELH(I=1,NK)=-0.87826E-04 -0.46248E-04 -0.12832E-03  0.64653E-04 -0.83871E-04
 0.70671E-04 -0.12542E-03  0.11955E-03 -0.12097E-03  0.71097E-04
RAIN= 0.572E+03 RO FROM UPSTREAM= 0.323E+03 INFIL= 0.278E+03 RO OUT= 0.158E+02
INFLOW= 0.894E+03 OUTFLOW= 0.293E+03 STOR. = 0.636E+03 ERROR=-0.388E+01 %
  *                              *                               *
  *                              *                               *
    TIME IS 1380.00000 SEC., RAIN RATE IS         0.00000 IPH*****************
QL(IPH)=  -0.45872  -0.46010  -0.46015  -0.46010  -0.46013  -0.46016
 -0.46011  -0.46013  -0.46009  -0.46008
INFIL=   0.45872   0.46010   0.46015   0.46010   0.46013   0.46016
  0.46011   0.46013   0.46009   0.46008
SUP(I=1,NK)= 0.25573E-07  0.11211E-07  0.30515E-08  0.18521E-08  0.22400E-08
-0.23117E-07 -0.23959E-07 -0.28733E-07 -0.33593E-07 -0.39904E-07
H2(I=1,NK)=    0.01535   0.01892   0.02243   0.02487   0.02671   0.02823
  0.02958   0.03084   0.03205   0.03324
CMX(I=1,NK)= 0.0001683 0.0002384 0.0003165 0.0003761 0.0004235 0.0004644
0.0005020 0.0005381 0.0005738 0.0006098
CT(I=1,NK)= 0.0000000 0.0001786 0.0003028 0.0003685 0.0004151 0.0004820
0.0005171 0.0005541 0.0005899 0.0006264
DELH(I=1,NK)=-0.38637E-03 -0.26001E-03 -0.29806E-03 -0.88250E-04 -0.21739E-03
-0.61681E-04 -0.24263E-03 -0.13708E-05 -0.23047E-03 -0.42600E-04
RAIN= 0.154E+04 RO FROM UPSTREAM= 0.138E+04 INFIL= 0.521E+03 RO OUT= 0.186E+04
INFLOW= 0.292E+04 OUTFLOW= 0.238E+04 STOR. = 0.529E+03 ERROR= 0.424E+00 %
  *                              *                               *
  *                              *                               *
  *                              *                               *
     GEOM. PARAMETERS ARE  L=  200.0  W=  100.0  S= 0.0600
     ROUGHNESS COEF. ARE MANNINGS N=0.100  LAMINAR K=  1000.0
     INFILT. PARAMETERS ARE FMIN= 0.06800  G=  10.400  SI=    0.25
       POR=   0.400  SMAX=    0.83   ROC=    0.20  RECS=   0.200
     EROSION PARAMETERS ARE ---
       LAW=  1 CF= 100.     CG=0.110E-01 CH= 300.     CO=0.100E-02
       CS=0.100E-02 D50=0.500E-03 RHOS=  2.65 POR=  0.40 PAVE.FAC.= 0.100
     ACCUMUL. SURFACE DEPOSIT. OR EROSION (NEG.) AT EACH NODE (FT.)
-0.39050E-03 -0.25957E-03 -0.29323E-03 -0.73423E-04 -0.20490E-03 -0.44728E-04
0.22418E-03  0.19500E-04 -0.21357E-03 -0.20918E-04

                **** WATER BALANCE AT END OF PLANE ****
           <INFLOW BASED ON (PPT*GAGE WT) - INTER. + RUNON>
  INFLOW= 0.302E+04 OUTFLOW= 0.299E+04 STOR.= 0.366E+02 ERROR=-0.122E+00 %

------------------------------------------------------------------------

        ** CHANNEL NO    5 DIAGNOSTIC INFORMATION **
 *                               *                               *
 *                               *                               *
T(  8)= 0.4200E+03    Q(  8)= 0.2074E+00    QL(  8)= 0.3767E-02
SUP(I=1,NK)= 0.39432E-07  0.36675E-06  0.36675E-06  0.36675E-06  0.36675E-06

A2(K=1,NK)=  0.0000  0.0298  0.0461  0.0589  0.0696
```

Figure 24--Continued.
Auxiliary output file for example 2.

```
CMX(K=1,NK)= 0.000000 0.058323 0.074315 0.083231 0.092521
CT(K=1,NK)= 0.000012 0.000311 0.000613 0.000912 0.001201
DELH(K=1,NK)=  0.00002  0.00000  0.00000  0.00000  0.00000
  UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.161E+02  INFIL. OUTFLOW= 0.000E+00
  CHAN. OUTFLOW= 0.782E+01      STORAGE= 0.424E+01            ERROR= 0.249E+02 %

T(  9)= 0.4800E+03   Q(  9)= 0.5683E+00   QL(  9)= 0.7720E-02
SUP(I=1,NK)= 0.20365E-06  0.11331E-05  0.11331E-05  0.11331E-05  0.11331E-05

A2(K=1,NK)=  0.0000  0.0545  0.0884  0.1167  0.1417
CMX(K=1,NK)= 0.000000 0.081977 0.099923 0.109431 0.119658
CT(K=1,NK)= 0.000033 0.000072 0.000094 0.000109 0.000129
DELH(K=1,NK)=  0.00008  0.00000  0.00000  0.00000  0.00000
  UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.505E+02  INFIL. OUTFLOW= 0.000E+00
  CHAN. OUTFLOW= 0.311E+02      STORAGE= 0.826E+01            ERROR= 0.221E+02 %
 *                              *                               *
 *                              *                               *
T( 23)= 0.1320E+04   Q( 23)= 0.2091E+01   QL( 23)= 0.1989E-01
SUP(I=1,NK)= 0.32379E-05  0.11322E-04  0.11322E-04  0.11322E-04  0.11322E-04

A2(K=1,NK)=  0.0000  0.1264  0.2169  0.2976  0.3727
CMX(K=1,NK)= 0.000000 0.119943 0.138810 0.149009 0.151082
CT(K=1,NK)= 0.000243 0.000406 0.000493 0.000521 0.000534
DELH(K=1,NK)=  0.01904  0.00000  0.00000  0.00000  0.00000
  UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.261E+04  INFIL. OUTFLOW= 0.000E+00
  CHAN. OUTFLOW= 0.250E+04      STORAGE= 0.207E+02            ERROR= 0.352E+01 %

T( 24)= 0.1380E+04   Q( 24)= 0.1783E+01   QL( 24)= 0.1703E-01
SUP(I=1,NK)= 0.22225E-05  0.88370E-05  0.88370E-05  0.88370E-05  0.88370E-05

A2(K=1,NK)=  0.0000  0.1125  0.1925  0.2639  0.3305
CMX(K=1,NK)= 0.000000 0.115426 0.134823 0.145309 0.147392
CT(K=1,NK)= 0.000202 0.000372 0.000462 0.000491 0.000506
DELH(K=1,NK)=  0.01977  0.00000  0.00000  0.00000  0.00000
  UPPER INFLOW=  0.000E+00  LAT. INFLOW= 0.272E+04  INFIL. OUTFLOW= 0.000E+00
  CHAN. OUTFLOW= 0.261E+04      STORAGE= 0.184E+02            ERROR= 0.326E+01 %
 *                              *                               *
 *                              *                               *
 *                              *                               *
     GEOM. PARAMETERS ARE  L=  100.0  S= 0.0400
     TRAP. X-S  LEFT SLOPE= 2.000 RIGHT SLOPE= 2.000 BOTT. WID.=   0.50
     ROUGHNESS COEF. IS MANNINGS N= 0.020
     IMPERVIOUS CHANNEL
     CONTRIB. CHANNEL NUMBERS: NC1=   0 NC2=   0
     CONTRIB. PLANE NUMBERS:  LEFT=   3  RIGHT=   4  UPPER=   0
     EROSION PARAMETERS ARE ---
       LAW=  2 CG=0.110E-01 CO=0.000E+00 CS=0.000E+00
       D50=0.500E-03 RHOS=  2.65 SURF.POR.=  0.40 PAVE. FAC.= 1.000
     ACCUMUL. CHAN. BOTTOM DEPOSIT. OR EROSION (NEG.)AT EACH NODE (SQ.FT.)
  0.021875  0.000000  0.000000  0.000000  0.000000

               *** WATER BALANCE AT END OF CHANNEL ***
              <INFLOW BASED ON RUNIN + LATERAL INFLOW>
  INFLOW= 0.323E+04 OUTFLOW= 0.317E+04 STOR.= 0.134E+00 ERROR= 0.208E+01 %
-------------------------------------------------------------------------
```

Figure 24--Continued.
Auxiliary output file for example 2.

```
      ** CONDUIT NO    6 DIAGNOSTIC INFORMATION **


   GEOM. PARAMETERS ARE  L=  150.0  S= 0.0200
   CIRCULAR SHAPE  -   DIAMETER =  2.00000
   ROUGHNESS COEF. IS MANNINGS N= 0.012
   IMPERVIOUS CHANNEL
   CONTRIB. CHANNEL NUMBERS: NC1=    2 NC2=    5
   CONTRIB. PLANE NUMBERS:  LEFT=    0  RIGHT=    0  UPPER=    0
   EROSION PARAMETERS ARE ---
     LAW=  2 CG=0.110E-01 CO=0.000E+00 CS=0.000E+00
     D50=0.500E-03 RHOS=  2.65 SURF.POR.=   0.40 PAVE. FAC.= 1.000
   ACCUMUL. CHAN. BOTTOM DEPOSIT. OR EROSION (NEG.)AT EACH NODE (SQ.FT.)
0.000000  0.000000  0.000000  0.000000  0.000000  0.000000  0.000000

              *** WATER BALANCE AT END OF CONDUIT ***
                <INFLOW BASED ON UPSTREAM RUNIN ONLY>
INFLOW= 0.478E+04 OUTFLOW= 0.478E+04 STOR.= 0.439E+00 ERROR=-0.106E-01 %
```

Figure 24--Continued.
Auxiliary output file for example 2.

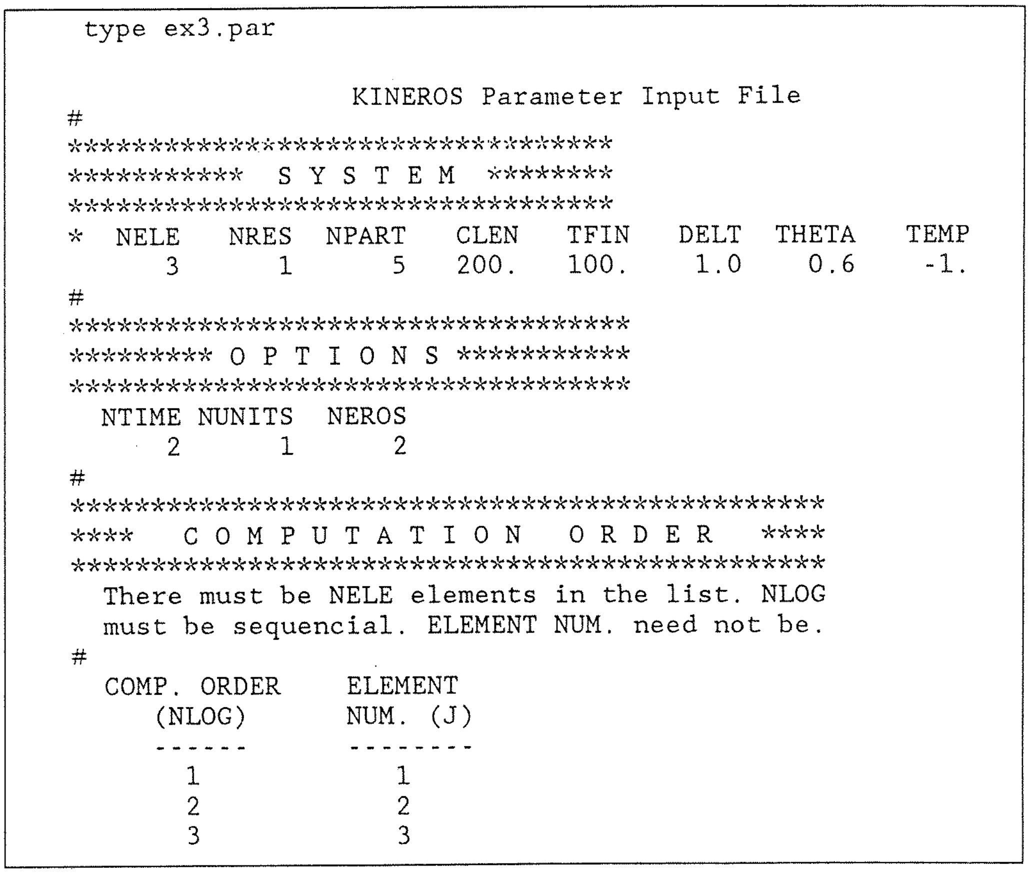
During the first few time steps the plane volume balance errors may become as large as 10 percent, but they quickly decrease until they are usually smaller than 1 percent. These errors are due to the numerical approximation involved in estimating the storage at each time step. When the storage is large relative to the total inflow, the errors can be about 10 percent. Later when the storage is small relative to the total inflow, they usually become inconsequential.

Detailed printouts for channel 5 are shown at two selected times in figure 24. At time [T(8) = 420s] the channel discharge at the lower boundary [Q(8)] is 0.207 cubic feet per second and the lateral inflow rate [QL(8)] is 0.003767 cubic feet per second per foot. The cross-sectional area of flow at each node is denoted by A2(K=1,NK). This channel is nonerodible so the sediment supply term SUP(I=1,NK) consists of the lateral inflow of sediment contributed by planes 3 and 4. The transport capacity at the upper node is zero so deposition is occurring. Consequently the net supply rate at node 1 is lower than the downstream nodes and deposition is indicated by a positive DELH. The channel is nonerodible so DELH remains zero at nodes 2 through 4 although the concentration (CT) is much lower than the transport capacity (CMX).

The purpose of the auxiliary file is to provide insight into the detailed computations and to assist in understanding runoff and erosion dynamics as described by the algorithms used in KINEROS. In the early stages of an analysis of a particular watershed, the auxiliary file should be examined carefully, for it can reveal inconsistencies in input parameters or problems with the finite difference schemes.

Example 3

For this example we modify example 1 to include infiltration and erosion and add a pond at the channel outlet. We describe the pond shape with cross section data at a sequence of stations beginning at the upper end of the pond. The pond cross sections must be taken to a high enough elevation so that the water surface elevation is always lower than the highest data points. In addition, we specify an outflow or spillway elevation-discharge rating and an initial pond water level. The pond data are contained in a file called EX3.PND and were created using the template file TEMP.PND. The parameter input file EX3.PAR is shown in figure 25.



```
  type ex3.par

                  KINEROS Parameter Input File
#
**********************************
***********  S Y S T E M  ********
**********************************
*  NELE    NRES   NPART    CLEN    TFIN    DELT   THETA    TEMP
      3       1       5    200.    100.     1.0     0.6     -1.
#
***********************************
********* O P T I O N S ***********
***********************************
  NTIME NUNITS  NEROS
      2      1      2
#
***********************************************
****   C O M P U T A T I O N   O R D E R   ****
***********************************************
  There must be NELE elements in the list. NLOG
  must be sequencial. ELEMENT NUM. need not be.
#
  COMP. ORDER    ELEMENT
     (NLOG)      NUM. (J)
     ------      --------
        1            1
        2            2
        3            3
```

Figure 25.
Parameter file for example 3.

```
#
************************************************
******   E L E M E N T - W I S E   I N F O ***
************************************************
    There must be NELE sets of the ELEMENT-WISE  prompts and data
    records; duplicate records from * to * for each element.  The
    elements may be entered in any order.
*
 J      NU      NR      NL     NC1     NC2  NCASE NPRINT    NPNT     NRP
 1       0       0       0       0       0      0      1       0       0
--------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW   DIAM      R1      R2
    100.0   200.0    0.05     0.0     0.0     0.0    0.0   0.013     0.0
--------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC   RECS   DINTR
     0.068    10.4     0.4    0.25    0.83     0.2    0.2    0.03
--------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50   RHOS    PAVE  SIGMAS
         3   200.0    0.02   300.0     1.0  0.0001   2.65     0.1    0.02
*
*
 J      NU      NR      NL     NC1     NC2  NCASE NPRINT    NPNT     NRP
 2       0       0       1       0       0      1      2       0       0
--------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW   DIAM      R1      R2
     200.0     0.0    0.03     1.0     1.0     2.0    0.0   0.013     0.0
--------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC   RECS   DINTR
       4.0     1.8    0.44    0.40    0.95     0.2    0.0     0.0
--------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50   RHOS    PAVE  SIGMAS
         6     0.0    0.01     0.0     0.0  0.0001   2.65     0.1    0.02
*
*
 J      NU      NR      NL     NC1     NC2  NCASE NPRINT    NPNT     NRP
 3       0       0       0       2       0      0      2       1       0
--------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW   DIAM      R1      R2
       0.0     0.0     0.0     0.0     0.0     0.0    0.0     0.0     0.0
--------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC   RECS   DINTR
       0.0     0.0     0.0     0.0     0.0     0.0    0.0     0.0
--------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50   RHOS    PAVE  SIGMAS
         0     0.0     0.0     0.0     0.0  0.0001   2.65     0.0    0.02
*
```

Figure 25--Continued.
Parameter file for example 3.

Under the "SYSTEM" heading, NELE is now 3 and TFIN has been increased to 100 to accommodate ponding delay. NPART = 5 causes the sediment size distribution, lognormal with mode = D50 (ft), and standard deviation = SIGMAS(NC1) to be represented by five equal volume parts, each represented by a mean sediment size calculated by the program. Under "OPTIONS, NEROS = 2 to allow erosion. The pond, element 3, has been added to NLOG. The geometries of elements 1 and 2 are the same as those for example 1, and the erosion parameters are identical to those in example 2, except that for plane 1 we have entered values for CF (200), CG (0.02), CS (1.0), and D50 (0.0001) and for channel 2 values for CG (0.01) and D50 (0.0001). Infiltration has been allowed in channel 2 by setting FMIN = 4.0, G = 1.8, SMAX = 0.95, POR = 0.44, and SI = 0.40. Data for the pond element 3 are added. NC1 = 2 indicates that channel 2 contributes to the pond. NPNT = 1 signifies that this is a pond element and that the pond geometry data must be read. The pond data file is shown in figure 26.

NPND will correspond to NPNT in the parameter file (1, 2, or 3). In this example, there is only one pond, so NPND = 1. NSEC is the number of cross section locations (4). MEL is the number of elevations at which cross-sectional areas (A) and top widths (TWP) are given. ELST is the water surface elevation at the beginning of the simulation (101.0 ft). ELVZ is the elevation of the lowest point on the pond bottom (100.0 ft). TDIFUS is the diffusion coefficient for pond mixing, specified as 0.0005 ft^2/s.

The NSEC (4) cross sections are at 0.0, 5.0, 10.0, and 20.0 ft (XSEC) from the upper end of the pond. NOPQ is 4, the number of stage-discharge pairs for the pond rating table, and ELZQ is the lowest elevation at which outflow begins (102.0 ft). ELQ and QSO are the elevations and discharges (ft^3/s) for the outflow rating table. Note that a very small value of discharge must be entered at ELZQ because logarithmic interpolation is used to estimate discharge between tabulated values.

Cross-sectional areas and widths are specified at MEL(5) elevations: 101., 102., 103., 104., and 105. ft. If the minimum elevation at that section is greater than the tabulated elevation, A and TWP are set to zero. The rainfall input data are printed (fig. 27) as are the hydrograph and sedigraph data (fig. 28). From the summary information in figure 28 we see that 223 pounds of sediment have been deposited in the pond.

```
 type ex3.pnd

1)                               KINEROS Pond Input Data
#
#   NOTE: If more then one pond exists the entire block of lines from
#         line one (1) to the * line after the last X-S must be repeated
#         with appropriate input values corresponding to that pond.
#
*****************************
 Pond Cross-section Layout
*****************************
POND     NUM. OF   NUM. OF ELEV.    BEG. POND    LOWEST ELEV.    POND DIFFUS.
NUMB.    POND X-S   IN POND X-S     ELEVATION     OF POND       COEF. (FT**2/S)
(NPND)    (NSEC)       (MEL)          (ELST)        (ELVZ)          (TDIFUS)
------    ------       -----          ------        ------          --------
  1         4            5             101.0         100.0            0.0005
#
 Enter the pairs of X-S number and the distance from the upper end of
 the pond (XSEC) to the associated cross section.
       X-S NUM       DIST. TO X-S
                        (XSEC)

       -------       ------------
          1               0.0
          2               5.0
          3              10.0
          4              20.0

#
**********************************
*  Outflow Rating Table          *
**********************************
     NUM. OF                ELEV. OF ZERO
  DEPTH-FLOW PAIRS              FLOW
      (NOPQ)                   (ELZQ)
      ------                   ------
        4                       102.0
#
   Enter (NOPQ) elevation (ELQ) - discharge (QSO) pairs.
   NOTE: The first elevation must = ELZQ and have
         (1.0E-10) discharge associated with it.
     (ELQ)      (QSO)
     -----      -----
      102.      1.0E-10
      103.       5.0
      104.      25.0
      105.     130.0
#
**********************************
   Specific Cross-section Data
**********************************
   There must be (NSEC) sets of cross-section records with (MEL) elevations
   per X-S with X-S area (A) and top width (TWP). For each cross-section
   repeat lines from * to * inserting the appropriate num. of elev. (MEL)
   ****
   NOTE: The pond cross section information must be defined to the "same"
   ****  elev. as the highest elev. in the elevation-discharge table.
```

Figure 26.
Pond geometry for example 3.

```
*
   X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                 (EL)          (A)           (TWP)
   -------      -----      --------     -------------
      1         101.0         0.0            0.0
      1         102.0         0.0            0.0
      1         103.0         1.0            3.15
      1         104.0         6.23           7.33
      1         105.0        10.30           9.58
*
*
   X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                 (EL)          (A)           (TWP)
   -------      -----      --------     -------------
      2         101.0         0.0            0.0
      2         102.0         0.46           2.11
      2         103.0         6.51           8.41
      2         104.0        16.20          11.31
      2         105.0        28.80          15.49
*
*
   X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                 (EL)          (A)           (TWP)
   -------      -----      --------     -------------
      3         101.0         1.52           3.05
      3         102.0         7.49           9.24
      3         103.0        21.10          14.30
      3         104.0        36.30          17.70
      3         105.0        52.75          22.45
*
*
   X-S NUM.     ELEV.       X-S AREA     X-S TOP WIDTH
                 (EL)          (A)           (TWP)
   -------      -----      --------     -------------
      4         101.0         1.71           4.22
      4         102.0         7.30           6.57
      4         103.0        15.20          10.70
      4         104.0        30.50          21.10
      4         105.0        44.30          27.70
*
```

Figure 26--Continued.
Pond geometry for example 3.

```
 type ex3.pre
                             KINEROS   Rainfall Input Data
#
****************************
      Gage Network Data
****************************
#
  NUM. OF RAINGAGES    MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
      (NGAGES)            (MAXND)
      --------            -------
         1                   5
#
 There must be NELE  pairs of (GAGE  WEIGHT) data.
*
 ELE. NUM. (J)     RAINGAGE     WEIGHT
 -------------     --------     ------
       1              1          1.0
       2              1          1.0
       3              1          1.0
#
*****************************
       Rainfall Data
*****************************
 There must be NGAGES sets of rainfall data. Repeat lines from * to *
 for each gage inserting a variable number of TIME-DEPTH data pairs
 (see example in User Manual).
#
* ALPHA-NUMERIC GAGE ID: EXAMPLE 1 - GAGE 1 = GAGE 1.
#
  GAGE NUM.     NUM. OF DATA PAIRS (ND)
  ---------     -----------------------
      1                    5
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time).
#
   TIME     ACCUM. DEPTH
  ------    ------------
    0.0         0.0
    5.0         0.2
   10.0         0.6
   20.0         1.0
  150.0         1.0
*
```

Figure 27.
Rainfall file for example 3.

```
type ex3.dat

INPUT POND FILE:          EX3.PND
 INPUT PARAMETER FILE:     EX3.PAR
 INPUT RAINFALL FILE:      EX3.PRE

                     === DESCRIPTIVE RUN TITLE ===
KINEROS MANUAL EXAMPLE 3 - 4/13/89



                                  VOL. BAL.        SED. TOTAL
          ELE #      TYPE          ERROR  %          (LBS.)
          -----      ----         ----------       ----------
            1       PLANE         -0.182E-01        412.324
            2       CHANNEL        0.398E+00        473.014
            3       POND          -0.106E+01        250.353


                       HYDROGRAPH FOR ELEMENT   3
 CONTRIBUTING AREA=  20000.000      SQ. FEET OR 0.45913681      ACRES

          TIME(MIN)         Q(CFS)     Q(IPH)     CONC.     QS(T/AC/HR)

             0.00          0.00000    0.000000  0.00000000  0.0000E+00
             1.00          0.00000    0.000000  0.00000000  0.0000E+00
             2.00          0.00000    0.000000  0.00000000  0.0000E+00
             3.00          0.00000    0.000000  0.00000000  0.0000E+00
             4.00          0.00000    0.000000  0.00000000  0.0000E+00
             5.00          0.00000    0.000000  0.00000000  0.0000E+00
             6.00          0.00000    0.000000  0.00000000  0.0000E+00
             7.00          0.60293    1.302334  0.00000000  0.0000E+00
             8.00          1.71459    3.703523  0.00214861   2.388
             9.00          1.85484    4.006453  0.00380759   4.578
            10.00          1.83688    3.967661  0.00278809   3.320
            11.00          1.64615    3.555693  0.00139102   1.484
            12.00          1.17935    2.547404  0.00099808  0.7631
              *               *          *          *          *
              *               *          *          *          *
            97.00          0.00002    0.000050  0.00024885  0.3723E-05
            98.00          0.00002    0.000050  0.00024735  0.3701E-05
            99.00          0.00002    0.000050  0.00024591  0.3679E-05
           100.00          0.00002    0.000050  0.00024453  0.3658E-05

          TIME TO PEAK FLOW RATE =  9.0000     (MIN)
          PEAK FLOW RATE         =  4.0065     (IPH)


 -------------------------------------------------------------------------



                     **** EVENT SUMMARY ****
                          ----- -------
```

Figure 28.
Parts of output file for example 3.

```
                    GLOBAL VOLUME BALANCE
            VALUES ARE IN UNITS OF LENGTH (VOL./BASIN AREA)

                 BASIN AREA =     20000.000      (FT**2)


                 TOTAL RAINFALL DEPTH =   0.970 (IN)



STORAGE REMAINING ON ALL PLANES            =   0.00000 (IN)
STORAGE REMAINING IN CHANNELS+CONDUITS     =   0.00001 (IN)
STORAGE REMAINING IN PONDS                 =   0.04301 (IN)
TOTAL INFILTRATION FROM ALL PLANES         =   0.29943 (IN)
TOTAL INFILTRATION FROM ALL CHANNELS       =   0.00992 (IN)
TOTAL BASIN RUNOFF                         =   0.62209 (IN)         1036.8 CU.FT.

                                              ---------
TOTAL OF STOR., INFIL. AND RUNOFF TERMS    =   0.97446 (IN)


               *** GLOBAL VOL. ERROR   =    -0.4596 PERCENT ***
```

Figure 28--Continued.
Parts of output file for example 3.

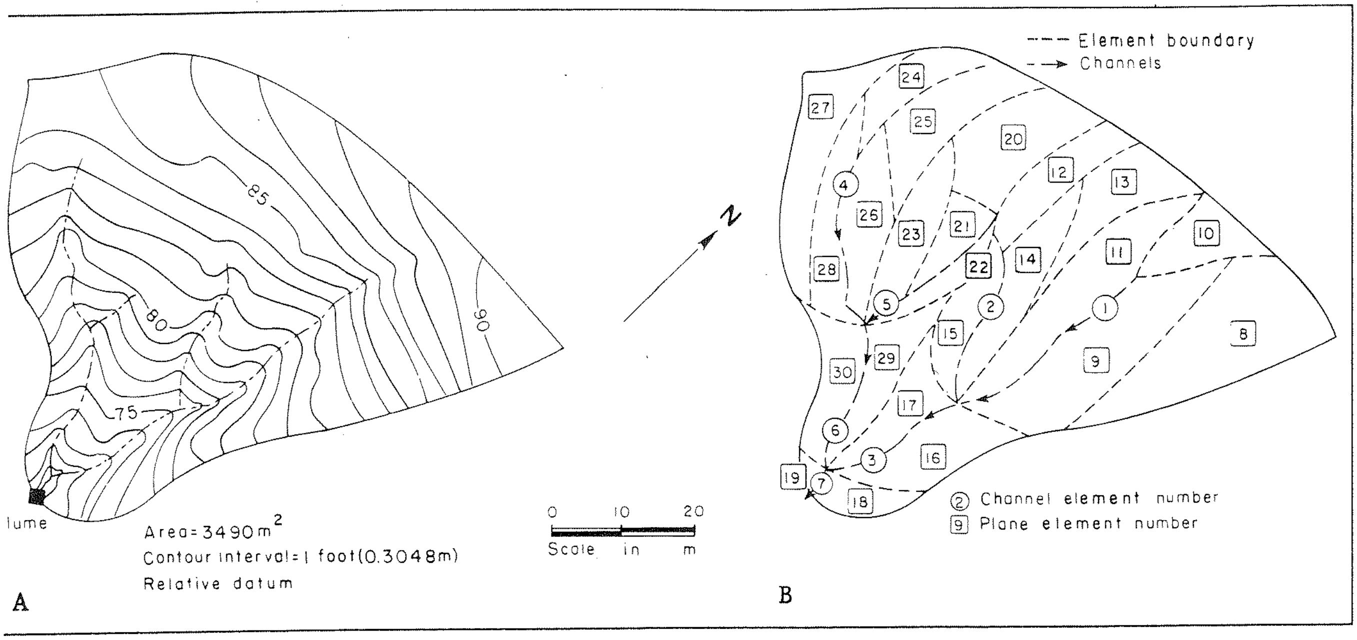
EXAMPLES USING REAL WATERSHEDS

Applications of previous versions of KINEROS have been demonstrated by Rovey et al. (1977), Rovey and Woolhiser (1977), Smith (1981), Osborn et al. (1982) and Wheater and Bell (1983); but a thorough validation has not been accomplished. Such a study should include data from several watersheds and comparison of observed and predicted hydrographs where (1) all parameters have been estimated a priori or (2) all parameters had been estimated from data not included in the prediction set, that is, split-sample tests. We do not intend to present such a study in this manual. However, examples 4 and 5 deal with real watersheds, and parameters were selected from the physical characteristics of the watersheds based on information provided in this manual.

Example 4

For this example, we have created a data file for Lucky Hills Watershed, LH106, a small (0.864 acre) subwatershed in the Walnut Gulch Experimental Watershed in southeastern Arizona. Watershed 106 has been instrumented since 1965. It was treated with a brush-killing chemical (Tebuthiuron) in 1981 and was reseeded with grasses and forbs in 1984. We wish to use KINEROS to investigate the effects of these dramatic changes in vegetative cover, so we provide a detailed geometric representation. The procedures used to develop the cascade of planes and channels are applicable to larger areas, although the geometric detail in this example is much greater.

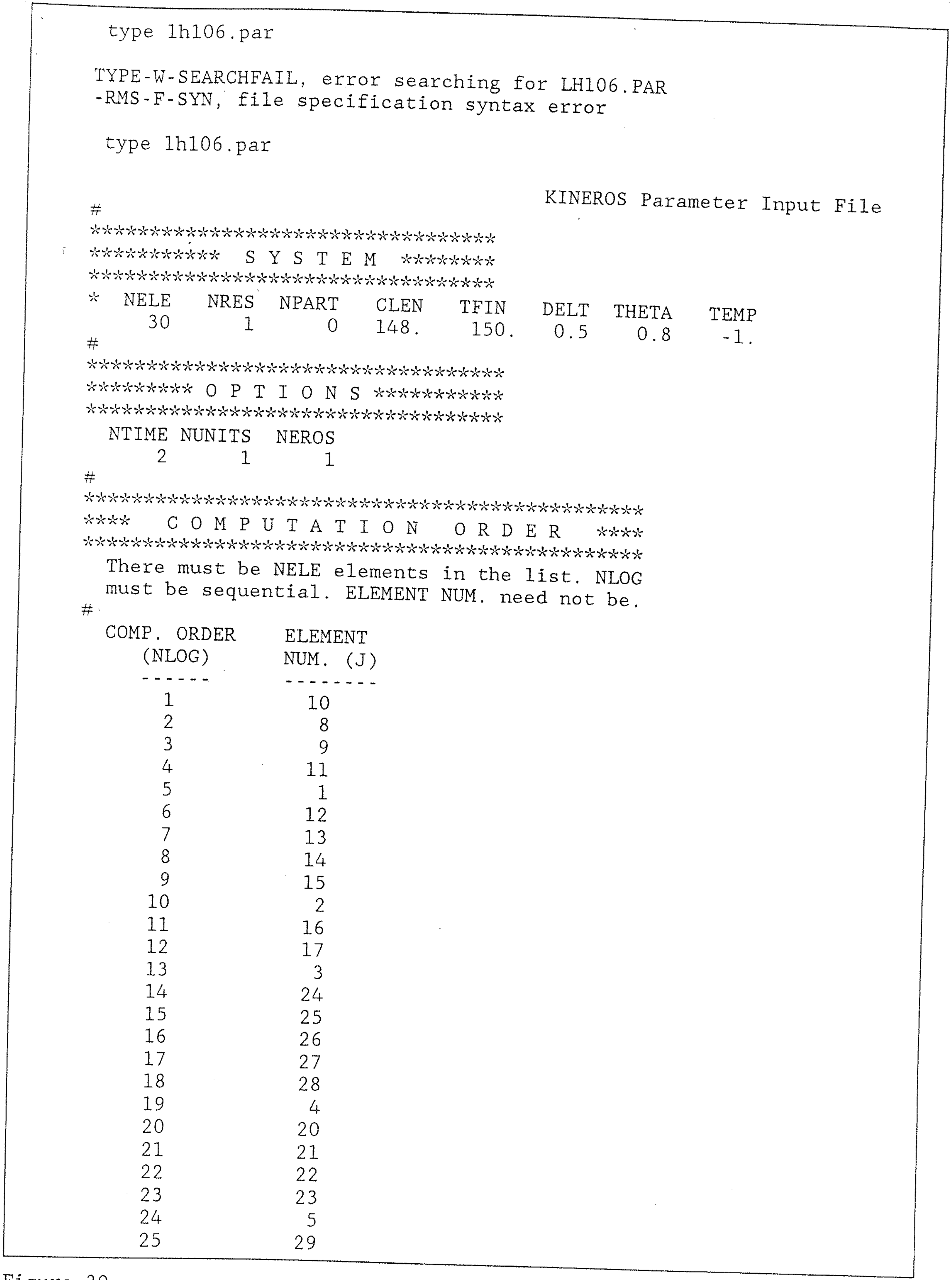
A topographic map of the watershed is shown in figure 29A. Using a tracing paper overlay, the channel system was traced, and the areas contributing to each channel were outlined by drawing dashed lines at right angles to the contours. Each first order channel has three contributing areas, one contributing to the upper end of the channel and one area contributing to each side of the channel (see fig. 29B). There are seven channel segments including one segment to add the outflow from the two tributaries that join above the measuring flume. There are 4 first order channels that require a minimum of 12 planes and 3 higher order channels that require a minimum of 6 planes. Therefore, the geometric representation requires a minimum of 25 elements. Identifying numbers were assigned to each channel element and are shown circled in figure 29B. It is useful to assign these numbers in the order that the flow in the channels will be calculated.



igure 29.
atershed LH106: A, topographic map; B, division into planes and channels.

Next, flow lines are drawn beginning at the midpoint of each channel and at the end of the first order channels toward the divide. These flow lines should be as long as the visually estimated average length of flow in the contributing area. The topographic profiles along these lines should be examined for significant changes of slope, and if a change (or changes) is detected, the contributing area should be segmented into more than one plane. For example, the area contributing to the left side of channel 3 has a uniform slope, so only one plane is required. The length of this plane is equal to the length of the flow line that has been drawn. The width is equal to the contributing area divided by the length. The slope was calculated by dividing the total difference in elevation along the flow line by the length of the plane. There is a break in slope along the flow line drawn within the area contributing to the left side of channel 1. Therefore, a line was drawn through the break in slope and approximately parallel to the channel. Plane numbers are shown in boxes on figure 29B.

Convergence such as that exhibited in the area contributing to the upper end of channel 1 may require the use of more than one plane. A change in soil type may also require further subdivision. For this watershed, soil characteristics are closely related to position on the slope, with highly eroded soils on the steep slopes, so no further delineation of subareas will be required. The total number of elements NELE = 30 is entered in the parameter file LH106.PAR (fig. 30). Because this is a natural watershed we selected the Manning resistance law (NRES = 1).



```
 type lh106.par

TYPE-W-SEARCHFAIL, error searching for LH106.PAR
-RMS-F-SYN, file specification syntax error

 type lh106.par

                                              KINEROS Parameter Input File
#
************************************
************  S Y S T E M  *********
************************************
*  NELE    NRES   NPART    CLEN    TFIN    DELT   THETA    TEMP
     30       1       0    148.     150.    0.5     0.8     -1.
#
*************************************
********** O P T I O N S ***********
*************************************
  NTIME NUNITS  NEROS
      2      1      1
#
*************************************************
****   C O M P U T A T I O N   O R D E R   ****
*************************************************
  There must be NELE elements in the list. NLOG
  must be sequential. ELEMENT NUM. need not be.
#
  COMP. ORDER     ELEMENT
     (NLOG)       NUM. (J)
     ------       --------
        1           10
        2            8
        3            9
        4           11
        5            1
        6           12
        7           13
        8           14
        9           15
       10            2
       11           16
       12           17
       13            3
       14           24
       15           25
       16           26
       17           27
       18           28
       19            4
       20           20
       21           21
       22           22
       23           23
       24            5
       25           29
```

Figure 30.
Parameter input file for example 4.

```
        26          30
        27           6
        28          18
        29          19
        30           7
#
**********************************************
******   E L E M E N T - W I S E   I N F O  ***
**********************************************
    There must be NELE sets of the ELEMENT-WISE  prompts and data
    records; duplicate records from * to * for each element.  The
    elements may be entered in any order.
*
 J      NU      NR      NL     NC1     NC2   NCASE NPRINT    NPNT     NRP
 1      10      11       9       0       0       1      1       0       0
-----------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
      116.     0.0     .13    .159    .159     0.5      0.     .02      0.
-----------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.0     0.0      .0      .0       0       0      0.      0.
-----------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE NPRINT    NPNT     NRP
 2      12      15      14       0       0       1      1       0       0
-----------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        85     0.0    .085    .159    .159     0.5      0.     .02      0.
-----------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
        .0     0.0     0.0     .00       0       0    0.00      0.
-----------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE NPRINT    NPNT     NRP
 3       0      17      16       1       2       1      1       0       0
-----------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        73     0.0    .062     .37     .37     0.5      0.     .02      0.
-----------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
        .0     0.0     0.0     .00       0       0    0.00      0.
-----------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE NPRINT    NPNT     NRP
 4      24      28      26       0       0       1      1       0       0
-----------------------------------------------------------------------
```

Figure 30--Continued.
Parameter input file for example 4.

```
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        89     0.0    .069     .14     .14     0.5      0.     .02      0.
 ------------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
        .0     0.0     0.0     .00       0       0    0.00      0.
 ------------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
J       NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
5       21      23      22       0       0       1       1       0       0
 ------------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        27     0.0     .11    .087    .087     0.5      0.     .02      0.
 ------------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
        .0     0.0     0.0     .00       0       0    0.00      0.
 ------------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
J       NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
6        0      30      29       4       5       1       1       0       0
 ------------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        79     0.0    .075    .212    .212     0.5      0.     .02      0.
 ------------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
        .0     0.0     0.0     .00       0       0    0.00      0.
 ------------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
J       NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
7        0      19      18       6       3       1       1       0       0
 ------------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        15     0.0    .067     1.0     1.0     0.5      0.     .02      0.
 ------------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
        .0     0.0     0.0     .00       0       0    0.00      0.
 ------------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
J       NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
8        0       0       0       0       0       0       1       0       0
 ------------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        80      52     .08      0.      0.      0.      0.     .03      0.
 ------------------------------------------------------------------------
```

Figure 30--Continued.
Parameter input file for example 4.

```
       FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.31    5.00    .453     0.2    0.91     .40    0.36      0.
  ----------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
          0       0       0       0       0       0       0       0       0
*
*
  J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
  9       8       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW    DIAM      R1      R2
         68    56.5     .11      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.28    5.00    .453     0.2    0.91    .445    0.36      0.
  ----------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
          0       0       0       0       0       0       0       0       0
*
*
  J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 10       0       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW    DIAM      R1      R2
         51    23.5    .078      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.31    5.00    .453     0.2    0.91     .40    0.36      0.
  ----------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
          0       0       0       0       0       0       0       0       0
*
*
  J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 11       0       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW    DIAM      R1      R2
         72      39     .10      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.28    5.00    .453     0.2    0.91    .445    0.36      0.
  ----------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
          0       0       0       0       0       0       0       0       0
*
*
  J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
 12       0       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW    DIAM      R1      R2
         88      17     .07      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.31    5.00    .453     0.2    0.91     .40    0.36      0.
  ----------------------------------------------------------------------
```

Figure 30--Continued.
Parameter input file for example 4.

```
          LAW       CF       CG       CH    CO-CS      D50     RHOS     PAVE  SIGMAS
            0        0        0        0        0        0        0        0       0
 *
 *
  J        NU       NR       NL      NC1      NC2    NCASE   NPRINT     NPNT     NRP
 13         0        0        0        0        0        0        1        0       0
 ---------------------------------------------------------------------------------
           XL        W        S       ZR       ZL       BW     DIAM       R1      R2
           63       29     .06       0.       0.       0.       0.      .03      0.
 ---------------------------------------------------------------------------------
         FMIN        G      POR       SI     SMAX      ROC     RECS    DINTR
         0.31     5.00     .453     0.2     0.91      .40     0.36       0.
 ---------------------------------------------------------------------------------
          LAW       CF       CG       CH    CO-CS      D50     RHOS     PAVE  SIGMAS
            0        0        0        0        0        0        0        0       0
 *
 *
  J        NU       NR       NL      NC1      NC2    NCASE   NPRINT     NPNT     NRP
 14        13        0        0        0        0        0        1        0       0
 ---------------------------------------------------------------------------------
           XL        W        S       ZR       ZL       BW     DIAM       R1      R2
           27       59      .11       0.       0.       0.       0.      .03      0.
 ---------------------------------------------------------------------------------
         FMIN        G      POR       SI     SMAX      ROC     RECS    DINTR
         0.28     5.00     .453     0.2     0.91     .445     0.36       0.
 ---------------------------------------------------------------------------------
          LAW       CF       CG       CH    CO-CS      D50     RHOS     PAVE  SIGMAS
            0        0        0        0        0        0        0        0       0
 *
 *
  J        NU       NR       NL      NC1      NC2    NCASE   NPRINT     NPNT     NRP
 15         0        0        0        0        0        0        1        0       0
 ---------------------------------------------------------------------------------
           XL        W        S       ZR       ZL       BW     DIAM       R1      R2
           20       48      .10       0.       0.       0.       0.      .03      0.
 ---------------------------------------------------------------------------------
         FMIN        G      POR       SI     SMAX      ROC     RECS    DINTR
         0.28     5.00     .453     0.2     0.91     .445     0.36       0.
 ---------------------------------------------------------------------------------
          LAW       CF       CG       CH    CO-CS      D50     RHOS     PAVE  SIGMAS
            0        0        0        0        0        0        0        0       0
 *
 *
  J        NU       NR       NL      NC1      NC2    NCASE   NPRINT     NPNT     NRP
 16         0        0        0        0        0        0        1        0       0
 ---------------------------------------------------------------------------------
           XL        W        S       ZR       ZL       BW     DIAM       R1      R2
           34       49      .13       0.       0.       0.       0.      .03      0.
 ---------------------------------------------------------------------------------
         FMIN        G      POR       SI     SMAX      ROC     RECS    DINTR
         0.36     5.00     .453     0.2     0.91     .296     0.36       0.
 ---------------------------------------------------------------------------------
          LAW       CF       CG       CH    CO-CS      D50     RHOS     PAVE  SIGMAS
            0        0        0        0        0        0        0        0       0
 *
```

Figure 30--Continued.
Parameter input file for example 4.

```
 *
 J       NU      NR      NL     NC1     NC2   NCASE NPRINT   NPNT    NRP
17        0       0       0       0       0       0      1      0      0
------------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW   DIAM     R1     R2
         25      48     .10      0.      0.      0.     0.    .03     0.
------------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC   RECS  DINTR
       0.36    5.00    .453     0.2    0.91    .296   0.36     0.
------------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50   RHOS   PAVE SIGMAS
          0       0       0       0       0       0      0      0      0
*
*
 J       NU      NR      NL     NC1     NC2   NCASE NPRINT   NPNT    NRP
18        0       0       0       0       0       0      1      0      0
------------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW   DIAM     R1     R2
         42      15     .12      0.      0.      0.     0.    .03     0.
------------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC   RECS  DINTR
       0.36    5.00    .453     0.2    0.91    .296   0.36     0.
------------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50   RHOS   PAVE SIGMAS
          0       0       0       0       0       0      0      0      0
*
*
 J       NU      NR      NL     NC1     NC2   NCASE NPRINT   NPNT    NRP
19        0       0       0       0       0       0      1      0      0
------------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW   DIAM     R1     R2
         18       9     .17      0.      0.      0.     0.    .03     0.
------------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC   RECS  DINTR
       0.36    5.00    .453     0.2    0.91    .296   0.36     0.
------------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50   RHOS   PAVE SIGMAS
          0       0       0       0       0       0      0      0      0
*
*
 J       NU      NR      NL     NC1     NC2   NCASE NPRINT   NPNT    NRP
20        0       0       0       0       0       0      1      0      0
------------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW   DIAM     R1     R2
         57      42    .056      0.      0.      0.     0.    .03     0.
------------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC   RECS  DINTR
       0.44    5.00    .453     0.2    0.91    .146   0.36     0.
------------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50   RHOS   PAVE SIGMAS
          0       0       0       0       0       0      0      0      0
*
*
 J       NU      NR      NL     NC1     NC2   NCASE NPRINT   NPNT    NRP
21       20       0       0       0       0       0      1      0      0
```

Figure 30--Continued.
Parameter input file for example 4.

```
-----------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        56    15.7     .07      0.      0.      0.      0.     .03      0.
 -----------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
      0.35    5.00    .453     0.2    0.91    .314    0.36      0.
-----------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
22       0       0       0       0       0       0       1       0       0
-----------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        58      11     .08      0.      0.      0.      0.     .03      0.
 -----------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
      0.35    5.00    .453     0.2    0.91    .314    0.36      0.
-----------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
23       0       0       0       0       0       0       1       0       0
-----------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        74      19     .09      0.      0.      0.      0.     .03      0.
 -----------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
      0.35    5.00    .453     0.2    0.91    .314    0.36      0.
-----------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
24       0       0       0       0       0       0       1       0       0
-----------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        82      14    .028      0.      0.      0.      0.     .03      0.
 -----------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
      0.44    5.00    .453     0.2    0.91    .146    0.36      0.
-----------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         0       0       0       0       0       0       0       0       0
*
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
25       0       0       0       0       0       0       1       0       0
-----------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
        79      22     .04      0.      0.      0.      0.     .03      0.
```

Figure 30--Continued.
Parameter input file for example 4.

```
  ----------------------------------------------------------------------
     FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.44    5.00    .453     0.2    0.91    .146    0.36      0.
  ----------------------------------------------------------------------
      LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
        0       0       0       0       0       0       0       0       0
 *
 *
    J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
   26      25       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
       XL       W       S      ZR      ZL      BW    DIAM      R1      R2
       41      39    .085      0.      0.      0.      0.    .030      0.
  ----------------------------------------------------------------------
     FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.35    5.00    .453     0.2    0.91    .314    0.36      0.
  ----------------------------------------------------------------------
      LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
        0       0       0       0       0       0       0       0       0
 *
 *
    J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
   27       0       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
       XL       W       S      ZR      ZL      BW    DIAM      R1      R2
       38      55    .055      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
     FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.35    5.00    .453     0.2    0.91    .314    0.36      0.
  ----------------------------------------------------------------------
      LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
        0       0       0       0       0       0       0       0       0
 *
 *
    J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
   28      27       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
       XL       W       S      ZR      ZL      BW    DIAM      R1      R2
       19      76     .08      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
     FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.35    5.00    .453     0.2    0.91    .314    0.36      0.
  ----------------------------------------------------------------------
      LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
        0       0       0       0       0       0       0       0       0
 *
 *
    J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
   29       0       0       0       0       0       0       1       0       0
  ----------------------------------------------------------------------
       XL       W       S      ZR      ZL      BW    DIAM      R1      R2
       26      55     .08      0.      0.      0.      0.     .03      0.
  ----------------------------------------------------------------------
     FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
     0.35    5.00    .453     0.2    0.91    .314    0.36      0.
```

Figure 30--Continued.
Parameter input file for example 4.

```
------------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE SIGMAS
          0       0       0       0       0       0       0       0      0
*
*
  J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT    NRP
 30       0       0       0       0       0       0       1       0      0
------------------------------------------------------------------------
         XL       W       S      ZR      ZL      BW    DIAM      R1     R2
        38.      34     .10      0.      0.      0.      0.     .03     0.
------------------------------------------------------------------------
       FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       0.36    5.00    .453     0.2    0.91    .296    0.36      0.
------------------------------------------------------------------------
        LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE SIGMAS
          0       0       0       0       0       0       0       0      0
*
```

Figure 30--Continued.
Parameter input file for example 4.

The longest total length of overland flow is found in the areas contributing to the left side of channel 1, so the characteristic length CLEN equals the sum of the lengths of planes 8 and 9 or 148 ft. The rainfall event lasted a total of 96 min, so TFIN = 150. The variable DELT, which is the fixed time step, will vary with the length, slope, and hydraulic resistance of planes and channels and with the rate of lateral inflow. An approximate value can be obtained from the relation

$$DT = \frac{1}{5}\left[\frac{CLEN\ (n)}{1.49\ S^{1/2}\left(QI_{max} - FMIN\right)^{2/3}}\right]^{3/5} \qquad [48]$$

for the Manning equation (in English units) or

$$DT = \frac{1}{5}\left[\frac{CLEN}{C\ S^{1/2}\left(QI_{max} - FMIN\right)^{1/2}}\right]^{2/3} \qquad [49]$$

for the Chezy equation, where QI_{max} is the maximum rainfall rate for the event. According to equations [48] and [49], DT is chosen to equal 0.20 of the kinematic time to equilibrium for a plane of length (CLEN) and slope (S) with rainfall excess equal to QI_{max} - FMIN.

For this example

$$DT = \frac{1}{5}\left\{\frac{148\ (0.03)}{1.49\ (0.10)^{0.5}[(4.2-\ 0.3)/43{,}200]^{0.667}}\right\}^{0.6} = 32\ \mathrm{s}\ [50]$$

Therefore DELT = 0.5 min.

THETA is the weighting factor in the finite difference equations for overland and channel flow. We use a value of 0.8.

TEMP is the water temperature [65°F]. For options description, NTIME = 2, indicating time in minutes, NUNITS = 1 indicating English units, and NEROS = 1 indicating that erosion computations will not be made.

The order of calculation can occur in many ways, but in general the calculations can begin on either the area tributary to channel 3 or the area tributary to channel 6. For this example, we start with element 10, a tributary of channel 3. The calculation sequence is entered into the file LH106.PAR. The parameters for position in system, output options, geometry, hydraulic resistance, and infiltration are entered into the appropriate elementwise descriptions for each plane element.

Watershed 106 was originally covered with sparse brush, mostly whitethorn and creosote bush, with bare areas between. These areas have an erosion pavement covering approximately 40 percent of the area. From table 4 a Manning's n of 0.03 was estimated for all plane elements. Therefore the parameter R1 was set to 0.03 for all planes.

Infiltration Parameters

Soil samples at 0- to 5-cm and 5- to 10-cm depths were taken at six sites at LH106 and were analyzed for percent rock, sand, silt, and clay. Rock was taken as the fraction not passing a 2-mm sieve. Infiltration parameters G, POR, SMAX, FMIN, and ROC were assigned to each plane based on the textural characteristics of the sample from 0-5 cm at the nearest sampling point.

The textural classification of the surface soil for all locations was sandy loam. From table 2 we selected the values of G, POR, and K_s as 5.0, 0.453, and 1.0 in/h, respectively. The parameter G will be corrected for the rock fraction by the program. Therefore G is 5.0 for all planes. K_s, however, should be corrected for volume of rock and for air entrapment *before* it is entered as FMIN. To correct K_s, it was first divided by 2 to approximate K_s under imbibition; then it was multiplied by the factor (1-ROC) to correct for the rock fraction. The rock fraction (R_r) is expressed in fraction by weight. This was converted to volume fraction (P_r) by the relationship

$$P_r = \left[1 + 1.65 \left(\frac{1-R_r}{R_r} \right) \right]^{-1} \qquad [51]$$

To derive this expression it was assumed that the specific gravity of rock is 2.65 and the bulk density of the soil matrix is 100 lb/ft^3. ROC is equivalent to P_r in this expression; the fraction of rock from the nearest sample was used for each plane. A typical value for SMAX, the maximum volumetric water content achieved under imbibition, is 0.91, so this value was entered for each plane. The initial volumetric water content may range from the residual relative saturation (S_r in table 2) to SMAX. We assumed a relatively dry initial condition and set SI = 0.20 for all planes. Finally, the parameter RECS was estimated for the planes. This parameter controls the proportion of the area of a plane in which infiltration by surface water continues after rainfall stops. Its value should be related to the surface microtopography, with a very small value of RECS (not zero) representing a hydraulically smooth surface and a larger value representing a rilled surface. RECS has units of length. If we assume that the plane surface is completely covered with water when the average depth is 0.03 ft, then RECS = 0.36 in.

Channel Parameters

The channels in watershed 106 are incised and do not have significant deposits of sand in the bottom. Because of this, infiltration rates should be very close to the rates on adjacent planes, and infiltration in the channels themselves can be ignored. Therefore, FMIN was set to zero for all channel elements. The length of the channel (XL) was scaled from the map and the element width (W) was set to zero to indicate that this element is a channel. The slope (S) was estimated from the map. The channel cross sections were obtained in the field by measuring the bottom width (BW) and the side slopes (ZL and ZR). Manning's n for the channels was estimated as 0.02 and is shown as R1.

Rainfall Information

Rainfall information was entered into the file LH106P3.PRE (fig. 31). A rainfall event that occurred on August 23, 1982, was used for this example. Rainfall was measured on a weighing recording raingage designated as gage 83, located adjacent to the watershed. Thus, NGAGES = 1 for this example. The variables WEIGHT and RAINGAGE are required inputs. WEIGHT refers to the relative depth of total rainfall at RAINGAGE that fell on ELEMENT(J). Because we have only one raingage, both WEIGHT and RAINGAGE are 1 for all 30 watershed elements. RAINGAGE must be from 1 to NGAGES. A note may be added in the data showing equivalence of watershed gage number (83) to RAINGAGE(1). MAXND refers to the maximum number of time depth pairs that appear in the following rainfall data. In this case MAXND = 26.

Entries under ACCUM.DEPTH represent the accumulated rain depth corresponding to the TIME sequence. ACCUM.DEPTH begins at zero and the last two entries are equal, indicating the end of accumulation and representing the total rainfall. Note that the last time must be greater than TFIN, so that rainfall intensities are defined up to TFIN. ND refers to the number of time depth pairs for each raingage (so with multiple gages, MAXND is the largest ND value).

Checking Parameter Files

With the detailed representation used to describe watershed LH106, it is easy to make mistakes in setting up the flow logic or entering data into the parameter file. It is an excellent practice to check the logic by creating one file with an impervious watershed, that is, FMIN = 0.0 for all elements, and to create an input rainfall file with a constant intensity (for example, 1.0 in/h) and a duration longer than the basin time to equilibrium. If the output hydrograph approaches a steady state rate nearly equal to the input rate, all elements are contributing and numerical errors are acceptable. If the output hydrograph approaches a lower rate, it is likely that the parameter NU has been incorrectly set to zero for some plane or that NU, NC1, NC2, NL, or NR has been incorrectly set to zero for a channel element.

Output Files

Summary information on each plane and channel and the computed hydrograph are written to LH106P3.DAT, part of which is shown in figure 32. The computed and observed hydrographs from channel 7 for the event of August 23, 1982, are shown in figure 33. Although there are differences between the hydrographs, agreement is fairly good considering that all parameters were estimated a priori. No adjustments have been made to calibrate the model results to measured data.

```
 type lh106p3.pre

                                   KINEROS   Rainfall Input Data
#
******************************
      Gage Network Data      RAIN EVENT  OF 8-23-82: GAGE 83
******************************
#
  NUM. OF RAINGAGES     MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
      (NGAGES)             (MAXND)
      --------             -------
         1                  26
#
 There must be NELE  pairs of (GAGE  WEIGHT) data
*
 ELE. NUM. (J)       RAINGAGE      WEIGHT
 -------------       --------      ------
       1                1           1.0
       2                1           1.0
       3                1           1.0
       4                1           1.0
       5                1           1.0
       6                1           1.0
       7                1           1.0
       8                1           1.0
       9                1           1.0
      10                1           1.0
      11                1           1.0
      12                1           1.0
      13                1           1.0
      14                1           1.0
      15                1           1.0
      16                1           1.0
      17                1           1.0
      18                1           1.0
      19                1           1.0
      20                1           1.0
      21                1           1.0
      22                1           1.0
      23                1           1.0
      24                1           1.0
      25                1           1.0
      26                1           1.0
      27                1           1.0
      28                1           1.0
      29                1           1.0
      30                1           1.0
 #
******************************
       Rainfall Data
******************************
 There must be NGAGES sets of rainfall data. Repeat lines from * to *
 for each gage inserting a variable number of TIME-DEPTH data pairs
 (see example in User Manual).
#
```

Figure 31.
Rainfall data for example 4.

```
* ALPHA-NUMERIC GAGE ID: WALNUT GULCH GAGE #83 = GAGE NUM. 1
#
  GAGE NUM.      NUM. OF DATA PAIRS (ND)
  ---------      -----------------------
      1                    26
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time)
#
   TIME     ACCUM. DEPTH
  ------    ------------
    0.0          0.00
    4.0          0.02
    6.0          0.11
   11.0          0.27
   15.0          0.34
   17.0          0.42
   20.0          0.49
   23.0          0.59
   28.0          0.67
   34.0          0.74
   42.0          0.75
   49.0          0.79
   51.0          0.84
   54.0          0.87
   57.0          0.92
   61.0          0.94
   66.0          0.95
   69.0          0.97
   73.0          1.01
   77.0          1.08
   81.0          1.10
   84.0          1.15
   86.0          1.17
   90.0          1.19
   96.0          1.21
  175.0          1.21
*
```

Figure 31--Continued.
Rainfall data for example 4.

```
type lh106p3.dat

INPUT POND FILE:            DUMMY.PND
 INPUT PARAMETER FILE:       LH106.PAR;3
 INPUT RAINFALL FILE:        LH106P3.PRE

                       === DESCRIPTIVE RUN TITLE ===
KINEROS MANUAL EXAMPLE LH106 - 4/14/89




                                VOL. BAL.            SED. TOTAL
       ELE #       TYPE          ERROR  %              (LBS.)
       -----       ----         ----------           ----------
        10        PLANE         -0.543E-01             0.000
         8        PLANE         -0.451E-01             0.000
         9        PLANE          0.102E-01             0.000
        11        PLANE         -0.305E-01             0.000
         1        CHANNEL        0.927E-01             0.000
        12        PLANE         -0.272E-01             0.000
        13        PLANE         -0.349E-01             0.000
        14        PLANE         -0.584E-02             0.000
        15        PLANE         -0.325E+00             0.000
         2        CHANNEL        0.562E-01             0.000
        16        PLANE         -0.119E-01             0.000
        17        PLANE         -0.154E-01             0.000
         3        CHANNEL        0.421E-03             0.000
        24        PLANE         -0.155E-01             0.000
        25        PLANE         -0.359E-01             0.000
        26        PLANE         -0.151E-02             0.000
        27        PLANE         -0.171E-01             0.000
        28        PLANE         -0.232E-01             0.000
         4        CHANNEL        0.177E+00             0.000
        20        PLANE         -0.488E-01             0.000
        21        PLANE         -0.307E-02             0.000
        22        PLANE         -0.193E-01             0.000
        23        PLANE         -0.151E-01             0.000
         5        CHANNEL        0.162E-01             0.000
        29        PLANE         -0.156E-01             0.000
        30        PLANE         -0.182E+00             0.000
         6        CHANNEL        0.281E-02             0.000
        18        PLANE         -0.183E+00             0.000
        19        PLANE         -0.158E-01             0.000
         7        CHANNEL        0.171E-04             0.000


                       HYDROGRAPH FOR ELEMENT    7
CONTRIBUTING AREA=  37600.699      SQ. FEET OR 0.86319327      ACRES

        TIME(MIN)          Q(CFS)      Q(IPH)       CONC.     QS(T/AC/HR)

          0.00            0.00000    0.000000   0.00000000   0.0000E+00
          1.00            0.00000    0.000000   0.00000000   0.0000E+00
          2.00            0.00000    0.000000   0.00000000   0.0000E+00
```

Figure 32.
Part of output file for example 4.

```
      3.00          0.00000     0.000000  0.00000000  0.0000E+00
      4.00          0.00000     0.000000  0.00000000  0.0000E+00
      5.00          0.00000     0.000000  0.00000000  0.0000E+00
      6.00          0.00000     0.000000  0.00000000  0.0000E+00
      7.00          0.00000     0.000000  0.00000000  0.0000E+00
      8.00          0.00000     0.000000  0.00000000  0.0000E+00
      9.00          0.00053     0.000606  0.00000000  0.0000E+00
     10.00          0.01482     0.017027  0.00000000  0.0000E+00
       *               *           *          *           *
       *               *           *          *           *
    130.00          0.00005     0.000059  0.00000000  0.0000E+00
    131.00          0.00005     0.000053  0.00000000  0.0000E+00
    132.00          0.00004     0.000048  0.00000000  0.0000E+00
    133.00          0.00004     0.000044  0.00000000  0.0000E+00
    134.00          0.00003     0.000040  0.00000000  0.0000E+00
    135.00          0.00003     0.000036  0.00000000  0.0000E+00
    136.00          0.00003     0.000033  0.00000000  0.0000E+00
    137.00          0.00003     0.000030  0.00000000  0.0000E+00
    138.00          0.00002     0.000027  0.00000000  0.0000E+00
    139.00          0.00002     0.000024  0.00000000  0.0000E+00
    140.00          0.00002     0.000022  0.00000000  0.0000E+00
    141.00          0.00002     0.000020  0.00000000  0.0000E+00
    142.00          0.00002     0.000018  0.00000000  0.0000E+00
    143.00          0.00001     0.000017  0.00000000  0.0000E+00
    144.00          0.00001     0.000015  0.00000000  0.0000E+00
    145.00          0.00001     0.000014  0.00000000  0.0000E+00
    146.00          0.00001     0.000014  0.00000000  0.0000E+00
    147.00          0.00001     0.000013  0.00000000  0.0000E+00
    148.00          0.00001     0.000012  0.00000000  0.0000E+00
    149.00          0.00001     0.000011  0.00000000  0.0000E+00
    150.00          0.00001     0.000010  0.00000000  0.0000E+00

   TIME TO PEAK FLOW RATE =  23.000     (MIN)
   PEAK FLOW RATE         = 0.80152     (IPH)


-----------------------------------------------------------------------


                    **** EVENT SUMMARY ****
                         ----- -------


                     GLOBAL VOLUME BALANCE
        VALUES ARE IN UNITS OF LENGTH (VOL./BASIN AREA)

             BASIN AREA =     37600.699      (FT**2)


             TOTAL RAINFALL DEPTH =   1.210 (IN)


 STORAGE REMAINING ON ALL PLANES            =    0.00000 (IN)
 STORAGE REMAINING IN CHANNELS+CONDUITS     =    0.00000 (IN)
```

Figure 32--Continued.
Part of output file for example 4.

```
STORAGE REMAINING IN PONDS                 =    0.00000 (IN)
TOTAL INFILTRATION FROM ALL PLANES         =    1.03663 (IN)
TOTAL INFILTRATION FROM ALL CHANNELS       =    0.00000 (IN)
TOTAL BASIN RUNOFF                         =    0.17369 (IN)           544.2 CU.FT.

                                              ----------
TOTAL OF STOR., INFIL. AND RUNOFF TERMS =       1.21032 (IN)


             *** GLOBAL VOL. ERROR   =      -0.0264 PERCENT ***
```

Figure 32--Continued.
Part of output file for example 4.

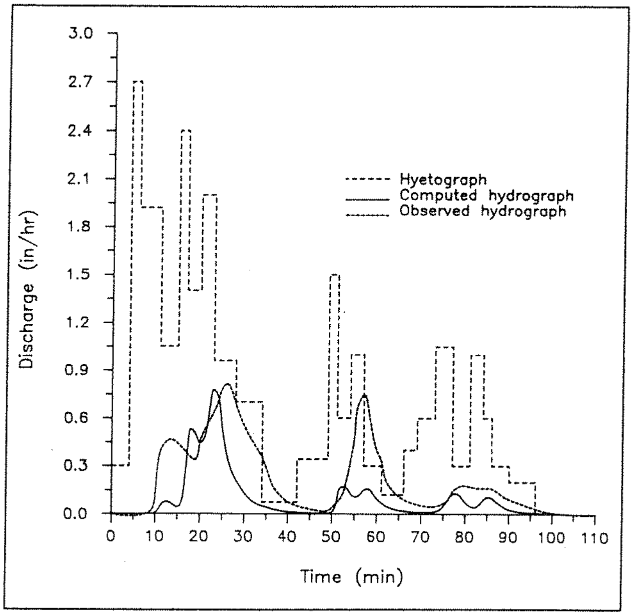


Figure 33.
Observed and computed hydrographs for example 4 for Lucky Hills - 106.

Example 5

In this example we simulate a much larger watershed in considerably less detail than was used in example 4. We have created a data file for watershed 63.011 (2,000 acres), a subwatershed of the Walnut Gulch Experimental Watershed. It has a combined grass and brush cover and has been grazed for about 100 years. It is drained by three principal channels, referred to as the north, central, and south branches (fig. 34). Since runoff from the central branch is largely intercepted by two stock ponds, the watershed above these ponds was omitted. The channel in the north branch is incised, has a sand bottom, and extends to within 1,200 ft of the head of the drainage. The south branch has an incised channel on the lower half of the drainage. An active headcut is moving up the south branch, cutting into a broad, grassy swale. There are 10 weighing-type recording raingages on or adjacent to this watershed. Runoff is measured with Walnut Gulch flumes (Smith et al. 1982).

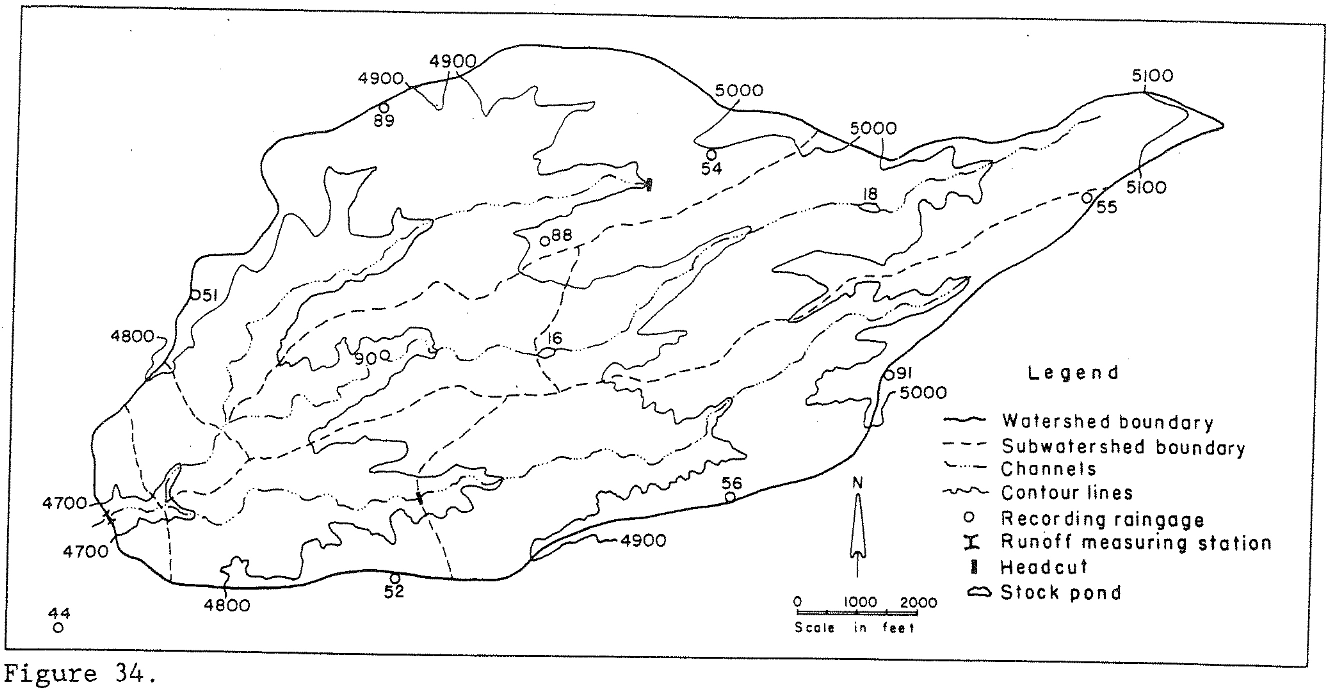


Figure 34.
Map of Walnut Gulch Watershed 11.

Geometric Representation

The simplified geometric representation of this watershed is shown in figure 35. One of the planes is superimposed on the topographic map of the contributing area that it represents in figure 36. Clearly the length of this plane is much greater than the overland flow length and, in fact, flow within this element is a combination of overland and channel flow. With this high degree of abstraction, the Manning's n value should be viewed as a fitting parameter.

Channel 13 is the longest flow element, so CLEN = 7020. KINEROS will assign 15 Δx increments of 468 ft to this channel. The Δx increments for other channels and planes will be approximately the same length except that no element can have fewer than five increments. Using equation [48] we find that a DELT of 3 min is adequate.

The incised channels have a sand bottom, so values of G, POR and FMIN were selected from the values for sand in table 2. Since the sand was considered to be dry, SI = 0.05. The upper channels on the south branch (20 and 23) are broad swales, so we use infiltration parameters suitable for a loam soil and a higher Manning's n reflecting the resistance due to vegetation. The infiltration parameters and Manning's n for the planes have been adjusted to improve the fit of the computed and observed hydrographs, but the parameters are still rather consistent with the ranges of parameter values presented in tables 2 and 3 for a sparsely vegetated sandy loam soil. Part of the input file WG11.PAR is shown in figure 37. The entire file is on the enclosed diskette.

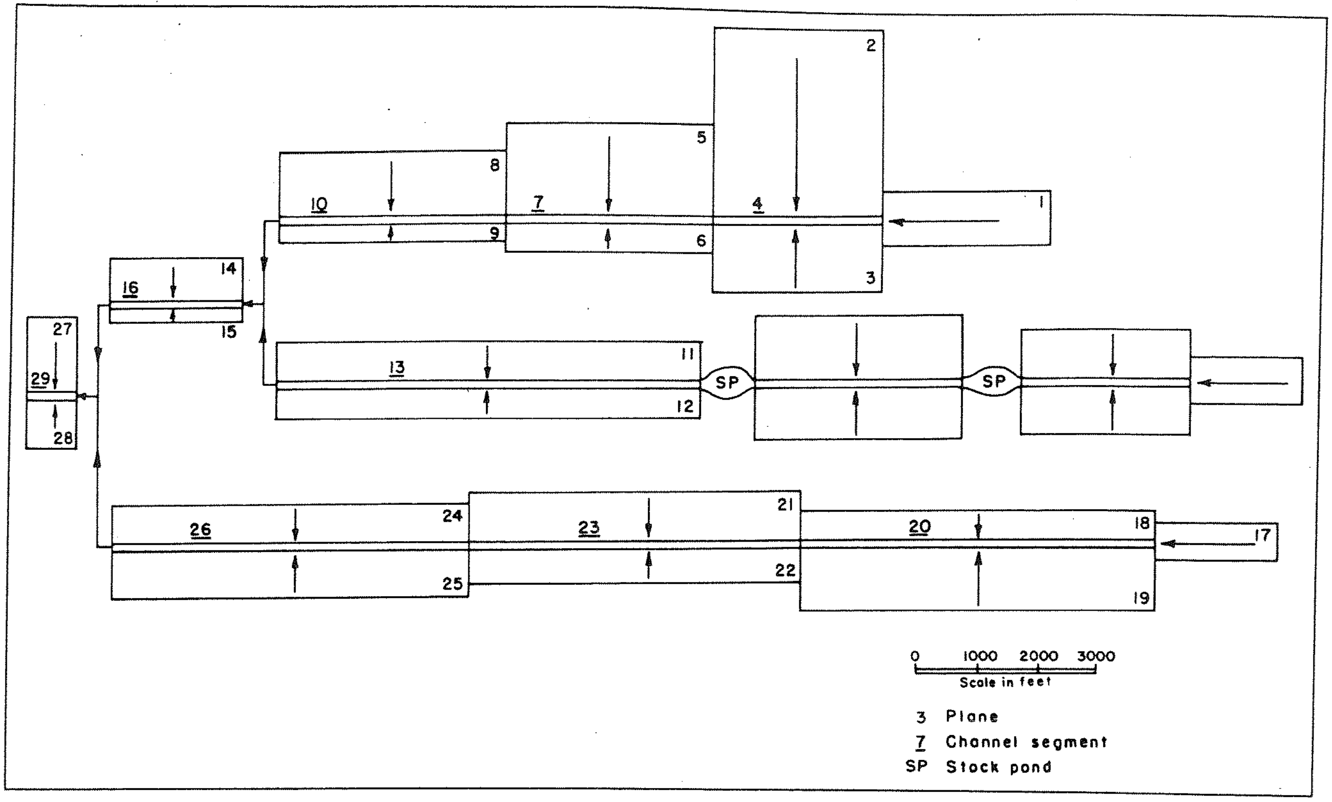


Figure 35.
Plane and channel configuration of Walnut Gulch Watershed 11.

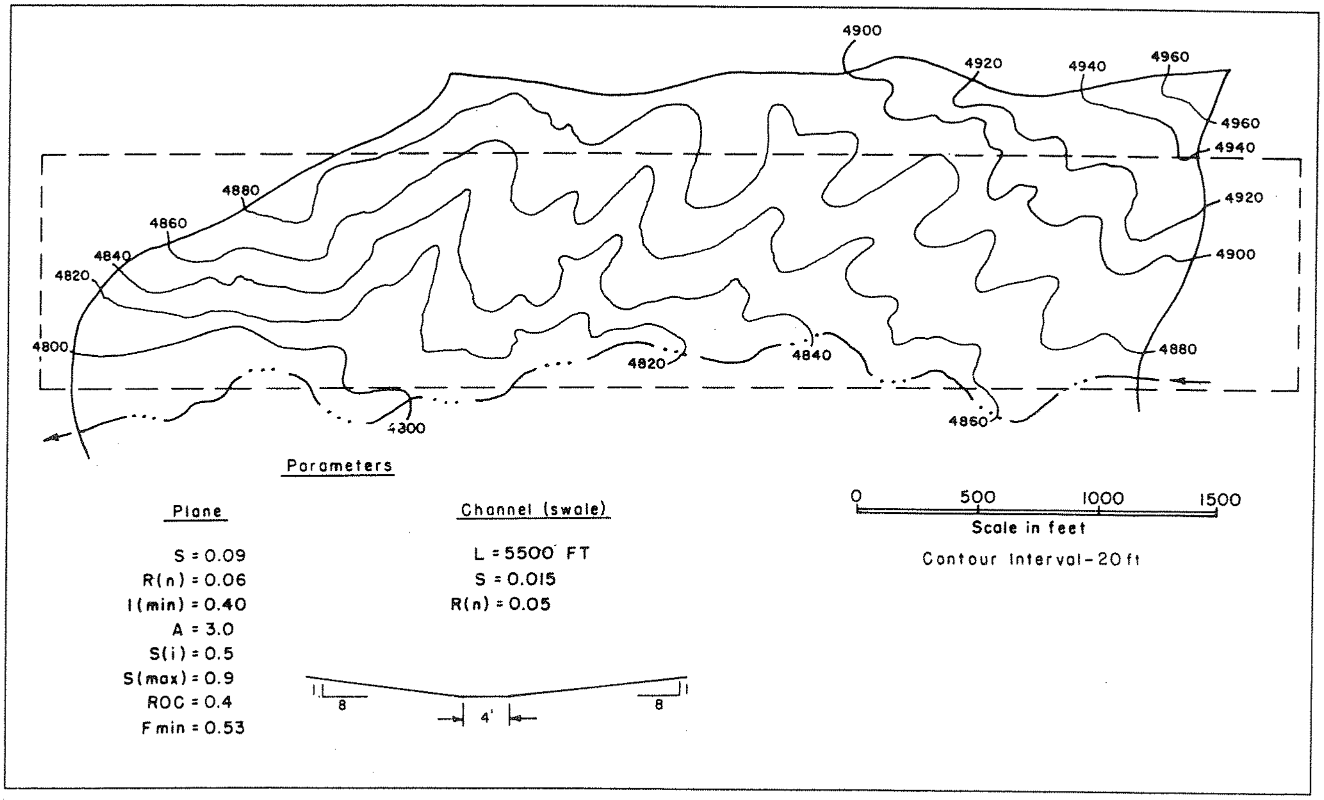
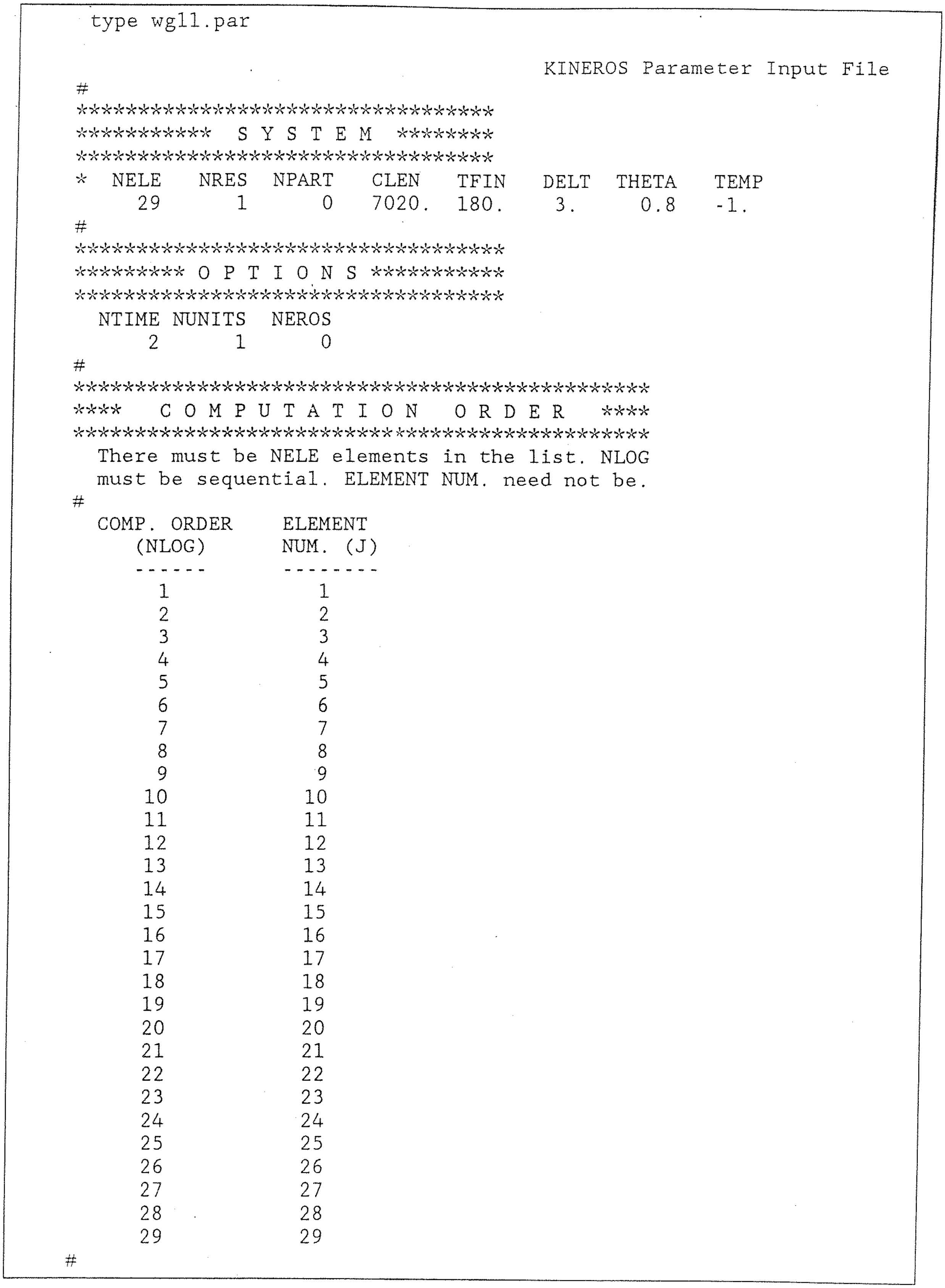


Figure 36.
Comparison of contour map of part of Walnut Gulch Watershed 11 with its representation as a plane.



```
 type wg11.par

                                      KINEROS Parameter Input File
#
**********************************
***********  S Y S T E M  ********
**********************************
*  NELE   NRES  NPART   CLEN   TFIN   DELT  THETA   TEMP
     29      1      0   7020.  180.    3.     0.8   -1.
#
***********************************
********* O P T I O N S ***********
***********************************
  NTIME NUNITS  NEROS
      2      1      0
#
***********************************************
****   C O M P U T A T I O N   O R D E R   ****
***********************************************
  There must be NELE elements in the list. NLOG
  must be sequential. ELEMENT NUM. need not be.
#
  COMP. ORDER    ELEMENT
     (NLOG)      NUM. (J)
     ------      --------
        1            1
        2            2
        3            3
        4            4
        5            5
        6            6
        7            7
        8            8
        9            9
       10           10
       11           11
       12           12
       13           13
       14           14
       15           15
       16           16
       17           17
       18           18
       19           19
       20           20
       21           21
       22           22
       23           23
       24           24
       25           25
       26           26
       27           27
       28           28
       29           29
#
```

Figure 37.
Part of parameter file for Walnut Gulch Watershed 11.

```
***********************************************
******   E L E M E N T - W I S E   I N F O  ***
***********************************************
    There must be NELE sets of the ELEMENT-WISE  prompts and data
    records; duplicate records from * to * for each element.  The
    elements may be entered in any order.
*
 J      NU      NR      NL     NC1     NC2  NCASE NPRINT   NPNT    NRP
 4       1       2       3       0       0      1      2      0      0
-----------------------------------------------------------------------
        XL       W       S      ZR      ZL     BW   DIAM     R1     R2
      2840     0.0   0.015    0.50    0.50   20.0     0.  0.025     0.
-----------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX    ROC   RECS  DINTR
       9.9    4.41   0.453     .05    0.95    .01   0.12      0
-----------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS    D50   RHOS   PAVE SIGMAS
         0       0       0       0       0      0      0      0      0
*
*
 J      NU      NR      NL     NC1     NC2  NCASE NPRINT   NPNT    NRP
 7       0       5       6       4       0      1      1      0      0
-----------------------------------------------------------------------
        XL       W       S      ZR      ZL     BW   DIAM     R1     R2
      3450     0.0   0.014    0.50    0.50   20.0     0.  0.025     0.
-----------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX    ROC   RECS  DINTR
       9.9    4.41   0.453     .05    0.95    .01   0.12      0
--------------------------  -------------------------------------------
       LAW      CF      CG      CH   CO-CS    D50   RHOS   PAVE SIGMAS
         0       0       0       0       0      0      0      0      0
*
         *                           *                           *
         *                           *                           *
         *                           *                           *
*
 J      NU      NR      NL     NC1     NC2  NCASE NPRINT   NPNT    NRP
28       0       0       0       0       0      0      1      0      0
-----------------------------------------------------------------------
        XL       W       S      ZR      ZL     BW   DIAM     R1     R2
       310    2260   0.148      0.      0.     0.     0.   0.06     0.
-----------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX    ROC   RECS  DINTR
      0.47    4.41   0.453     0.5     0.9    0.4   0.12     0.
-----------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS    D50   RHOS   PAVE SIGMAS
         0       0       0       0       0      0      0      0      0
*
```

Figure 37--Continued.
Part of parameter file for Walnut Gulch Watershed 11.

Rainfall Information

Rainfall information for an event of September 1, 1977, was entered into the file WG11.PRE. Rainfall was measured at 10 recording raingages. The weighting factors for each plane were calculated by dividing the total rainfall at the approximate center of gravity of the area corresponding to each plane by the total rainfall at the nearest raingage. Isohyetal maps of total storm rainfall were prepared to estimate the average rainfall over each plane. Weighting factors for channels are inoperative so are shown as 9.9. Storm rainfall ranged from 0.58 in at gage 55 at the upper end of the watershed to 2.35 in at gage 90 west of the watershed center. Part of the rainfall file is shown in figure 38 and the entire file is on the enclosed diskette.

Output Files

Summary information on each plane and channel and the computed hydrograph are written to WG11.DAT, part of which is shown in figure 39. The computed and observed hydrographs from channel 29 are shown in figure 40. Although some parameters have been adjusted to provide this good fit, the parameter values are consistent with tabulated values and also provide good fits for other events. The timing of the peaks is especially good and suggests that the time response characteristics of the watershed have been accurately modeled.

```
 type wg11.pre

                                   KINEROS   Rainfall Input Data
#
*****************************
      Gage Network Data    WG11 EVENT OF 1 SEPT 77
*****************************
#
  NUM. OF RAINGAGES    MAX. NUM. OF TIME-DEPTH DATA PAIRS FOR ALL GAGES
      (NGAGES)              (MAXND)
      --------              -------
        10                    31
#
 There must be NELE  pairs of (GAGE  WEIGHT) data
*
 ELE. NUM. (J)       RAINGAGE     WEIGHT
 -------------       --------     ------
       1                4          .97
       2                5          .86
       3                5          .97
       4                1          9.9
       5                1          .94
       6                3          .90
       7                1          9.9
       8                2         1.13
       9                2         1.26
      10                1          9.9
      11                3          .93
      12                3          .95
      13                1          9.9
      14                2          .94
      15               10         1.44
      16                1          9.9
      17                6         1.15
      18                7         1.17
      19                7         1.10
      20                1          9.9
      21                8         1.31
      22                9          .79
      23                1          9.9
      24                3          .87
      25                9          .93
      26                1          9.9
      27               10         1.09
      28               10         1.11
      29                1          9.9
#
*****************************
       Rainfall Data
*****************************
 There must be NGAGES sets of rainfall data. Repeat lines from * to *
 for each gage inserting a variable number of TIME-DEPTH data pairs
 (see example in User Manual).
#
* ALPHA-NUMERIC GAGE ID: WALNUT GULCH GAGE #89 = GAGE NUM. 1
```

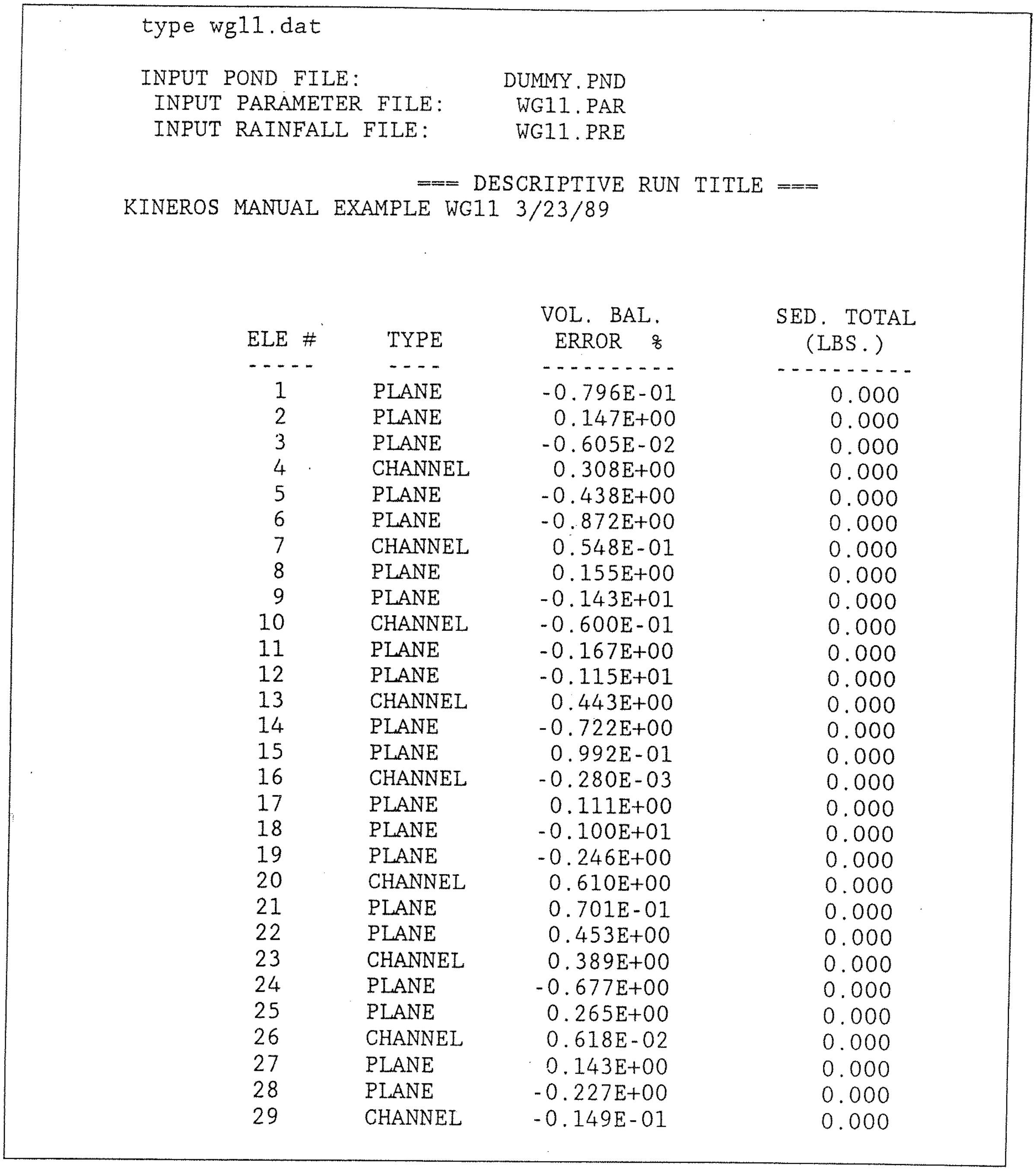
Figure 38.
Part of rain file for event of September 1, 1977
in Walnut Gulch Watershed 11.

```
#
  GAGE NUM.     NUM. OF DATA PAIRS (ND)
  ---------     -----------------------
    1                      27
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time)
#       [ starting time - 1900 hrs]
   TIME      ACCUM. DEPTH
  ------     ------------
     00          0.00
     29          0.03
     36          0.04
     39          0.08
     43          0.15
     45          0.19
     48          0.29
     51          0.50
     53          0.65
     55          0.76
     59          0.92
     62          1.02
     67          1.26
     74          1.49
     76          1.61
     79          1.75
     83          1.81
    103          1.83
    115          1.84
    119          1.86
    132          1.86
    139          1.87
    164          1.88
    169          1.92
    172          1.95
    184          1.96
    190          1.96
#
* ALPHA-NUMERIC GAGE ID: WALNUT GULCH GAGE #51 = GAGE NUM. 2
#
  GAGE NUM.     NUM. OF DATA PAIRS (ND)
  ---------     -----------------------
    2                      27
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time)
#       [ starting time - 1900 hrs]
   TIME      ACCUM. DEPTH
  ------     ------------
     00          0.00
     39          0.00
     41          0.04
     43          0.05
     65          0.07
     68          0.16
     73          0.17
     76          0.26
     78          0.38
     80          0.52
     82          0.59
```

Figure 38--Continued
Part of rain file for event of September 1, 1977
in Walnut Gulch Watershed 11.

```
        84          0.82
        91          0.89
        95          0.95
        98          1.07
       101          1.16
       104          1.32
       108          1.38
       131          1.39
       163          1.42
       168          1.43
       190          1.45
       197          1.49
       201          1.55
       204          1.55
       221          1.57
       230          1.57
#
     *            *                       *
     *            *                       *
     *            *                       *
* ALPHA-NUMERIC GAGE ID: WALNUT GULCH GAGE #44 = GAGE NUM. 10
#
  GAGE NUM.     NUM. OF DATA PAIRS (ND)
  ---------     -----------------------
   10                      27
#
 There must be ND pairs of time-depth (T D) data: NOTE: The last time
 must be greater than TFIN (the total computational time)
#       [ starting time - 1900 hrs]
   TIME     ACCUM. DEPTH
  ------    ------------
     00         0.00
     05         0.04
     08         0.08
     13         0.09
     32         0.12
     36         0.17
     39         0.24
     42         0.29
     47         0.42
     50         0.57
     52         0.71
     55         0.87
     58         0.99
     62         1.08
     66         1.13
     71         1.17
     95         1.21
    126         1.25
    131         1.34
    137         1.37
    152         1.40
    161         1.46
    169         1.52
    174         1.58
    183         1.61
    199         1.63
    202         1.63
*
```

Figure 38--Continued
Part of rain file for event of September 1, 1977
in Walnut Gulch Watershed 11.



```
   type wg11.dat

   INPUT POND FILE:             DUMMY.PND
    INPUT PARAMETER FILE:        WG11.PAR
    INPUT RAINFALL FILE:         WG11.PRE

                       === DESCRIPTIVE RUN TITLE ===
  KINEROS MANUAL EXAMPLE WG11 3/23/89



                                VOL. BAL.        SED. TOTAL
          ELE #      TYPE        ERROR  %          (LBS.)
          -----      ----       ----------       ----------
            1        PLANE      -0.796E-01          0.000
            2        PLANE       0.147E+00          0.000
            3        PLANE      -0.605E-02          0.000
            4        CHANNEL     0.308E+00          0.000
            5        PLANE      -0.438E+00          0.000
            6        PLANE      -0.872E+00          0.000
            7        CHANNEL     0.548E-01          0.000
            8        PLANE       0.155E+00          0.000
            9        PLANE      -0.143E+01          0.000
           10        CHANNEL    -0.600E-01          0.000
           11        PLANE      -0.167E+00          0.000
           12        PLANE      -0.115E+01          0.000
           13        CHANNEL     0.443E+00          0.000
           14        PLANE      -0.722E+00          0.000
           15        PLANE       0.992E-01          0.000
           16        CHANNEL    -0.280E-03          0.000
           17        PLANE       0.111E+00          0.000
           18        PLANE      -0.100E+01          0.000
           19        PLANE      -0.246E+00          0.000
           20        CHANNEL     0.610E+00          0.000
           21        PLANE       0.701E-01          0.000
           22        PLANE       0.453E+00          0.000
           23        CHANNEL     0.389E+00          0.000
           24        PLANE      -0.677E+00          0.000
           25        PLANE       0.265E+00          0.000
           26        CHANNEL     0.618E-02          0.000
           27        PLANE       0.143E+00          0.000
           28        PLANE      -0.227E+00          0.000
           29        CHANNEL    -0.149E-01          0.000
```

Figure 39.
Part of output file for Walnut Gulch Watershed 11.

```
                         HYDROGRAPH FOR ELEMENT  29
CONTRIBUTING AREA=  72734656.        SQ. FEET OR  1669.7579       ACRES

        TIME(MIN)          Q(CFS)      Q(IPH)       CONC.    QS(T/AC/HR)

          0.00           0.00000    0.000000  0.00000000   0.0000E+00
          3.00           0.00000    0.000000  0.00000000   0.0000E+00
          6.00           0.00000    0.000000  0.00000000   0.0000E+00
          9.00           0.00000    0.000000  0.00000000   0.0000E+00
         12.00           0.00000    0.000000  0.00000000   0.0000E+00
         15.00           0.00000    0.000000  0.00000000   0.0000E+00
         18.00           0.00000    0.000000  0.00000000   0.0000E+00
         21.00           0.00000    0.000000  0.00000000   0.0000E+00
         24.00           0.00000    0.000000  0.00000000   0.0000E+00
         27.00           0.00000    0.000000  0.00000000   0.0000E+00
         30.00           0.00000    0.000000  0.00000000   0.0000E+00
         33.00           0.00000    0.000000  0.00000000   0.0000E+00
         36.00           0.00000    0.000000  0.00000000   0.0000E+00
         39.00           0.00000    0.000000  0.00000000   0.0000E+00
         42.00           0.00000    0.000000  0.00000000   0.0000E+00
         45.00           0.02240    0.000013  0.00000000   0.0000E+00
         48.00           0.42309    0.000251  0.00000000   0.0000E+00
         51.00          33.29013    0.019772  0.00000000   0.0000E+00
         54.00         164.56206    0.097740  0.00000000   0.0000E+00
         57.00         361.69540    0.214825  0.00000000   0.0000E+00
         60.00         555.35382    0.329847  0.00000000   0.0000E+00
         63.00         691.96106    0.410983  0.00000000   0.0000E+00
         66.00         750.25299    0.445605  0.00000000   0.0000E+00
         69.00         744.20386    0.442012  0.00000000   0.0000E+00
         72.00         706.35266    0.419531  0.00000000   0.0000E+00
         75.00         671.35376    0.398744  0.00000000   0.0000E+00
         78.00         670.98926    0.398527  0.00000000   0.0000E+00
         81.00         721.38715    0.428460  0.00000000   0.0000E+00
         84.00         821.07404    0.487668  0.00000000   0.0000E+00
         87.00         930.67834    0.552767  0.00000000   0.0000E+00
         90.00         967.81537    0.574824  0.00000000   0.0000E+00
         93.00         899.54919    0.534278  0.00000000   0.0000E+00
         96.00         772.63135    0.458896  0.00000000   0.0000E+00
         99.00         644.59534    0.382851  0.00000000   0.0000E+00
        102.00         543.89172    0.323039  0.00000000   0.0000E+00
        105.00         475.31485    0.282308  0.00000000   0.0000E+00
        108.00         428.82800    0.254698  0.00000000   0.0000E+00
        111.00         385.60995    0.229029  0.00000000   0.0000E+00
        114.00         332.92313    0.197736  0.00000000   0.0000E+00
        117.00         273.42453    0.162398  0.00000000   0.0000E+00
        120.00         216.77664    0.128752  0.00000000   0.0000E+00
        123.00         169.17757    0.100481  0.00000000   0.0000E+00
        126.00         131.74890    0.078251  0.00000000   0.0000E+00
        129.00         103.25227    0.061326  0.00000000   0.0000E+00
        132.00          81.78383    0.048575  0.00000000   0.0000E+00
        135.00          65.68036    0.039010  0.00000000   0.0000E+00
        138.00          53.66309    0.031873  0.00000000   0.0000E+00
```

Figure 39--Continued.
Part of output file for Walnut Gulch Watershed 11.

```
     TIME(MIN)        Q(CFS)      Q(IPH)      CONC.    QS(T/AC/HR)

      141.00        44.47689    0.026417  0.00000000  0.0000E+00
      144.00        37.21624    0.022104  0.00000000  0.0000E+00
      147.00        31.39346    0.018646  0.00000000  0.0000E+00
      150.00        26.67612    0.015844  0.00000000  0.0000E+00
      153.00        22.80873    0.013547  0.00000000  0.0000E+00
      156.00        19.59949    0.011641  0.00000000  0.0000E+00
      159.00        16.91007    0.010044  0.00000000  0.0000E+00
      162.00        14.64006    0.008695  0.00000000  0.0000E+00
      165.00        12.71267    0.007551  0.00000000  0.0000E+00
      168.00        11.06776    0.006574  0.00000000  0.0000E+00
      171.00         9.65783    0.005736  0.00000000  0.0000E+00
      174.00         8.44509    0.005016  0.00000000  0.0000E+00
      177.00         7.39898    0.004395  0.00000000  0.0000E+00
      180.00         6.49444    0.003857  0.00000000  0.0000E+00

     TIME TO PEAK FLOW RATE =  90.000      (MIN)
     PEAK FLOW RATE         = 0.57482      (IPH)
 -----------------------------------------------------------------------
                     **** EVENT SUMMARY ****
                          ----- -------

                      GLOBAL VOLUME BALANCE
          VALUES ARE IN UNITS OF LENGTH (VOL./BASIN AREA)

              BASIN AREA =    72734656.      (FT**2)


              TOTAL RAINFALL DEPTH =   1.542 (IN)



  STORAGE REMAINING ON ALL PLANES         =   0.00052 (IN)
  STORAGE REMAINING IN CHANNELS+CONDUITS  =   0.00711 (IN)
  STORAGE REMAINING IN PONDS              =   0.00000 (IN)
  TOTAL INFILTRATION FROM ALL PLANES      =   0.98437 (IN)
  TOTAL INFILTRATION FROM ALL CHANNELS    =   0.11664 (IN)
  TOTAL BASIN RUNOFF                      =   0.43476 (IN)      2635158.0 CU.FT.

                                             ---------
  TOTAL OF STOR., INFIL. AND RUNOFF TERMS =   1.54339 (IN)

             *** GLOBAL VOL. ERROR  =    -0.0811 PERCENT ***
```

Figure 39--Continued.
Part of output file for Walnut Gulch Watershed 11.

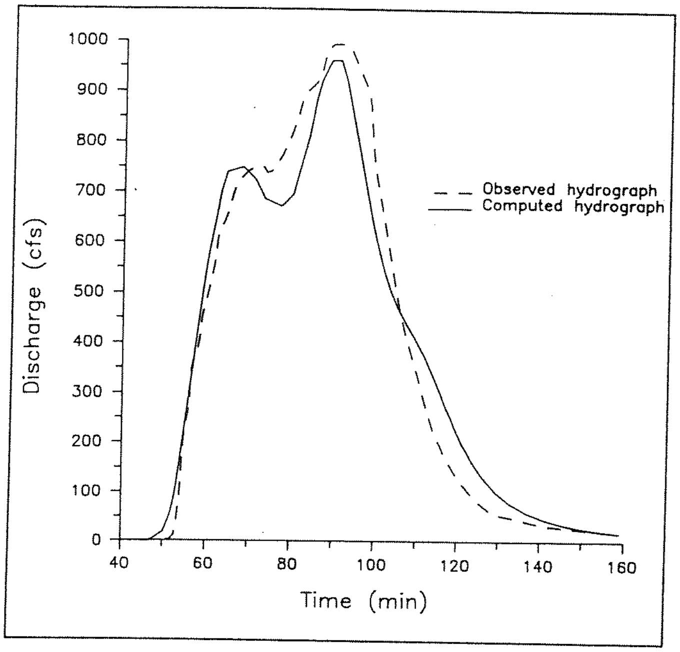


Figure 40.
Observed and computed hydrographs
for Walnut Gulch Watershed 11.

CONCLUDING REMARKS

The KINEROS model, implemented in FORTRAN on the enclosed diskette, simulates the response of a catchment to a user-specified rainfall event. Since runoff is generated only when rainfall rates exceed the infiltration capacity, the model should not be used where other runoff-generating mechanisms are important. The user has an option to simulate erosion as well as runoff, and ponds may also be included.

Since KINEROS was developed as a research tool, many options are included that may be of little use to the practitioner. Guidelines for estimating parameters have been presented where information is available. Where there is little or no information, runoff and erosion predictions may be subject to significant error if they are sensitive to the parameter in question.

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APPENDIX: SEDIMENT TRANSPORT CAPACITY RELATIONS AVAILABLE IN KINEROS

The following transport capacity relations are numbered as in table 10 and as inputted under LAW in the parameter input file. Each expression defines an "equilibrium" sediment concentration in terms of hydraulic and sediment parameters.

Most of the symbols used are defined under "Symbols;" others are defined as they appear in this section.

$u_* = \sqrt{gh_d S}$ [L/T]

h_d = hydraulic depth, flow area divided by top width [L]

ρ_s = particle density [m/L^3]

1. Simple tractive force (Meyer and Wischmeier 1969):

$$C_{mx} = C_s \frac{u^4}{h} \qquad [A.1]$$

2. Unit stream power (Yang 1973) (only for 0.062mm < d < 2mm)

$$\log_{10}(\rho_s C_{mx}) = -0.565 - 0.286A_p - 0.457B_p + C_p D_p \qquad [A.2]$$

in which $A_p = \log_{10}\left(\frac{v_s d}{\nu}\right)$

$B_p = \log_{10}(u_*/v_s)$

$C_p = 1.799 - 0.409A_p - 0.314B_p$

and $D_p = \log_{10}\left[(u/v_s - v_b)S\right]$

with
$$v_b = \begin{cases} \left(\dfrac{2.5}{\log_{10}E_p - 0.06}\right) + 0.66; & 0<E_p<70 \\ \text{or } 2.05; & E_p \geq 70 \end{cases}$$

where $E_p = \frac{u_* d}{\nu}$

3. Bagnold/Kilinc (Kilinc and Richardson 1973):

$$C_{mx} = \frac{C_o\left[u\left(\tau - \tau_c\right)\right]^{1.67}}{h\gamma_w u} \quad ; \quad \tau > \tau_c \qquad [A.3]$$

in which $\tau = \gamma_w hS$,

γ_w = specific weight of water,

τ_c = shields critical tractive force, and

C_o = parameter

4. Ackers and White (1973) (only for $d \geq 0.04$ mm):

$$C_{mx} = \frac{dC_p}{h}\left[\frac{u}{u_*}\right]^n \left[\frac{F_g}{A_p} - 1\right]^m (10^6) \qquad [A.4]$$

in which

$$F_g = \frac{u_*^{\,n}}{\sqrt{d_g\left(S_s - 1\right)}} \left\{\frac{u}{\sqrt{32}\,\log_{10}(10h/d)}\right\}^{1-n} \qquad [A.5]$$

and in which, defining dimensionless grain diameter as:

$$d_g = d\left[\frac{g(S_s - 1)}{\nu^2}\right]^{1/3} \qquad [A.6]$$

the following parameter definitions apply:

$$n = \begin{cases} 1 - 0.56 d_g ; & 1 < d_g \leq 60 \\ 0 ; & d_g > 60 \end{cases} \qquad [A.7]$$

$$A_p = \begin{cases} 0.23/\sqrt{d_g} + 0.14 ; & 1 < d_g \leq 60 \\ 0.170 ; & d_g > 60 \end{cases} \qquad [A.8]$$

$$m = \begin{cases} 9.66/d_g + 1.34 ; & 1 < d_g \leq 60 \\ 1.50 ; & d_g > 60 \end{cases} \qquad [A.9]$$

and

$$\log C_p = 2.86 \log d_g - \left[\log(d_g)\right]^2 - 3.53; \quad 1 < d_g \leq 60 \qquad [A.10]$$

or

$$C_p = 0.025; \qquad d_g > 60 \qquad [A.11]$$

5. Yalin (1963):

$$C_{mx} = 0.635 d u_* S_s \frac{A_n}{uh} \left[1 - \frac{1}{B_p A_n} \ln\left(1 + A_n B_p\right)\right] \qquad [A.12]$$

in which

$$A_n = \frac{Y}{Y_c} - 1 \quad ; \; Y > Y_c$$

$$= 0 \quad \text{otherwise}$$

$$B_p = \frac{2.45}{(S_s)^{0.4}} \sqrt{Y_c}$$

$$Y = \frac{u_*^2}{(S_s - 1) g d}$$

Y_c = critical tractive force, based on particle Reynolds number

6. Engelund and Hansen (1967):

$$C_{mx} = \frac{0.05 \, u \, u_*^3}{g^2 d h (S_s - 1)^2} \qquad [A.13]$$

* U.S. GOVERNMENT PRINTING OFFICE: 1990--720-599/D6639