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A STOCHASTIC MODEL FOR SOIL EROSION

The Ohio State University

Ph.D. 1981

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A STOCHASTIC MODEL FOR SOIL EROSION

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Mostafa El-Sayed Mossaad, B.Sc. (honors), M.A.Sc.

* * * * *

The Ohio State University

1981

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CHAPTER I

INTRODUCTION

The problems of erosion and sedimentation have plagued man since those first days in ancient times when he began to alter the natural condition of the earth's surface for agricultural and other developmental activities. Millions of tons of soil are being eroded every year from agricultural fields, construction sites, and surface mining areas. Not only is the most productive surface soil being lost, but also serious environmental and economic problems are encountered due to sedimentation of this eroded soil in waterways and reservoirs.

Wise selection of land management practices to control erosion requires better estimation of erosion and sediment yield. Therefore, since the turn of the century, enormous efforts were made to develop better understanding and more accurate prediction of soil erosion.

The complexity of the process of soil erosion arises from the random nature of the natural factors that control erosion, which include rainfall characteristics, soil type, geology, and local topography. As described by Meyer et al. (25), the erosion process normally begins when raindrops strike a sloping soil surface. The impact of raindrops detaches soil particles from the soil mass. Conceptually, all rainfall is infiltrated so long as the infiltration capacity

exceeds the rainfall rate. The infiltration rate, however, decreases gradually due to the saturation of the surface soil, and due to the sealing of the surface voids by the raindrop impact. Once the rainfall rate exceeds the infiltration rate, some of the excess water may be ponded as surface storage in depressions, and the remainder becomes runoff by shallow overland flow. As the overland flow moves downslope, it increases in volume, and tends to concentrate into rills because of tillage marks and/or natural microtopography of the slope. The flow erodes soil and transports it downslope as suspension or as bed-load or both. Successive rainstorms deepen the rills progressively until they become gullies.

The importance of the phenomenon of "rilling" has been addressed by many researchers (4, 24, 25, 46). Yet, existing erosion models either ignore the process of rilling, or include it as an empirical term without consideration of the process taking place in individual rills. This is, of course, due to the difficulty imposed by the complicated rill patterns, which change continuously with time.

The general objective of the present study is to develop an erosion model which can deal with the surface geometry on the small scale of individual rills, and which can describe the temporal evolution of the surface geometry as the erosion process accelerates. With the complexity of the erosion process in mind, it is obviously difficult to achieve a comprehensive model which accounts for all or most of the randomness involved in that process in a single study. Therefore, the model represents a first step along this line.

The present study considers the original surface irregularities, or microrelief, as a major factor contributing to the rilling process which is, in turn, an important feature of soil erosion. More specifically, the objective of this study is to develop a computer model which can perform the following:

1. Analyze the surface roughness data (microrelief measurements);
2. Based upon the statistical properties obtained from Item (1), the model should regenerate the slope surface in a fashion suitable for subsequent erosion computations;
3. Carry out erosion computations using a mathematical model which is based on the principles of erosion mechanics and hydraulics;
4. Account for temporal changes in the surface geometry, and its effect on subsequent erosion by an updating computational process.

The analysis of surface roughness data is carried out using the method of spectral analysis. For a given random surface generated by the model, the overland flow during any time interval is computed at every nodal point. During any time interval, the flow properties and the geometry are assumed to be constant. Material eroded from rills and from interrill areas is then computed. The change in

elevation due to erosion during any time interval is used to revise the surface elevations. This is used for computations of the following time interval.

The scope of this study is limited to cases in which rill patterns are developed in a random fashion, depending on the surface roughness conditions. It is important to mention that the tendency of rills to meander decreases as the slope steepens. In very steep slopes, the rill pattern develops into a number of almost straight gullies. In such cases, the randomness of the flow pattern is greatly eliminated, and the mechanism of the erosion process becomes different.

At the present stage, the model is designed for bare plane slopes with small scale irregularities. Deep tillage marks and local topographic variations are considered as large scale variations.

After reviewing the state of the art in Chapter II, the basic concepts and the model formulation are discussed in Chapters III and IV. Chapter V describes the computer model with the various mechanisms involved in the simulation process. The sensitivity of the model to different parameters and mechanisms is tested in Chapter VI. The model results are compared with the general features of the process of soil erosion through a number of numerical experiments described in Chapter VII. Chapter VIII summarizes the conclusions and recommendations for further work.

The work presented herein, although far from being ready for practical use, provides a new approach to the problem of soil erosion.

Further perfection of the techniques used can be valuable for the purpose of erosion prediction, and definitely improves the understanding of this phenomenon.

CHAPTER II

REVIEW OF LITERATURE

To design against erosion, researchers have continuously attempted to develop methods to estimate the amount of soil eroded from the land under different topographic and climatic conditions. Approaches found in the literature to tackle this problem can be classified into two main categories: empirical models based on large amounts of data collected over the years, and analytical models utilizing the improved knowledge of erosion mechanics and hydraulics.

2.1 Empirical Models

Earlier investigations indicated that the erosion rate and consequently the sediment yield are functions of: (i) direct rainfall or snowmelt; (ii) soil type and geology; (iii) catchment topography and geometry; and (iv) land use, including vegetative and mechanical treatment. Thus, for such a complex problem, the regression technique seemed to be an effective way to analyze the available data.

Since the late thirties, several correlation equations have been proposed. Zingg (47) published an empirical equation expressing soil loss as a function of slope length and steepness. Other researchers used this relation as a basis for developing erosion prediction

equations. Of those, we mention Musgrave (27), Wischmeier and Smith (40), Meyer and Kramer (22), and Young and Mutchler (45).

The most widely used correlation equation is the so-called Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (40), and Wischmeier (41). It includes greater detail in several aspects than the Musgrave (27) equation, or other predecessors. The USLE has the form:

$$A = R K L S C P \quad (2.1)$$

which identifies the average annual soil loss, A , in terms of six major factors: rainfall erosiveness, R ; soil erodability, K ; slope length factor, L ; slope steepness factor, S ; cropping and management practices factor, C ; and the supporting conservation practice factor, P . The mathematical relationships for the six factors were determined from statistical analysis of more than 10,000 plot years of data. The USLE was designed to estimate the long-term average annual soil losses for upland slopes where deposition is negligible. Erosion from gullies and stream channels or deposition on or below upland slopes is not considered in the USLE. The equation is applicable to seasonal periods with some increase in the margin of error, but it is least accurate for individual storms. Hence, for problems such as sediment control for construction sites, where soil loss estimates are needed for individual storm events, the computed estimates using the USLE may differ greatly from field observations (42). In addition, Frere et al. (10) indicated that some plant nutrients

and agricultural chemicals absorbed on sediments are also transported by overland flow. Evaluating the potential chemical yield requires the estimation of the amounts of sediment originating from the soil within the tillage layer. Generally, it is important to evaluate the amount of sediment coming from different locations along a slope (10). Unfortunately, these requirements are not fulfilled by the USLE.

2.2 Analytical Models

According to the previous section, the existing empirical equations do not meet the present need for a dynamic soil erosion model that can describe soil movement at different locations on a slope, at any time. This section reviews some of the important developments made along this line.

In the late sixties, researchers began developing soil erosion models based on concepts from erosion mechanics. An early effort in this field was made by Meyer and Wischmeier (23). Following the definition of soil erosion processes suggested by Ellison (5), they described soil erosion as a process of detachment and transportation of soil materials by the erosive agents: rainfall and runoff. Each agent has both a detaching and a transporting capacity, and Ellison suggested that these subprocesses must be studied separately. Similarly, the susceptibility of soil to erosion can be separated into its two components, susceptibility to detachment and susceptibility to transportation. In the same study, based upon some fundamentals of hydraulics and hydrology for steady

state conditions, Meyer and Wischmeier developed four equations describing the four subprocesses mentioned above. For the runoff, they adopted the principle of tractive force used in sediment transport mechanics, and derived equations to compute detachment capacity of the runoff, D_F , and the transport capacity of the runoff, T_F . Two other relations were derived to compute detachment capacity and transport capacity of rainfall (D_R and T_R , respectively). In each of those four equations, parameters were introduced to describe related soil properties. Their simulation model divides the slope length into segments. On each segment, the four quantities, D_F , T_F , D_R and T_R are evaluated, and the actual soil loss is considered the lesser of the two summations, $(D_F + D_R)$ and $(T_F + T_R)$. This concept means that, on one hand, only particles that have been detached from the soil mass will be eroded, no matter how great the transport capacity. On the other hand, only particles that can be transported by the flow will be eroded, no matter how much is detached and available for transportation. The model, although primarily conceptual, contributes to the understanding of the soil erosion process. To proceed beyond the steady-state condition, the different parameters should be considered as time-dependent variables. Among those parameters are rainfall intensity, infiltration rate, and rill geometry as it affects the hydraulics of runoff.

In their attempt to improve the model, Foster and Meyer (8) studied experimentally the applicability of the sediment transport equations developed for rivers, to the shallow overland flow problem.

According to their study, Yalin's transport equation (43), which is based on the principle of tractive force, gives the best fit to experimental results. Their observations indicate that during simulated rain storms, a large fraction of aggregates detached from a cohesive soil mass moves by saltation and by rolling along the bottom of the small flow channels, the same type of grain motion assumed in Yalin's derivation.

Recently, Foster et al. (6) developed a field scale erosion model as a part of the comprehensive model for agricultural management systems called CREAMS. This is based upon the already-described Meyer and Wischmeier (23) model. A modified Yalin equation, to account for more than one soil particle diameter, is used to compute the transport capacity of the overland flow. The model allows for overland flow, channel flow, and impoundment. Computations are performed on a single storm basis.

Although these models deal with detachment and transport capacities separately, as suggested by Ellison (5), it is understood that the two quantities are interrelated (23). To define the interrelationship, Foster and Meyer (7) suggested the equation:

$$\frac{\text{Detachment rate by flow}}{\text{Detachment capacity of flow}} + \frac{\text{Sediment load of flow}}{\text{Transport capacity of flow}} = 1 \quad (2.2)$$

which was based upon some observations. Equation (2.2) agrees with Einstein's assumption that the rate of deposition is directly proportional to the difference between the actual sediment concentration in

the flow and the equilibrium concentration for the flow conditions. Based on Equation (2.2) and on the continuity of mass equation, Foster and Meyer derived a closed form solution for erosion and deposition rates on a slope of variable configurations. The model, however, assumes a steady state condition and a constant rill pattern on the slope.

Li et al (11) considered the overland flow as a steady spatially-varied flow with the rainfall taken as lateral inflow. The shear stresses resulting from this flow were then used to compute the pick-up rate of sediment, on the basis of the following empirical relationship:

$$P_s = a \tau_0^b \quad (2.3)$$

where P_s is the sediment pick-up rate per unit area;
 τ_0 is the boundary shear stress; and,
 a, b are constants.

This model considers only straight slopes with no deposition. Komura (17) modified the model of Li et al. (19) by using Kalinske's bed load function to determine the values of the constants a and b in Equation (2.3). The results of his computations agree with the results of some field measurements.

A more general analytical solution was presented by Smith (38). Unlike most of the preceding analytical models, Smith developed a numerical model that accounts for variable slope shape, length, and boundaries, for unsteady state conditions. The equation is solved

implicitly with a time-weighted four-point method at each time step. The structure of the model enables it to simulate the response from complex watershed shapes and serve as a framework within which alternative erosion and transport models can be compared. The process of development of rills with space and time is not considered in this model.

2.3 Concept of Rill - Interrill Erosion

As we recall from the description of the erosion process in Chapter 1, the overland flow begins after the rainfall rate exceeds the soil infiltration rate. Then, as overland flow moves downslope, it tends to concentrate into rills. Realizing the important role of the rill pattern, researchers in the early seventies started to consider the erosion process as divided into two components: rill erosion, which results primarily from soil detached by concentrated runoff on a limited part of the land surface, and interrill erosion caused by raindrop impact and by a sheet flow over the remainder of the land surface.

All the models presented in Sections 2.1 and 2.2 combine rill and interrill erosion into a common effect. Consequently, they ignore the continuous change in the surface erodability due to the change in rill geometry with time and with distance downslope.

The importance of the rill-interrill erosion concept arises from the fact that the total amount of eroded soil depends greatly on the extent of "rilling" of a slope. This is due to the greater

transport capacity of rill flow than that of sheet flow (24). Moreover, the continuous change in rills geometry is clearly accompanied by a corresponding change in their hydraulic characteristics. Accordingly, their detachment and transport capacities vary with time and distance downslope. This, in turn, affects the total erosion rate from a slope. By separately evaluating a soil's susceptibility to rill erosion and to interrill erosion, we can improve our estimate of a soil's erodability, and the effect of variables such as slope length and initial microtopography.

In the same paper, Meyer et al. suggest that the four erosion subprocesses of soil detachment by rainfall, transport by rainfall, detachment by runoff, and transport by runoff can be recognized as operating on both rills and interrill areas of an eroding slope.

According to Meyer et al. (25), in their study of rill characteristics, there is a "critical" flow rate below which rill erosion does not begin. They suggest that the process of rill erosion is a complex combination of head cuts, detachment of soil by flow shear stresses, and slumping of undercut sideslopes with subsequent removal of slumped material by flow.

The idea of dividing the erosion computation into several components based on different susceptibility to erosion was utilized by David and Beer (4) in their simulation model. The daily sediment yield of a watershed is considered as the sum of soil quantities lost by splash, by erosion of impervious surfaces, by erosion of loose particles, by rill erosion, and by channel bed and bank scour. The

model computes the depth of overland flow using the Stanford Watershed Model based on daily precipitation data. Although the model realizes rill erosion as a separate component, the variation in rilling pattern is not accounted for. Also, the computational equations are only valid when the rill size is very small.

Meyer, Foster and Romkens (25) studied the effect of several factors such as soil susceptibility to rilling, slope length, slope steepness, and other factors, on the rill and interrill erosion. Their results indicate that the extent of rilling affects both the total quantity of eroded soil and the location on the slope where the soil is eroded. The slope length is another important factor since runoff increases with distance downslope. The increased flow will increase rill erosion at lower parts of the slope, whereas erosion from interrill areas is not influenced much by slope length. For this reason, rill erosion vanishes at the top of a slope, where all sediment is from interrill erosion, and increases downslope. The interrill contribution to the total upland erosion may then vary from nearly 100% on short slopes where rilling is negligible, to a small percentage for longer slopes where rill erosion is predominant (26).

Based on the concept of rill and interrill erosion, Foster and Meyer (9) presented a model for slope erosion. In the interrill areas, raindrop impact is a dominant factor in detaching soil particles. Transport capacity of interrill flow is expressed in terms of the slope geometry, rainfall rate, and the soil transportability.

For the rill erosion, Foster and Meyer used Yalin's equation to compute both detachment and transport capacities of rill flow. However, the variables of rill flow at all locations along every rill must be known to apply the Yalin's equation directly. These variables include the hydraulic radius, slope of the energy line, discharge, average velocity, roughness coefficient, and particle size. Unfortunately, little information concerning the frequency of rills or their cross-sectional geometry is available until after the rills have formed and measurements have been taken. To overcome this difficulty, Foster and Meyer (9) approximated the flow in each rill by imposing the average overland flow depth onto the microrelief profile.

From the review of research done toward utilizing this concept of rill and interrill erosion, it appears that an important need is a methodology to deal with rill patterns on an adequately detailed level.

2.4 Studies on Rill Patterns

Apparently, the first attempt to rationally predict the rill pattern on an eroding slope was presented by Leopold and Langbein (18). Their mechanism of drainage is a process that begins when the water first falls as precipitation on an uplifted land mass. The movement of a water drop downslope molds a path that will be taken by succeeding particles of water. There are, however, many possible paths for a water droplet and its sediment load. According to Leopold and Langbein, the path of this first water droplet can be

simulated by a random walk process. Random walks of different water droplets then will form a possible drainage network or a rilling pattern for the slope. The randomness postulated in this model is supported by observations of Horton (14). Horton suggests that the direction and micropiracy of incipient rills is a matter of chance until the rills deepen sufficiently to become master rills. It is then realized that the random walk simulation is suitable only in the early stage of the erosion process.

Based on the previous conceptual model, Schenck (33) developed a computer program to simulate drainage-basin networks. The model divides the slope area into many elementary areas with random directions of drainage. He used the Monte Carlo method of simulation to generate the random walk process. The geometrical properties of the simulated networks were found to be in agreement with those observed from natural drainage networks. A similar but more comprehensive study was done by Smart et al. (36).

Schneidegger (32) also used the random walk model to simulate drainage patterns of watersheds with different boundary conditions. His results agreed with some field observations.

An alternative approach to the problem of predicting a drainage pattern is presented by Seginer (34). His "random roughness" model utilizes the same matrix of elementary areas, squares. However, they are not assigned random directions. Rather, they are assigned random elevations which, in turn, control the drainage pattern. The construction of this model thus contains two links:

the first, which generates the elevations, essentially random, and the second, which produces a unique drainage network for any given topography, deterministic.

Merva et al. (21) emphasized the importance of the consideration of the random nature of drainage surfaces in studying drainage and erosion characteristics. In their paper, they explained the need for an adequate and feasible description of surface irregularities based on its statistical characteristics, and suggested that the spectral density function be used to describe the microrelief.

It is clear that the multitude of studies on drainage patterns and on surface irregularities contributed significantly to the understanding of the phenomenon of slope erosion. However, the link between studies on drainage patterns in general, or rill patterns in particular, and the actual application of these principles to obtain a value for the erosion rate does not exist.

2.5 Concluding Remark

Based on the previous review of literature, one can identify two main directions. The first direction is represented by the increasing appreciation of the random nature of the erosion process. The most important factor contributing to this randomness is probably the slope surface irregularities. Other factors such as rainfall characteristics and soil properties are also generally random in nature, and contribute to the overall random behavior. The second direction is seen in the tendency to deal with the mechanics of the problem on

more rational and less empirical bases. The principles of mechanics of sediment transport, although essentially derived for flow in rivers, provide a starting point for the present state of knowledge.

CHAPTER III

RANDOM SURFACE MODEL

3.1 General Outline

The model proposed for this research builds on the two major trends of research described in Section 2.5. It attempts to combine the random factors that control erosion with the principles of hydraulics and sediment transport.

Essentially, the model consists of two major submodels. First, the random surface model which performs statistical analysis of the surface roughness data obtained from field measurements. Based on the results of this analysis, the model generates a random surface in the form of an array of points with different elevations. Second, an erosion model which describes the movement of water from one point on the generated surface to another, and computes the resulting erosion at every point. The erosion equations are based on principles of hydraulics and mechanics of transport, as explained in Chapter IV.

Evolution of the erosion process with time is obtained by computation for discrete time intervals. Flow and erosion computations for the first time interval are based on the geometrical configurations of the initial random surface. During this and subsequent intervals, the flow properties and the geometry

are assumed to be constant, i.e., a steady state condition is assumed. The change in elevation due to erosion during the first time interval is used to revise the surface geometry which is then used for computations of the second time interval.

Generation of one random surface and then operating on it with the erosion mechanism for the required number of time intervals represents only one realization of the stochastic process. From this realization, we obtain one value of the total soil loss and the change in surface geometry due to the specified storm. By repeating the whole process and generating many random surfaces and subjecting them to erosion, we obtain a sample. This sample can then be used to study the probabilistic properties of the erosion process.

3.2 Analysis of Surface Roughness Data

The surface irregularities of a soil slope can generally be considered as consisting of a large number of small "humps" of irregular shapes and arrangements. When overland flow begins to move downslope, the water moves in the meandering depressions or paths, as shown in Figure 3.1.

The function of the random surface model is to generate, numerically, a random surface which has characteristics representative of the real surface. The similarity between real and generated surfaces depends on two factors. On the one hand, it is desirable that the statistical properties of the generated surface be as close as possible to those of the original surface. On the

other hand, the numerical representation of the surface must be suitable for subsequent erosion computations. The trade-off between those two conditions is the main consideration in the formulation of the random surface model.

3.2.1 Method of Spectral Analysis

Consider an elevation trace along any line on a slope surface, as shown in Figure 3.2. The spacing between measurements, Δx , must be small enough to reveal the necessary details, namely, rills and humps.

This profile can be considered as a continuous function, $f(x)$, with the distance, x , as the independent variable. Fourier analysis can then be used to express this function as a sum of an infinite number of sinusoidal terms. This is just the process of fitting to the data a trigonometric polynomial in the least square sense.

According to Fourier theorem (2), a periodic function, $x(t)$, having a fundamental period, T , and satisfying the conditions known as Dirichlet's conditions (2), can be represented by an infinite Fourier series,

$$x(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos n \omega_0 t + b_n \sin n \omega_0 t) \quad (3.1)$$

where $\omega_0 = 2\pi/T$ is the fundamental angular frequency,
 a_n and b_n are Fourier coefficients.

The previous expression is equivalent to decomposing the periodic function, $x(t)$, into an infinite number of harmonic components. That is, we are transforming the function from time (or space) domain to frequency domain. Transformation of a data record to frequency domain means determining its spectrum. Thus, spectral analysis is the process of calculating and interpreting a spectrum.

The frequency and/or wavenumber, which is the reciprocal of frequency, is in many respects a more significant and more useful variable to use than the time (or space) function. It should be noted that transforming a data vector, $x(t)$, into frequency domain does not mean the addition of anything new, but merely a rearrangement of the given data record according to frequency instead of time sequence. In many fields, the spectral analysis yields a better understanding of data as well as the systems which produced those data. The latter property has been very useful in geophysical applications (2, 29).

In practice, a data record must be expressed in the form of a finite number of sinusoidal waves. Each wave has its own contribution to the total variance of the record. This contribution depends on the value of the coefficients, a_n and b_n , associated with this wave. An alternative terminology for the total variance is the total power.

The detailed mathematical background for the application of the method of spectral analysis as well as the interpretation of its results may be found in Rayner (29) and Bath (2).

3.2.2 Important Assumptions and Considerations

The procedure used to apply the spectral analysis method and the assumptions associated with it are explained below.

The field measurements of the surface roughness are usually carried out by measuring the elevation of a number of equidistant points along a certain line. A measurement plot is composed of several profiles or elevation traces as shown, e.g., in Figure 3.3.

The surface roughness as represented by the random variations of elevation with distance can be regarded as a stochastic process. Each one of the elevation traces can be assumed as a realization of the same stochastic process, if the irregularity of the land surface is "homogeneous," a term introduced by Merva et al. (21). A surface is homogeneous if the nature of the irregularity does not change from location to location. This condition is usually fulfilled in cases where mechanical treatment of the surface is the same at all locations.

If each elevation trace represented a realization, then the group of traces in a measurement plot is considered as an ensemble (See Figure 3.3). The properties of the stochastic process are better represented in an ensemble than in a single realization. It is therefore preferable to include the whole ensemble in the spectral analysis.

The classical method of analyzing an ensemble in time domain is to compute the autocorrelation function of each realization, then the overall autocorrelation function is calculated by averaging values of autocorrelation functions at each time lag (28). In spectral analysis, however, the spectrum of a process contains the same information given by the autocorrelation function, but in frequency domain. Accordingly, the overall spectrum of a process can be computed by averaging Fourier coefficients of the same harmonic component for all realizations, then the average harmonic components are composed together to produce the spectrum.

According to Merva et al. (21), a surface is called isotropic if the statistical properties, estimated by measurements taken along two orthogonal traces, are identical. It is clear that such a condition cannot be met in plowed surfaces, or in surfaces which have experienced considerable erosion.

When field measurements are made along parallel traces, they represent elevation variation only in one direction. When the analysis of this data is used to generate a surface, the assumption of isotropy of the surface irregularities is then implied.

It is important to mention that the method of spectral analysis can be used to study the data in two-dimensional form directly. That is, the data of all points on a plot are treated as one data record (29). In fact, Shinozuka and Jan (35) described the procedure to use two-dimensional spectral analysis in generating a random surface. The generated surface in this case would

probably be a better representation of the original one, but would impose greater difficulties on the operation of erosion mechanisms. Therefore, in the present simplified model, the random surface is generated using one-dimensional analysis only.

3.2.3 Observations from Spectral Analysis

The present research utilizes a computer program for one-dimensional spectral analysis (16), as a subroutine in the model. For any data of an elevation trace, the program mainly computes the coefficients, a and b , of every harmonic component. This provides enough information to compute the amplitude, phase, and the contribution of any component to the total variance of the original function.

The data used for spectral analysis consists of elevation measurements from plots of the dimensions shown in Figure 3.3. The data was a part of a study conducted by Van Doren (39) at Wooster, Ohio. Analysis was done for the plots which were plowed and then disked four times. Other plots were disked fewer times, and would probably exhibit less isotropy due to deeper tillage marks.

The results of spectral analysis are presented in the form of a curve showing the relationship between different harmonic components and the corresponding contributions to the total variance, or power. This curve is usually called the spectral density function. Interpretation of the spectral density function is very

useful in understanding the system which generated the given data. A peak at any wave length generally indicates that this particular wave contributes more to the variance of the function than other waves of comparable length.

The spectral density function of the plot used in this study is shown in Figure 3.4. This curve is computed using the averaging procedure explained in Section 3.2.2. The spectrum is composed of 50 harmonic components with wavelengths ranging from 198 cm to 3.96 cm. The corresponding wavenumber, as shown in Figure 3.4, ranges from 1 to 50.

The overall spectrum is divided into two types of roughness: the macro-roughness, which is the part composed of waves with lengths greater than 30 cm; and the micro-roughness, which is the part composed of waves with lengths less than or equal to 30 cm. The rill pattern, being formed of small-scale surface irregularities, is considered to be represented by the micro-roughness. Therefore, the wave with the highest peak, in the micro-roughness range of the spectral density function, is assumed to be the "basic" wave.

Figure 3.4 indicates that some of the waves in the macro-roughness range may have the greatest contribution to the variance of the surface. Those large waves are attributed to local topographic variations combined with the effect of tilling. Such waves have little effect on the formulation of the elementary rill pattern on the surface, and are ignored.

3.3 Procedure of Random Surface Generation

In light of the assumptions and the observations discussed previously, it is now possible to lay out the procedure followed in this model for generating a random surface on the basis of spectral analysis. The procedure is composed of two major steps. The first step is the spectral analysis of the roughness data. The second step is the numerical generation of the surface, based on the characteristics obtained from the first step.

3.3.1 Analysis of the Data

This step is carried out in the following sequence:

1. Conduct spectral analysis on each one of the elevation traces obtained from the measurement plot. This means that each trace will be subjected to Fourier analysis and will be decomposed into a number of harmonic components with different wave lengths and coefficients, a and b .
2. Compute the average harmonic components by averaging the coefficients a and b from all elevation traces. The resulting composition of harmonic components is regarded as the spectrum of the measurement plot, and is presented in a form similar to that shown in Figure 3.4.

3. From within the range of micro-roughness, pick up the wave component with the highest contribution to variance. This is the basic wave.
4. Deduct the basic wave from each of the original elevation traces in order to obtain what is called the residual data. The residual data is treated as a random component and is represented by a normal distribution.
5. Compute the mean and standard deviation of the residual data from each trace. Then compute the average values which are the mean and the standard deviation for the whole plot.

The final outcome of this step is the length and amplitude of the basic wave, the mean, and the standard deviation of the residual data.

3.3.2 Construction of the Random Surface

The random surface is generated by superposing a matrix of circular humps, which represent the basic wave, on a plane surface, which has a slope equal to the average slope of the actual surface. As shown in Figure 3.5, the centerlines of

the low zones around the humps form a hexagonal mesh. At each nodal point, as well as at hump centers, a random component drawn from the distribution of the residual data is added.

The selection of a hexagonal mesh to simulate the elementary rill pattern is based on several considerations. In a rectangular grid, there is a possibility of three streams merging at a single point, since we have four branches connected together at each nodal point. This situation is seldom met in nature (34). With three members only meeting at each nodal point, the possibility of three streams merging at one point is much less. Accordingly, a hexagonal mesh provides a more realistic representation of a stream network in general. A hexagonal mesh is also a closer simulation of the actually curved rills. Moreover, a square mesh provides isotropy in two directions only, as shown in Figure 3.6, whereas a hexagonal mesh provides three directions of isotropy, as shown in Figure 3.7.

3.4 The Method of Zero-Crossing Analysis

The method of zero-crossing analysis is another method for analyzing surface roughness data. This section briefly discusses the outlines of this method of analysis and its application in our case. More details on the mathematical formulation and the computer program can be found in Reference (20).

3.4.1 Outline of the Method

A zero crossing is defined as the intersection of the continuous function, $x(t)$, with its mean line (Figure 3.8). Each point at which the function $x(t)$ ceases to decline and starts to rise, or ceases to rise and starts to decline, is called a turning point. A turning point is a peak when it is a relative maximum and a trough when it is a relative minimum. The longitudinal distance along the mean line between successive zero crossings is the zero crossing distance. The number of turning points between any two zero crossings is odd. If there is more than one turning point in a zero crossing distance, the peak (or trough) with the largest departure from the mean line will be considered the only peak (or trough) in this distance. With these considerations, there will be only one peak or one trough between two adjacent zero crossings.

The vertical distance between a peak and the mean line is the positive amplitude, (a_+) , and between a trough and mean line is the negative amplitude, (a_-) . Finally, the sum of the positive and negative amplitudes $(a_+ + a_-)$ is the wave height and also the sum of two adjacent zero crossing distances is the wave length.

For short records, the zero-crossing analysis can be done by manual computations, while long records are analyzed by means of a computer program. The first step, in either case, is to

identify the mean line. This can be done by the following procedure. The record is divided into q equal segments, such that each segment contains about 2 to 5 waves. For each part, the mean surface level is calculated and considered as a point at the center of the segment. Now there are q points, at the center of the q segments, and each point represents the mean surface level within that part. The problem is to pass an appropriate curve through these q points such that it can be considered as the mean line of the record. A third degree polynomial is selected for this purpose, in order that not only the profile is unique and continuous, but also its first and second derivatives representing slope and curvature.

When the profile of the mean line is defined, the problem of determination of the crossings with the mean line can be reduced to the determination of the crossings of the mean-removed data with the horizontal axis. For example, the number of zero crossings of the mean-removed data is equal to the number of its sign changes.

In addition to the number of zero crossings, four other sequences are obtained from zero-crossing analysis. These are the sequences of wavelength, positive amplitude, negative amplitude, and waveheight. Each of those sequences is considered as a sample from which the statistical properties of the random variable of interest can be inferred.

3.4.2 Generation of Random Surfaces

According to the definitions explained in Section 3.4.1, the sequence of wavelengths in any elevation trace, as shown in Figure 3.9, is represented by $\omega L_1, \omega L_2, \dots$. The computer program for zero-crossing analysis (20) provides the mean, the standard deviation, and the statistical distribution of the random variables representing wavelength, ωL ; positive amplitude, A ; and negative amplitude, B .

Following the procedure described in Section 3.3.2, we can use the results of zero-crossing analysis to generate the random surface. In this case, the basic wave will have length equal to ωL_{av} , and an amplitude equal to the average of A_{av} and B_{av} . The distribution of the residual data can then be computed as explained in Section 3.3.1. A sample random surface is shown in Figure 3.10.

The zero-crossing analysis was conducted using the same roughness data obtained from Wooster, Ohio. First, each one of the elevation traces was analyzed separately. Then, all of the traces were considered and analyzed as one record. The results are shown in Table 3.1. The average values for the wavelength and the waveheight are 17 cm and 29.5 mm, respectively.

The method of zero-crossing analysis can be more useful in studying the variation of the hump size. Such a study can be used to generate a random surface with a random rill pattern.

Consider the elevation trace shown in Figure 3.9. The sequence of wavelengths can be expressed as follows:

$$\begin{aligned}
 \omega L_1 &= \omega L_{av} + x_1^1 + x_2^1 \\
 \omega L_2 &= \omega L_{av} + x_1^2 + x_2^2 \\
 &\vdots \\
 \omega L_n &= \omega L_{av} + x_1^n + x_2^n
 \end{aligned} \tag{3.2}$$

where x_1^i and x_2^i are two random components applied at the two ends of the distance, ωL_{av} , in Figure 3.10.

It is reasonable to assume that x_1^i and x_2^i are two realizations of the same random variable, x . This variable is assumed to have a uniform distribution. The problem is then reduced to finding the parameters of this distribution. This can be simply done by computing, for each element, ωL_i , of the wavelength sequence. The corresponding value of x_i is as follows:

$$x_i = \frac{1}{2} (\omega L_i - \omega L_{av}) \tag{3.3}$$

Then the mean and the standard deviation of x can be computed.

On the basis of the assumptions of homogeneity and isotropy, we can use the same random variable, x , in the two directions, across and along the slope surface.

TABLE 3.1 RESULTS OF ZERO-CROSSING ANALYSIS

		MEAN VALUE		
Elevation trace	ωL (cm)	+ Amp. (mm)	- Amp. (mm)	waveheight (mm)
Number				
1	11.04	9.60	12.99	22.59
2	13.54	14.50	15.14	29.64
3	12.89	12.16	17.96	30.12
4	12.23	12.34	12.86	25.20
5	11.28	13.19	14.92	28.11
6	27.72	14.68	22.45	37.13
7	19.53	14.19	18.56	32.75
Combined	13.96	13.52	15.23	28.75

The procedure to generate the surface with random rill pattern consists of the following steps:

1. Using ωL_{av} as the hexagon width, generate a regular hexagonal mesh.
2. From the uniform distribution of the continuous interval, $(0,1)$, draw a random number for each nodal point. This number is used to determine the direction in which the random component of X will be applied. This is done according to the rule given in Table 3.2 below.

TABLE 3.2 DIRECTIONS OF RANDOM COMPONENT

Value of Random Number Drawn from $U(0,1)$	Direction of Random Component
$0.0 \leq r < 0.25$	upward
$0.25 \leq r < 0.50$	downward
$0.50 \leq r < 0.75$	left
$0.75 \leq r < 1.00$	right

3. From the uniform distribution of X , draw a random number for each nodal point. This number specifies the magnitude of the shift in the direction determined in Step (2).

5. Use the distribution of the residual data to generate a random component for the elevation of every nodal point.

Figures 3.11 and 3.12 show the rill patterns generated using hexagonal and random mesh, respectively.

3.5 Concluding Remarks

The use of the zero-crossing analysis in generating an irregular rill pattern may represent a better approximation of the surface. However, this irregularity imposes great difficulties in the coding of the flow-routing, and erosion mechanisms. Therefore, the present erosion model uses the hexagonal mesh as a rill pattern.

While the zero crossing analysis offers advantages, the present model uses the spectral analysis for analysis of the roughness data. The main reason for this is that spectral analysis allows us to recognize the relative importance of large-scale and small-scale surface irregularities. Therefore, we can define the part of the data which contributes most to the formation of the rill pattern. Moreover, the method of spectral analysis, although not fully utilized in this model, provides greater potential for improvement of surface roughness modeling.

The mechanism of selecting only one wave component of the spectrum as the basic wave created a problem in the simulation process. This is because the amplitude of this wave alone is not large enough to represent the humps. We note that the average wavelength and wave height obtained by using the zero-crossing analysis are about 17 cm and 29.5 mm, respectively (See Table 3.1). That is, the average amplitude can be taken as about 15 mm. On the other hand, the length and amplitude of the basic wave as determined by spectral analysis of the same data are 18 cm and 3.7 mm, respectively. If we use the amplitude of the basic wave to generate the surface, the top of the hump may become lower than some nodal points of the hexagon surrounding it. This creates rill segments with negative side slopes. If this condition occurs at all or most of the rill segments, the rill pattern, as a drainage network, would lose its function, and the rill-interrill characteristics of the surface would vanish.

To avoid this problem, the following simplified solution is used. For a basic wave of length ωL , the length of the hexagon's side is equal to $\omega L/\sqrt{3}$. If the surface is inclined with an angle of θ , then each hump center is raised by the amount $\frac{\omega L}{\sqrt{3}} \sin \theta$. For a slope of 20° , which is the slope used in this analysis, the additional increment, $\frac{\omega L}{\sqrt{3}} \sin \theta$, is equal to 35 mm, about twice the average amplitude computed using zero-crossing analysis. This value is equal to 18.1 mm

for a ten-degree-slope. Hence, we can see that the simplified approach described above is a reasonable approximation as compared with the results of zero crossing analysis. Prior to superposing the basic wave or the random component, the elevation of the hump center is equal to the elevation of the highest nodal point around it. Then the basic wave and the random increments in elevation are added. Due to this randomness, some of the humps could still be lower than some of the surrounding nodal points. Our model allows for some rill segments to be eliminated, depending upon the original roughness data.

Figure 3.1 Natural Surface Roughness

Figure 3.2 Elevation Trace

Figure 3.3 Measurement Plot

Figure 3.4 Spectral Density Function of Surface Roughness

Figure 3.5 Simulation of Surface Roughness

Figure 3.6 Isotropy in Square Rill Pattern

Figure 3.7 Isotropy in Hexagonal Rill Pattern

Figure 3.8 Parameters used in Zero-Crossing Analysis
Source: Ref (20)

Figure 3.9 Sequences Computed in Zero-Crossing Analysis

Figure 3.10 Average Wave used in Constructing a Hexagonal Rill Pattern

Figure 3.11 Uniform Rill Pattern

Figure 3.12 Random Rill Pattern

CHAPTER IV

EROSION MODEL

The subject of this chapter is the model for computation of erosion in rills and over interrill areas. Emphasis is placed on the development of computational procedures which are suitable for the surface model and are based on principles of hydraulics and sediment transport mechanics.

The present analysis considers only erosion of soil particles by the shearing action of flow in rills and over interrill areas. In other words, the direct detachment and transport process due to rainfall splash is not accounted for. The rainfall impact is only considered as an agent that detaches particles of surface soil and causes the soil aggregates of a cohesive mass to move in a fashion similar to that of cohesionless soil particles (8). For this reason, transport equations derived for cohesionless soils are usually applied on slopes of cohesive material (8, 6, 9).

Based on the description given in Chapter III, the random surface is composed of a matrix of higher points, humps, surrounded by small channels, rills, connecting the lower points. For the purpose of erosion computation, the geometrical configurations of the surface are simplified. The humps are assumed to be in the form of hexagonal pyramids with a different slope for each of the six sides,

depending on the random outcome of surface generation. Rills are assumed to be formed of channels with triangular cross sections with the side slopes of the adjacent humps forming its boundaries, as shown in Figure 4.1. A channel between two nodal points is termed a "rill segment." In the remaining sections of this chapter, the equations of erosion of rills and of humps are derived.

4.1 Rill Erosion Equation

Consider a rill segment, ab , as shown in Figure 4.1(a); let q_1 be the rate of water flow received from upslope at point a , and q_2 be the flow at b . q_2 is greater than q_1 by the amount of water drained from the two adjacent humps. The flow in the rill segment, ab , is actually a spatially-varied flow with the rainfall acting as a lateral inflow. Researchers such as Yoon and Wenzel (44), Li et al. (19), and Komura (17), considered the overland flow as a spatially-varied flow. However, since the present model deals with the erosion problem at a significantly smaller scale, equations of uniform flow are used to describe flow in a rill segment.

Erosion due to rill flow is based on the concept of tractive force which is generated by the shearing stresses between the flow and the boundaries. This criterion is used in the derivation of many sediment transport equations (12).

Consider the triangular cross-section of any rill segment, as shown in Figure 4.2. The average value of the tractive force per unit wetted area, i.e., the unit tractive force, τ_0 , is given by:

$$\tau_0 = \gamma R S_f \quad (4.1)$$

where

γ = unit weight of water;

R = hydraulic radius of the channel: $R = \text{Area/wetted perimeter}$;
and,

S_f = slope of the energy grade line.

Henderson (13) indicates that the slope of the energy line, S_f , can be approximated by the bed slope, S_0 , for a mountain type channel. Using this approximation, Equation (4.1) becomes:

$$\tau_0 = \gamma R S_0 \quad (4.2)$$

According to Chow (3), the unit tractive force in channels, except for wide open channels, is not uniformly distributed along the wetted perimeter. Therefore, it is more appropriate to use the tractive force per unit length of the rill as expressed by the following equation:

$$F_0 = \tau_0 \times P = \gamma A S \quad (4.3)$$

where

P = wetted perimeter; and

A = cross-sectional area of the flow.

In terms of the geometrical features of the triangular cross-section, as given in Figure 4.2, we have:

$$F_0 = \frac{\gamma S_0}{2} h^2 \left(\frac{1}{S_1} + \frac{1}{S_2} \right) \quad (4.4)$$

Neglecting the variation of S_0 along the segment ab, the value of F_0 is then dependent upon h at any point. The values of h_1 at a and h_2 at b depend on the corresponding values, q_1 and q_2 . Turbulence intensity measurements by Yoon and Wenzel (44) indicated that the flow under the influence of rainfall was turbulent. Therefore, to obtain the flow depth, h , at any point we can use Manning equation (3),

$$V = \frac{1}{n} R^{2/3} S_f^{1/2} \quad (4.5)$$

where

V = the mean velocity in meter/sec;

R = the hydraulic radius in meters;

S_f = the slope of the energy line; and,

n = the coefficient of roughness, specifically known as Manning's n .

Using the approximation $S_f = S_0$, and the relation $q = V \cdot A$, we get:

$$q = \frac{A}{n} R^{2/3} S_0^{1/2} \quad (4.6)$$

which can be expressed in terms of h as:

$$q = \left(\frac{1}{2} \frac{c_1 h^2}{n} \right) \left(\frac{1}{2} c_3 h \right)^{2/3} S_0^{1/2} \quad (4.7)$$

Therefore,

$$h = \frac{2^{5/3} n q}{c_1 c_3^{2/3} S_0^{1/2}} \quad (4.8)$$

where c_1 and c_3 are defined in Figure 4.2.

The flow in rills has been so far treated as open channel flow. The flow characteristics are then used to compute the amount of soil eroded. This scheme implies that the effect of sediment already carried in the flow is not considered. That is, the concentration of sediment is assumed small enough so that the equation of motion for sediment-laden water can be approximated by the equation of motion for water only.

According to Li et al. (19), the continuity equation for sediment can be expressed as:

$$\frac{d q_s}{dx} = p_s \quad (4.9)$$

where

q_s = the sediment discharge per unit width of channel, and

p_s = the fine-sediment pick-up rate per unit area.

q_s is a function of the flow characteristics and specifically, the flow tractive or shearing force. The bed load equation derived by Kalinske (12) is used to obtain q_s . It is expressed in the nondimensional form as:

$$\frac{q_s}{U_* D} = a_s \left[\frac{U_*^2}{\left(\frac{\rho_s}{\rho_w} - 1 \right) g D} \right]^p \quad (4.10)$$

where

q_s = the sediment discharge including suspended sediment in volume of material per unit time and unit width;

- U_* = the friction velocity;
 D = the mean sediment size;
 ρ_s and ρ_w = densities of sediment and water, respectively;
 g = the gravity acceleration;
 a_s = a constant; and
 p = a dimensionless exponent.

The reasons for using Kalinske's equation are discussed in the last section of this chapter.

Substituting for U_* by τ_0 / ρ_w , q_s can be expressed as:

$$q_s = \frac{\beta_1}{\rho_w^{(1+2p)/2}} \tau_0^{(1+2p)/2} \quad (4.11)$$

in which τ_0 = the unit tractive force and

$$\beta_1 = \frac{a_s}{\left(\frac{\rho_s}{\rho_w} - 1\right) g^p D^{p-1}} \quad (4.12)$$

Assuming that a similar relation exists between the "total" sediment discharge per unit length of the channel, Q_s , and the corresponding tractive force per unit length, F_0 , Equation (4.11) can be rewritten in the form:

$$Q_s = \frac{\beta_1}{\rho_w^{(1+2p)/2}} F_0^{(1+2p)/2} \quad (4.13)$$

It should be noticed that the Kalinske's equation is derived for a two-dimensional flow condition. This implies that the hydrodynamic forces exerted on any soil particle is assumed to be acting in the longitudinal direction only, and no lateral forces (in the cross-sectional direction) exist. Such condition can be represented by the flow over interrill areas. For the rill flow, however, the triangular cross-section gives rise to a lateral gravity component acting on soil particles resting on the side slope of the rill. The transition from Equation 4.11 to Equation 4.13 is therefore an approximation in which the effect of this lateral gravity component is not considered.

The continuity equation for sediment, given by Equation (4.9), can also be modified as:

$$\frac{dQ_s}{dx} = P_s \quad (4.14)$$

in which P_s is the fine-sediment pickup rate per unit length of the channel.

For a long slope, the average erosion rate per unit area is defined by Li et al. (19) as the average pickup rate along the slope and is expressed as:

$$E = \frac{1}{L} \int_L P_s \, dx \quad (4.15)$$

where L is the length of the slope in the x -direction. But for the short segments considered in our case, E is taken as directly equal to P_s . Accordingly, the erosion rate in volume per unit length of the channel, E_v , is given by:

$$E_v = \frac{dQ_s}{dx} \quad (4.16)$$

Taking the derivative of Equation (4.13), we obtain:

$$E_v = \left(\frac{1}{2} \frac{(1+2p) \beta_1}{\rho_w (1+2p)/2} \frac{d F_0}{dx} \right) F_0^{(2p-1)/2} \quad (4.17)$$

in which F_0 at any point is obtained from Equations (4.4) and (4.8), in terms of the water discharge.

Considering, again, the size of the channel, the term $\frac{dF_0}{dx}$ can be rewritten in difference form. That is, for the rill segment of length L , the erosion rate of rills, in volume per unit time, E_v , can be expressed as:

$$E_r = \frac{1}{2} \frac{(1+2p) \beta_1}{\rho_w (1+2p)/2} \left(\frac{F_{02} - F_{01}}{L} \right) \left(\frac{F_{01} + F_{02}}{2} \right)^{\frac{2p-1}{2}} \times \Delta L$$

and the final computational form for E_r becomes:

$$E_r = \frac{1}{2} \frac{(1+2p) \beta_1}{\rho_w (1+2p)/2} (F_{02} - F_{01}) \left(\frac{F_{01} + F_{02}}{2} \right)^{\frac{2p-1}{2}} \quad (4.18)$$

where β_1 is given by Equation (4.12) and F_{01} and F_{02} are computed from Equations (4.4) and (4.8).

4.2 Interrill Erosion Equation

A similar approach is used to express the erosion rate of interrill areas in terms of the flow characteristics, which differ somewhat from those of rill flows. The flow in this case is approximated by a sheet flow with $q_1 = 0$ at the top and q_2 at the bottom, with an amount depending on the area between different rills.

Consider a surface with slope S_0 and length L , as shown in Figure 4.3. Assume that the flow depth increases linearly downslope from $y_1 = 0$ at the top to y_2 at length L . The unit tractive force

resulting from this flow at points a and b, respectively, is given by:

$$\tau_{01} = \gamma y_1 S_0 = 0 \quad (4.19)$$

and

$$\tau_{02} = \gamma y_2 S_0 \quad (4.20)$$

in which the wide-channel approximation, $R \approx y$, has been applied.

The flow depth is also determined using Manning's equation which gives, for this case:

$$q = \frac{1}{n} y^{2/3} S_0^{1/2} \quad (4.21)$$

The flow depth at any point is given in terms of the flow rate as,

$$y = \left(\frac{n q}{\sqrt{S_0}} \right)^{3/5} \quad (4.22)$$

Based on the continuity equation for sediment (Equation 4.9), in conjunction with Kalinske's bed load formula, an expression for erosion rate of interrill areas can be written as:

$$E_i = \frac{1}{2} \frac{\beta_1}{\rho_w} \frac{(1+2p)}{\frac{1+2p}{2}} \frac{1}{L} \times \tau_{02}^{\frac{2p+1}{2}} \quad (4.23)$$

where

E_i = erosion rate of interrill areas in volume per unit area per unit time;

β_1 = as given in Equation (4.12); and,

τ_{02} = the unit tractive force, or shear stresses, at distance L downslope, and is computed from Equations (4.22) and (4.20).

Although the water flows over the humps in a more or less radial fashion, the present analysis assumes a one-dimensional flow in the direction of the centerline of each one of the six sides of the hexagonal pyramid. Furthermore, the total amount of erosion from each (triangular) side is computed for the equivalent rectangle, as shown in Figure 4.4.

4.3 Concluding Remarks

It is important to notice that the derived erosion equations do not compare the transport capacity of the flow with its detachment capacity, as explained in Chapter II. The model, for simplicity, assumes that the slope surface will always provide the overland flow with a sediment load which is adequate to its transport capacity. This assumption, in fact, depends on the effect of rainfall impact on loosening the surface soil and detaching a sufficient amount of soil aggregates. In other words, the erosion equations by themselves do not account for the possibility of deposition. Nevertheless, the process of deposition is being, partly, considered in this model through the use of computational mechanisms as explained in Section 5.2.2.

The use of Kalinske's bed load equation in the mathematical model for erosion computation is the subject of the remaining part of this discussion. Essentially, all sediment transport equations are derived for the simplified case of two-dimensional flow (43).

which approximates flow in wide rivers. Nevertheless, no single equation has been found to hold for all situations. For the special case of overland flow, on the basis of the present knowledge, there is no compelling theoretical reason to choose any of the existing sediment transport equations over any other.

The choice of Kalinke's equation for this study is primarily empirical. It has been actually used by Komura (17) in developing a mathematical model for slope erosion by overland flow. The study is especially useful in defining the range of values for some constants in the equation, when applied to overland flow.

We have also compared the results of some field measurements of rill erosion (25) with the corresponding values computed by Equation (4.18) (See Appendix A). We used the value of 0.2 mm as the soil aggregate diameter, .025 for Manning's coefficient, and the values suggested by Komura (17) for the remaining parameters. The agreement of the results further supports the use of Kalinke's equation in our model.

a) Plan

b) Section A-A

Figure 4.1 Surface Idealization

Figure 4.2 Rill Cross-section

Figure 4.3 Flow Over Interrill Area

Figure 4.4 Geometrical Basis for Interrill Erosion Computation

CHAPTER V

SIMULATION MODEL

Based upon the theoretical and practical considerations discussed in Chapters III and IV, a computation scheme is constructed to simulate the process of slope erosion by rainfall. A random surface is first generated on the basis of the statistical properties of the original surface, as explained in Chapter III. The overland flow is assumed to move downslope following the rill pattern created by a hexagonal mesh. The resulting erosion in rills and over inter-rill areas is then computed for the specified number of time intervals.

The details of the simulation model are described in the following sections. The listing of the computer program with a sample output is presented in Appendix B.

5.1 Main Features of the Model

In this section, the computation schemes for simulating the main features of the model are described. Those are the routing of the overland flow and the sediment load over the surface, the topographical changes due to erosion, and the changes in the process with successive time intervals. There are, however, a number of auxiliary mechanisms which are very important; these will be discussed in the next section.

5.1.1 Routing of Water and Sediment

Part of the rain falling on the test area is assumed to infiltrate through the surface layer. The rate of infiltration is known to decay with time. However, for simplicity, the model assumes a constant runoff coefficient, RNF (which is the fraction of rainfall that becomes runoff). This part is divided between the rills, which occupy a limited area of the surface, and the interrills, or the humps, which occupy most of the surface area. However, the water falling on the interrill areas, in excess of infiltration, is drained to the surrounding rill segments (as had been stated earlier), as shown in Figure 5.1.

The rate of flow and the sediment load at any nodal point of the hexagonal mesh depends on its position in the mesh, as well as the random elevation. The hexagonal mesh allows for two types of nodal points, as represented by points a and b in Figure 5.1. Point a receives flow from two branches and discharges it in only one direction downslope. Whereas point b has only one inflow branch, then the flow routed downslope is divided between two branches.

The flow in rills moves forward only if the bed slope of the rill segment is positive, i.e., inclined downwards. If the bed slope is either zero or negative, the flow routing of this rill is terminated at this point, and no further movement downslope is permitted. The rill flow is thus not allowed to move upslope even if the random elevations of the nodal points created such a situation.

At points such as a in Figure 5.1, the flow merging from the

two inflow branches is automatically directed to the third, outflow, branch. But for points such as b, the incoming water is divided between the outflow branches according to the ratio of the square root of the two bed slopes, i.e., $(S_{01}/S_{02})^{1/2}$. This procedure complies with the slope exponent in Manning's formula as shown in Equation (4.6). As for the sediment load, we use the ratio of $(S_{01}/S_{02})^{\frac{5}{16}(2p+1)}$ which is obtained from Equations (4.18) and (4.4), in which p is the exponent of Kalinske's bed load equation.

5.1.2 Erosion of the Surface

Erosion of a rill segment affects its geometry in both cross-sectional and longitudinal directions. The amount of soil eroded by rill flow for one time interval is computed from Equation (4.18). This amount is then removed from the rill cross-section in the manner indicated by the shaded area in Figure 5.2. The bed level is then lowered by the distance, DE.

Interrill erosion is computed from Equation (4.23) for the area of the side slopes which is above the water level. Interrill erosion is supposed to steepen the side slopes gradually. To account for this action in a simplistic manner, the new side slopes, S_1 and S_2 , to be considered for the next interval, are assumed to be represented by the dashed lines on Figure 5.2. This is an approximation of the actual condition which results in different side slopes below and above the water. However, this approximation eliminates a considerable computational difficulty. Moreover, the water depth in

rills increases downslope, where rills are more important. Thus, the error due to this approximation also decreases downslope.

In the longitudinal direction, the rill segment is assumed to be eroded uniformly. But since more than one rill segment always meet at each nodal point, the final decrease in the elevation of this nodal point is taken to be the average of the three values of DE computed for each branch.

5.1.3 Temporal Change

The time-dependent nature of the erosion process is accounted for by using a number of steady state time intervals. That is, during each time interval, the elevations of all nodal points and humps remain constant. The changes in the surface geometry due to erosion are then computed at the end of the interval, and the new elevations of all points are used for the next time interval. The effect of the time interval length on the model results is discussed later in Section 6.2.

The water flow at any nodal point, during a time interval, is the sum of the rill flow arriving from upslope and the water drained from the adjacent humps. The same mechanism applies for sediment load at any point. The total amount of sediment yield produced during any time interval is computed as the sum of sediment load at the nodal points at the bottom of the slope.

It has been mentioned earlier that runoff actually starts at different points on the surface after the rainfall rate has exceeded

the infiltration rate. It is important to notice, however, that the computations begin at the time when the runoff initiated at the top of the slope has reached the bottom. The amount of sediment eroded before that time is neglected.

5.2 Auxiliary Mechanisms

Beside the main computational schemes previously described, there is a number of auxiliary mechanisms which are very important for the development of the simulation of the erosion process, and provide the model with more realistic features.

5.2.1 Ponding

Recalling the mechanism of flow routing discussed in Section 5.1.1, the flow in any rill segment moves forward only if the bed slope of the rill is positive, i.e., inclined downward. When the bed slope is either zero or negative, the model assumes that the water ponds and that the flow velocity becomes zero along this segment.

At the nodal points, where three segments are connected, the ponding mechanism is as follows. For a point such as a in Figure 5.3, ponding occurs when the branch a_i has a slope less than or equal to zero. The inflow (received from upslope) in segments i_j and i_k is then equal to zero. Such rill segments will only receive water that is drained from adjacent humps. At a point such as b in Figure 5.3, complete ponding occurs only if both b_i and b_j have

slopes less than or equal to zero. When only one of the two branches is ponded, then the flow is automatically routed through the other branch.

According to Manning's equation (Equation 4.6), the flow velocity, and consequently erosion, vanishes when the bed slope is equal to zero. This is, indeed, true when the equation is applied to an isolated channel. In our case, however, the small channels representing rill segments are connected with each other at nodal points. It is easy to realize that the water can flow, at least to some distance, in a channel with a zero or negative bed slope if the momentum of the upstream flow is sufficient. In other words, the present model maintains the condition of mass continuity at nodal points, whereas continuity of momentum (or energy) is not considered at this stage.

5.2.2 Deposition Due to Ponding

When ponding occurs, the flow is assumed to have reached a zero velocity, and therefore deposition becomes certain at ponded areas. The presence of ponding also influences the velocity of flow at points some distance upstream, and causes a reduction in the erosion rate at these points. This model uses a simplified mechanism to simulate the effect of ponding on deposition, as well as on reducing erosion at locations upslope.

Consider the case when ponding occurs at point 1 in Figure 5.4. This means that the bedslope of the lower branches is less than or equal to zero, and there is no other possibility for routing

the flow. The flow in the segment 2-1 is assumed to approach a zero velocity at point 1. The total sediment load arriving at point 1 is then deposited on the bottom of several rill segments upstream and downstream of point 1. The pattern of depositing the sediment load is also shown in Figure 5.4. The final change in the elevation of any point is the net difference between this deposition and erosion as computed from Equations (4.18) and (4.23). It is clear that the deposition mechanism is simple and, to some extent, arbitrary. Nevertheless, it serves the purpose of incorporating deposition in the model.

5.2.3 Stability of Rills' Side Slopes

As described in Section 2.3, the process of rill development is a combination of erosion, slumping of undercut side slopes, and head cuts. Since the progression of rill and inter-rill erosion steepen the side slopes, it is important to define a criterion with which we can check the stability of the side slopes at any time during the erosion process. On the other hand, this criterion must be simple so that it may be incorporated in the model.

The stability criterion used in this model consists, simply, of an arbitrarily chosen value of the limiting gradient, $SLIMIT$, that a side slope can withstand. When the gradient exceeds $SLIMIT$, the slope fails and assumes a new, arbitrary, flatter gradient, $SSTART$. The side slopes are assumed to remain plane, before and

after failure. The values of the two limits can be estimated from experience with the type of soil in question.

When a side slope fails, the top of the slope, which is the center of the hump, is lowered by a certain distance, as shown in Figure 5.5. Some of the sides of the hump may fail while others may still be stable. Therefore, in computations, each side has its own elevation at its top. At the end of the test period, and for the purpose of plotting only, the final elevation of the hump center is computed as the average of the top elevation of the six sides.

The soil mass removed after each slope failure should be added to the sediment load of the rill segment in which failure occurred. Usually, such masses cannot be directly carried by the transport capacity of the flow, and they require a more complicated account of deposition over the length of the rill. Therefore, these masses are presently ignored in the computation of the total sediment load. Due to this approximation, the model may be underestimating the total sediment yield.

5.2.4 Low Humps

In this model, the elevation of a hump is usually greater than the elevations of all six nodal points of the surrounding hexagon. However, if, due to the random designation of elevations, one or more of the six points become higher than the hump center, then this hump is called here a "low" hump. For example, in Figure 5.5, if point a is higher than both points i and j, then the cross-section of the rill segment ij would have the

configurations shown in Figure 5.6. In this case, the two side slopes are positive. On the other hand, if point a happens to be lower than the average elevation of ij which is represented by point b, then the rill would have the cross-section shown in Figure 5.7. Such a condition prevents the development of a rill in the first place, and the flow routing is altered.

To illustrate the various possibilities that are associated with a low hump, the rill segment ij in Figure 5.5 is assumed to have the cross-section shown in Figure 5.7. Consider the whole cross-section passing through points c, b, a, and d. Differentiation between various possibilities depends on two factors, namely, the bed slope, S_0 , of ij , and the side slope, S_p , of the opposite rill segment, $m1$. The bed slope, S_0 , must be, in the first place, positive so that the flow at point i can move forward. However, the flow will move in either the direction of ij or the direction ba , depending upon the difference in the absolute value of S_0 , and S_2 in Figure 5.7. That is, the flow is routed in the direction of maximum slope. On the other hand, the sign of S_p determines whether the flow passing over the negative slope, S_2 , would continue over slope S_p and join the rill flow in segment $m1$, or would just pond at a. Figure 5.8 illustrates the possible cases and the corresponding routing considered in each case. It should be mentioned that there is always a need to make some modifications to different mechanisms when applied at points on the boundaries of the test area. Details of those modifications are not presented herein. They are, rather, indicated within the computer program algorithm.

5.3 Structure of the Program

The computer program developed for the simulation model is composed of five main consecutive steps, as shown in Figure 5.9. This section presents the outlines of each computational step with the selected computer subroutines.

5.3.1 The Input Data

The input data is divided into the three groups described below:

(a) Surface Roughness Data: This consists of the measured elevation traces of the original surface. The data variables of this group are:

YYP = a vector variable describing the elevation
at all points on all elevation traces in
sequence;

NPF = number of elevation traces;

NP = number of measurements on each trace;

DX = spacing between measurements;

TLEN = total length of the elevation trace.

(b) Physical Parameters: These are the variables describing the physical properties of the problem, used in erosion computations, namely:

UWT = unit weight of the soil, in N/m^3 ;

DMLM = representative diameter of soil particles,
in mm;

RN = Manning's roughness coefficient;

- G = gravity acceleration, in m/sec^2 ;
- SG = soil specific weight;
- RO = water density, kg/m^3 ;
- p = exponent of Kalinske's equation; see Equation (4.10);
- ASR = soil constant, a_s , in erosion equation; see Equations (4.18) and (4.12); and,
- ASH = soil constant, a_s , in interrill erosion equation; see Equations (4.23) and (4.12).

(c) Storm and Slope Data

- NX = number of nodal points in the cross-direction of the underlying rectangular mesh, see Section 5.3.3;
- NY = number of nodal points in the longitudinal direction of the underlying rectangular mesh;
- SLOPE = the average slope of the test area, in degrees;
- RNL = rainfall intensity in mm/hr;
- RNF = runoff coefficient, See Section 5.1.1;
- TI = length of time interval, in minutes;
- NTI = number of time intervals; and,
- NRS = number of random surfaces to be generated. A sample of size = NRS can then be used in any further statistical analysis.

5.3.2 Analysis of Surface Roughness Data

The input to this step is the surface roughness data. The analysis is conducted in the following sequence:

1. For each of the elevation traces, remove the mean (Subroutine FILTER), then compute Fourier coefficients (Subroutine POWER). Fourier coefficients are computed using the method of Fast Fourier Transform, which is documented in the computer package called IMSL (15), and is called by Subroutine POWER.
2. Compute the average coefficients for each wave component (Subroutine CWAVE).
3. From the range of waves of length ≤ 30 cm, pick up the wave component with maximum contribution to total variance. Then compute the residuals from each trace (Subroutine CWAVE).
4. Compute the mean and the standard deviation of the residuals from each trace (Subroutine RESDL).
5. Compute the average mean and standard deviation for all traces (Subroutine CWAVE).

5.3.3 Generation of the Random Surface

The input to this step is the amplitude, AMP, and the wavelength, WL, of the basic wave, plus the mean and the standard deviation of the residual data.

The computational procedure for generating a random surface is described as follows:

1. Compute the nodal coordinates of a rectangular mesh $NX \times NY$ with the mesh size as indicated in Figure 5.10 (Subroutine HXMESH).
2. Assign codes to nodal points according to their location in the mesh. Points such as b are assigned code = 2, whereas points such as a are assigned code = 1. The remaining points of the rectangular mesh, such as c, are given code = 0. The hexagonal mesh is formed when points of code = 0 are eliminated, as shown by the solid lines in Figure 5.10.
3. Compute the elevations of the plane surface at nodal points using the value of SLOPE for the surface gradient (Subroutine ELEVTN).
4. Superimpose the basic wave on the plane surface according to the given values of amplitude.
5. Using Subroutines RANORM and RANDU, draw a random number for each nodal point and add it to the elevations obtained by Subroutine ELEVTN.

6. Draw another group of random numbers to randomize the elevations of the humps (Subroutine HUMP).
7. Check the stability of side slopes of all rill segments (Subroutine SFILR). Criterion and mechanisms for this procedure are discussed in Section 5.2.3.

These steps generate the initial random surface, which is then subjected to overland flow and erosion.

5.3.4 Computation of Overland Flow

Based on the considerations described in Sections 5.1 and 5.2, the routing of overland flow is carried out for each time interval as follows:

1. Survey all rill segments to check for ponding along any path, on the basis of the mechanisms explained in Section 5.2.1 (Subroutine POND).
2. Compute the flow at each nodal point (Subroutine FLOW).
3. When low humps exist, revise flow computations on the basis of the mechanism explained in Section 5.2.4 (Subroutine RDISTB).

5.3.5 Erosion Computation

Given the elevation and the overland flow at every nodal point, the erosion in rill segments and over adjacent humps are computed. Rill segments whose upstream nodal point has code=1 are dealt with in Subroutine ERSN1. Rills whose upstream node has code = 2 are processed through Subroutine ERSN2. Computations for every rill segment are conducted in the following order:

1. For any rill segment, identify the surrounding humps which form its side slopes (Subroutine IDHMP).
2. Compute new values of bed slope and side slopes (Subroutine ERSN1, or ERSN1).
3. Determine flow depth and width in rill segment (Subroutine CSEC).
4. Compute erosion on side slopes of humps, or interrill erosion (Subroutine HERSN).
5. Compute rill erosion and the corresponding change in rill geometry on the basis of the mechanism explained in Section 5.1.2 (Subroutine RERSN).

6. Compute the total amount of soil eroded, and transported by the flow above a nodal point (Subroutine ERSN1 or ERSN2). If ponding exists along a rill path, the deposition mechanism described in Section 5.2.2 is applied.
7. Revise the distribution of sediment load at nodal points in order to account for the presence of low humps (Subroutine SNEGTV). The mechanism used in this step is explained in Section 5.2.4.
8. Calculate and store the total amount of sediment load received at nodal points at the bottom of the slope. This quantity represents the total sediment yield in a specific time interval.
9. Elevation of nodal points and humps are revised to account for erosion during the preceding time interval. Arrays of flow and erosion are initialized, in preparation for the new values of the next time interval.

The computation steps explained in Sections 5.3.4 and 5.3.5 are repeated for successive time intervals until the end of

6. Compute the total amount of soil eroded, and transported by the flow above a nodal point (Subroutine ERSN1 or ERSN2). If ponding exists along a rill path, the deposition mechanism described in Section 5.2.2 is applied.
7. Revise the distribution of sediment load at nodal points in order to account for the presence of low humps (Subroutine SNEGTV). The mechanism used in this step is explained in Section 5.2.4.
8. Calculate and store the total amount of sediment load received at nodal points at the bottom of the slope. This quantity represents the total sediment yield in a specific time interval.
9. Elevation of nodal points and humps are revised to account for erosion during the preceding time interval. Arrays of flow and erosion are initialized, in preparation for the new values of the next time interval.

The computation steps explained in Sections 5.3.4 and 5.3.5 are repeated for successive time intervals until the end of

the test period. Figure 5.11 shows a schematic representation of the relation between different subroutines.

Figure 5.1 Typical Routing of Rill and Interrill Flow

Figure 5.2 Change in Rill Geometry due to Rill Erosion

Figure 5.3 Ponding Conditions

Figure 5.4 Deposition due to Ponding

a) Plan

b) Section A-A

Figure 5.5 Mechanism of Side-Slope Failure

Figure 5.6 Segment with Positive Side Slopes

Figure 5.7 Segment with a negative side slope

W_1 : water flowing on side slope C_6
 h_1 : hump erosion from side slope ab
 W_2 : water flowing in rill ij
 h_3 : hump erosion from side slope bc
 W_3 : water flowing in side slope ba

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Subroutines associated
with different steps:

Figure 5.9 Computational Scheme

Figure 5.10 Construction of the Hexagonal Mesh

Figure 5.11 Schematic Representation of Model Subroutines

CHAPTER VI

SENSITIVITY ANALYSIS OF THE MODEL

The discussion presented in this chapter investigates the sensitivity of the model to variations in different parameters and factors considered in its development.

The computational procedure of the computer program is long, and thus requires a preliminary study to determine reasonable limits of time and space for which the model can be applied. Accordingly, the first part of the sensitivity analysis is devoted to investigating the effect of some factors such as the length of time interval, and the configurations of the test area on the performance of the model.

The second part of this analysis examines the sensitivity of the model to the important parameters in erosion equations. Those parameters are n , a_s , and p , which appear in Equations (4.8) and (4.12).

The last part of this chapter investigates the sensitivity of the model to randomness in coordinates of surface points. This includes the effect of the rill pattern on the performance of the model. Specifically, we studied the case in which the uniform hexagonal rill pattern is distorted by a random component in the plane of the slope.

In most of the cases studied, the criterion for judging the performance of the model is the shape of the curve relating the soil Erosion Rate, in $\text{kg/m}^2/\text{hr}$, to time (ER vs. T). When relevant, we also use the relation between Rill-Interrill Erosion Ratio and time, (R/I vs. T).

6.1 Geometric Limitations

As described in Section 6.3.1, the model computes the time-dependent erosion in increments of time. During each time interval, the flow passing by any point is assumed at steady state, the resulting erosion is computed for that time interval. The elevations of mesh points are then revised at the end of each time interval.

The width of the hexagonal mesh element is determined from the results of the spectral analysis of the surface roughness (length of the basic wave). For a given mesh size, we can try to control the length of time interval, and the size of the test area.

A preliminary test was conducted using a rectangular area covered by a 20 x 50 mesh (i.e., $NX = 20$ and $NY = 50$, as defined in Section 5.3.1). The results, shown in Figure 6.1, indicate strong fluctuations in the ER vs. T curve.

A closer study of the numerical scheme indicated that this phenomenon is related to the shape of the test area. In

rill segments, such as ab in Figure 5.1, if b becomes higher than a, due to difference in erosion rates, the water and sediment reaching point a is ponded at a. Therefore, the total amount of sediment collected at the bottom of the slope is decreased by the same amount. If the width of the test area is small, then the number of segments such as ab across the width is also small. Accordingly, if ponding occurs at any segment, especially the ones near the bottom of the slope, the ER vs. T curve will experience a significant drop. Then, in subsequent intervals, when deposition elevates point a above b, the ponding situation disappears, and the amount of sediment reaching the bottom rises again. The drop and rise lead to fluctuations in the ER vs. T curve.

When the test area is wide enough, the ER vs. T curve for exactly the same conditions has smaller fluctuations. Figure 6.2 shows the results when using a 50 x 20 mesh.

The program's capacity is presently limited to a maximum number of nodal points of 2000. Therefore, subsequent runs are conducted using a 65 x 30 mesh.

6.2 Sensitivity to Time Interval

The study of the effect of the length of time interval is important in dynamic simulation models. Figures 6.3 and 6.4 show the variation of the model performance with time intervals ranging from 2.0 to 360 minutes. The results indicate a significant change in the shape of the ER vs. T curve with increasing

time interval. For short time intervals, the erosion rate generally increases with time. However, the value of the erosion rate at a specific time is larger for shorter intervals. Moreover, the erosion rate of the first time interval is the same in all cases.

In the erosion mechanism explained in Section 5.1.2, we find that with the progress of rill erosion, the side slopes become steeper and steeper until they reach the failure limit, (SLIMIT). Thereafter, the failed side slope assumes a new value, (SSTART). The subsequent interrill erosion on that sideslope will have a lower rate. Consequently, during a long time interval, more sideslopes will reach failure limit, and the interrill erosion of the next interval will be more significantly reduced. Furthermore, the fact that the soil masses which fail are not accounted for in the sediment yield also reduces the computed erosion (see Section 5.2.3).

Another factor influencing the model's behavior is the effect of updating the elevations after each time interval. In shorter time intervals, the updating process takes place more frequently, and therefore, the erosion process accelerates with a faster rate, and vice versa in longer time intervals.

On the basis of the above understanding, and to avoid excessive computation costs, a time interval of 10 minutes is used in the rest of the study.

6.3 , Sensitivity to Parameters in Erosion Equations

The erosion model approximates the flow in rills and over interrill areas by a uniform flow, as expressed by the Manning equation (Equation 4.5). Therefore, it is important to investigate the effect of Manning's coefficient on the results of the model.

Other important parameters in the erosion models are the exponent, P , and the constant, a_s , in Kalinske's bed load equation (Equation 4.10). However, a_s for rill erosion may be considerably different from a_s for interrill erosion. Therefore, ASR is used to denote a_s in the rill erosion equation, Equation (4.18) and ASH is used in interrill erosion equation, Equation (4.23).

Table 6.1 indicates the values adopted for different parameters in the sensitivity analysis.

6.3.1 Coefficient n in Manning's Equation (N)

The value of n is strongly dependent on the roughness of the surface over which water flows. Values of n , for a variety of cases, are reported by Chow (3). However, because of the small scale at which the erosion problem is analyzed, it is very difficult to choose the appropriate values of n . To test the model, arbitrary values of 0.02, 0.03, 0.04 and 0.05 were used for n . As shown in Table 6.1, when other parameters were tested, n took on the value of 0.04.

TABLE 6.1 PARAMETERS USED IN SENSITIVITY ANALYSIS

Parameters Fixed During the Analysis	Parameters Varied During the Analysis*
NX x NY = 65 x 30	N = 0.02, 0.03, (0.04), 0.05
RNL = 64 mm/hr	ASR = 200, 300, (400), 500
RNF = 0.5	ASH = 10, (20), 30, 40
TTIME = 6 hours	P = (1.5), 1.75, 2, 2.5
TI = 10 min.	SLIMIT = 1.1, 1.2, 1.3, (1.4)
D = 0.01 mm	
SLOPE = $20^{\circ} \approx 37\%$	
SSTART = 1.1	

* Values in parentheses are used when testing other parameters.

The ER vs. T curves for different values of n are shown in Figure 6.5. In general, the erosion rate increases with the increase of n . Although a higher value of n decreases the flow velocity, yet it increases the flow depth and consequently, the shear stresses, which controls erosion in this model (Equations 4.3 and 4.4).

It can also be seen that the fluctuation of the ER vs. T curve increases with n . This can be attributed to the effect of the ponding mechanism, since with higher erosion rate, associated with increasing n , the flow carries more sediment. Thus, the drops and rises in ER vs T curve are due to increased frequency of ponding.

The effect of Manning's coefficient on the rill-interrill erosion characteristics is shown in Figure 6.6. This effect varies with time during the test period. At late times, when erosion is sufficiently accelerated, higher values of n result in higher rill-interrill erosion ratio. The reason for this is explained below.

The erosion mechanism as described in Section 5.1.2 directly relates the erosion of the bed of a rill with the erosion from its sides. That is, if a rill bed is lowered by a certain distance, the slopes of the sides are increased by a corresponding amount. But the increase in the slope of the bed is less than that of the sides because erosion lowers both ends of the rill segment, although by different amounts. Therefore, the rill erosion

actually increases the interrill erosion of adjacent humps more than the rill erosion in the segment itself. Realizing that rills comprise only a small fraction of the surface, we can see why the progress of erosion results in a continuous reduction in the rill-interrill erosion ratio.

The increase of interrill erosion causes the side slopes to reach failure limit (SLIMIT) at a faster rate. Subsequent interrill erosion will be significantly reduced, causing the rill-interrill erosion ratio to increase for the rill segment in question. This is the reason for the fluctuations in the R/I vs. T curve.

From the previous explanation, we can see that the overall R/I ratio will decrease with time until side slope failure begins to affect a large enough number of humps in every time interval. At this point, interrill erosion ceases to increase, while the rill erosion continues to increase, and the trend of the R/I vs. T curve is reversed. The time at which the R/I ratio begins to increase depends on parameters which control erosion. In this test, higher values of n result in greater erosion rates, and shorten the time to reach this point. We can see from Figure 6.6 that the R/I ratio begins to increase at 240 minutes where $n = 0.05$. When the test period is extended for the case of $n = 0.04$, as shown in Figure 6.7, the R/I ratio begins to increase after about 380 minutes.

In summary, we find that, within the tested range, i.e., 0.02 to 0.05, the model is sensitive to Manning's coefficient. Its value affects both the total erosion rate, and the rill-interrill characteristics.

6.3.2 The Constant a_s for Rill Erosion (ASR)

According to Komura (17), the value of a_s when rills and gullies exist (denoted by ASR), is about 300. For interrill erosion, a_s (denoted by ASH) takes on a value of about 30.

The sensitivity to ASR was tested for values equal to 200, 300, 400 and 500. When other parameters were tested, ASR took on the value of 400.

The effect of ASR on the erosion rate is shown in Figure 6.8. It can be seen that the model is not very sensitive to the value of ASR. However, this parameter has more influence on the rill-interrill characteristics. Figure 6.9 indicates that higher values of ASR result in larger R/I ratio. An increase in ASR clearly accelerates rill erosion. Therefore, the R/I vs. T curve for the case of ASR = 500 begins to reverse its trend before other cases.

6.3.3 The Constant a_s for Interrill Erosion (ASH)

The test was conducted using ASH values of 10, 20, 30 and 40. When other parameters were tested, ASH was given a value of 20.

As shown in Figure 6.10, the erosion rate generally increases with the increase of ASH. The maximum erosion rate of the case $ASH = 40$ is about three times that of the case, $ASH = 10$. The erosion rate is clearly more sensitive to ASH than to ASR.

In terms of the rill-interrill characteristics, as expected, R/I erosion ratio decreases with the increase of ASH, as shown in Figure 6.11.

6.3.4 The Exponent p

The parameter p is an empirical exponent in the Kalinske equation, as shown in Equation (4.10). For open channels, Kalinske and Brown (see Rouse (14)) suggest a value of 2 for p .

To investigate the effect of p on the model, erosion is computed for p values of 1.5, 1.75, 2.0, and 2.5. Figure 6.12 shows the effect of p on the erosion rate. Smaller values of p result in higher rates of erosion. The erosion rate is sensitive to p , and the sensitivity increases for smaller values of p . The R/I ratio is less sensitive but generally, smaller values of p produce higher rill-interrill erosion ratio. For example, at the end of the test, R/I ratio for $p = 1.5$ is twice as much as that for $p = 2.5$, as shown in Figure 6.13.

6.4 Sensitivity to Criterion of Side Slope Failure

The mechanism of side slope failure, although simple, is very important in erosion simulation over longer time periods.

The two controlling factors are the upper and lower limits of the slopes, SLIMIT and SSTART, respectively.

The purpose of this test is to study the behavior of this model under different values of the quantity (SLIMIT - SSTART). To do so, SSTART is assigned a fixed value of 1.1, whereas SLIMIT varies from 1.1 to 1.4.

The influence of this factor on the erosion rate is shown in Figure 6.14. The sensitivity of the model to the quantity (SLIMIT - SSTART) is generally low, but it increases somewhat as the erosion progresses.

For an individual rill segment, a larger value of (SLIMIT - SSTART) allows for steeper side slopes. Therefore, we can expect higher rate of interrill erosion, and higher total erosion. But for the multitude of rill segments of the random surface, the combined effect of slope steepening and failure reduces the difference in results between different values of (SLIMIT - SSTART). The same low level of sensitivity is also noticed from the R/I vs. T curves shown in Figure 6.15.

6.5 Effect of Randomness in Elevation

This part of the analysis is aimed at studying the sensitivity of the model to the randomness in elevations of nodal points on humps. Therefore, a comparison is made between the model results when randomness is included and when it is omitted in the slope surface.

The case when randomness is included can be represented by the results in Figure 6.14, described in the previous section. The test is repeated under the same conditions, except with the random component set equal to zero. The latter scheme results in a surface with identical humps. Furthermore, all rill segments emerging out of a nodal point of code = 1 (e.g., point a in Figure 5.1), will have a bed slope equal to the average slope. Rill segments emerging out of nodal points of code = 2 (e.g., point b in Figure 5.1), will have identical bed slope which is less than the average slope.

Figure 6.16 shows the relationship between the erosion rate and time for the uniform surface. In comparison with the results in Figure 6.14, we can see that the uniform surface produces higher rates of erosion at all times. The erosion rate increases nearly uniformly with time, with little or no fluctuation, depending on the value of SLIMIT.

It seems obvious that the non-random case presents a surface with less "obstacles," and with no possibility of ponding along rill paths. Thus, water flows downslope in identical channels, resulting in uniform erosion of the surface. It is therefore possible to conclude that the randomness in elevations of the surface points has a considerable effect on the results of the model.

Further examination of the shape of the erosion rate curve provides better understanding of the way the mechanism of side

slope failure operates. Figure 6.16 represents the results of four identical surfaces, but with different limits for the side slope failure. In the case of $SLIMIT = 1.1$, the erosion rate increases uniformly with time for a period of about 160 minutes. At this point, the side slopes of all rill segments reached the limit ($SLIMIT$), and the rate of interrill erosion remains the same with time. The total erosion rate, however, continues to increase, with a lower rate, due to the increase in rill erosion.

It is easy to see that the reduction in the erosion rate takes place in all the cases, but with different magnitudes, and at different times. The larger the value of $SLIMIT$ (i.e., larger $SLIMIT - SSTART$), the more the time needed to reach the failure limit, and the greater the drop in erosion rate due to side slope failures.

6.6 Effect of Randomness in Rill Pattern

As described in Section 3.2, the surface of a new soil slope consists of many humps and depressions, as shown in Figure 3.1. The actual path of overland flow is quite irregular, at least in the early stages of erosion, before well-defined master rills are formed (See Horton (14)).

The uniform hexagonal mesh used in this model, as an elementary rill pattern, is an important simplification. As part of the sensitivity analysis, an attempt is made in this

section to compare the performance of the model with the results of a simplified model using a random rill pattern.

The random rill pattern is generated according to the procedure described in Section 3.4.2, using the results of zero-crossing analysis. The amount of soil eroded at any point is directly dependent on the flow characteristics at this point. Therefore, instead of comparing amounts of soil eroded, we can use the flow as a basis for comparison. Consequently, the problem is reduced to a comparison between water quantities from humps, and flowing in different rill segments. Such comparison is far from being complete, yet it serves as an indication to the potential effect of the rill pattern.

The random surface used in the comparison covers an area of $NX = 15$ and $NY = 8$, with an average slope of 20 degrees. For the random rill pattern, the surface is generated according to the procedure described in Section 3.4.2. For simplicity, we assume a unit amount of water to be drained into each rill segment from adjacent humps. At nodal points, the flow is also divided between different segments according to the rules described in Section 5.1.1. Flow computations are done manually. For this reason, the comparison is made using a relatively small area (15×8). For the hexagonal rill pattern, results are directly obtained from the model (output of Subroutine FLOW).

Because the rill flow increases downslope, we must compare the flow of rill segments at approximately the same relative

position on the slope. Two samples in each surface are selected to make the comparison. The first sample consists of the rill segments of the 4th "row" from the top. The second sample consists of rill segments in the 6th "row". The location of samples are shown in Figures 6.17 and 6.18. Each sample contained 14 segments.

Figures 6.19 and 6.20 show the empirical distributions of the flow obtained in each case. The results indicate that the null hypothesis, that the two samples belong to the same distribution, is rejected in the test on the 4th row. The same hypothesis, however, is accepted in the other test. The significance level in both tests is 0.05.

It can be seen from Figures 6.19 and 6.20 that the distribution of rill flow using uniform rill pattern has larger variation. It is not possible, however, to draw more specific conclusions about the overall effect of randomness in rill patterns on the model results. On one hand, limitations imposed by manual computations dictated the use of a small mesh, which produces a small sample of rill segments, leading to higher probability of sampling error. On the other hand, the results of the statistical testing are marginal. Therefore, it is believed that this point warrants further investigation. The above analysis, however, presents a possible starting point.

It is important to notice that the randomness in the generated surface creates randomness in the overland flow.

Auxilliary mechanisms of ponding and low humps account for this randomness, and thus, reduce the degree of idealization of a uniform rill pattern. Consider, for example, the mesh shown in Figure 6.21(a). Before superposing any random component on the elevations of surface points, a cross section such as A.A would result in a uniform profile, as shown in Figure 6.21(b). This profile is composed of identical and equidistant rill segments. Such surface is probably an unrealistic representation of the actual surface.

When the random component of elevation is imposed on each of the points 1-9 on Figure 6.21(a), two kinds of profiles can be obtained. In the first, the random components alter the heights of different points on the profile, yet the original rill pattern is basically the same, with minor differences only in the size of the rills. This case is presented in Figure 6.21(c). This can take place mostly in cases where the random component is generally small. On the other hand, if some points such as 3 and 7 have a relatively large negative random component, low humps are created at points 3 and 7. This results in a significantly different rill pattern, as shown in Figure 6.21(d). The mechanism explained in Section 5.2.4 shifts the flow from the rill passing by point 4 to the adjacent rill passing by point 2. Therefore, the rill passing by point 4 no longer contributes to rill erosion computation. Another possibility is

that a hump such as that at point 7 is so low that it eliminated the two adjacent rills and formed a ponding zone in place of the hump.

The above examples indicate that the uniform hexagonal grid actually serves as a "reference" frame for computations, rather than a fixed rill pattern. This allows for geometrical irregularities such as low humps and ponded zones to be simulated.

Figure 6.1 ER vs T curve for a 20 x 50 mesh

Figure 6.2 ER vs T curve for a 50 x 20 mesh

Figure 6.3 Relationship between Erosion rate and time interval; short range

Figure 6.4 Relationship between Erosion rate and time interval; long range

Figure 6.5 Effect of Manning's Coeff. on erosion rate

Figure 6.6 Effect of Manning's Coeff. on R/T Erosion ratio

Figure 6.7 R/T vs T curve for $n = 0.04$ for an 8-hr test

Figure 6.8 Effect of the constant ASR on Erosion rate

Figure 6.9 Effect of the constant ASR on R/I erosion ratio

Figure 6.10 Effect of the constant ASH on Erosion rate

Figure 6.11 Effect of the constant ASH on R/I Erosion ratio

Figure 6.12 Effect of the exponent p on Erosion rate

Figure 6.13 Effect of the exponent p on R/I erosion ratio

Figure 6.14 Effect of the factor SLIMIT on Erosion Rate

Figure 6.15 Effect of the factor SLIMIT on R/I erosion ratio

Figure 6.16 Erosion on uniform surface.

Figure 6.17 Test Samples from Uniform Rill Pattern

Figure 6.18 Test Samples from Random Rill Pattern

Figure 6.19 Effect of Rill Pattern Randomness on Flow; Test no. 1

Figure 6.20 Effect of Rill Pattern Randomness on Flow; Test no. 2

Figure 6.21 Irregularity in Generated Surfaces

CHAPTER VII

NUMERICAL EXPERIMENTS

Having examined the sensitivity of the model to important parameters and mechanisms, it is now possible to conduct some numerical experiments. Successful simulation models are extremely useful in understanding simulated processes, and in predicting their behavior. The numerical experiments discussed in this chapter serve as an indication of the potential benefit of this model in that regard.

First, the predictions of the model are compared with some field experiments. However, it is important to emphasize that we are only interested in comparing the orders of magnitude of erosion. A close agreement between predicted and measured values is not expected at this stage. This is because proper verification of the model requires that the experiments be made on bare slopes with no large-scale variations in surface geometry, and data on micro-relief of the original surface be available. We also need to obtain the model parameters, particularly the soil representative diameter, D , and the Manning's coefficient, n . Most of this information is not available in published erosion data at the present time. In addition, the results of the experimental studies on rill-interrill erosion characteristics are mostly preliminary.

In fact, the available results are obtained from plots with artificial straight rills (24, 25). Such conditions are not suitable for comparison with the predictions of this model.

Next, model predictions are used to establish the influence of important physical conditions which are slope gradients, slope length, and rainfall intensity, and compared with trends known from experience and existing empirical relations.

7.1 Comparison with Field Measurements

Some measurements from newly formed highway embankments are used to compare the model's results with field data. To study the effect of erosion control methods on highway backslopes, Barnett et al. (1) conducted field experiments at four different locations using rainfall simulators. In each location, seven plots with different mulch treatments were prepared, one of which was left as bare surface. Each site was graded to $2\frac{1}{2}$:1 slope, seeded, rototilled, and then firmed with a cultipacker.

In two of the four locations, the soil was classified as clay. The soil in the other two locations was classified as sandy clay loam.

The test storm was applied at an intensity of $2\frac{1}{2}$ i.p.h. in two increments of 30 minutes each. The first increment, $1\frac{1}{2}$ inches in 30 minutes, corresponds to a one-year frequency storm; the entire test represents a 10-year frequency storm within the geographical region of the test, which is Georgia.

Obviously, many parameters and measurements are needed as input data to the model. Nevertheless, some of those parameters are assumed common for slope erosion problems. Among those are the constants, ASR, ASH and p , and the constants describing the properties of water. On the other hand, some data such as the representative size of soil particles, the Manning's coefficient, and the surface roughness measurements are unique characteristics of each site.

It is not surprising that no information about the surface roughness was reported in the paper by Barnett et al. With due reservations, the roughness data obtained from Wooster, Ohio, which has been analyzed in Chapter III, is used here to represent a well-cultivated surface.

Since the field study was not concerned with comparing flow and erosion results with any theoretical model, no estimate of Manning's coefficient, n , was presented. Use is made of the results of the investigation by Ree et al. (30) on the value of n in overland flow. Values as high as 0.3 were reported in their study, for poor-cover conditions. Even higher values (0.6) were reported for fair and good cover conditions. For the bare surface in question, computations are made for a range of n from 0.025 to 0.2.

According to Foster and Meyer (8), clay particles are detached by rainfall as aggregates. These aggregates move along the bottom of the rills as cohesionless particles.

The previous consideration is the basis for the choice of the values of the soil particle representative diameter, D , in the two types of soils. For the plot classified as clay, the reported gradation was 39% sand, 27% silt, and 34% clay. The clay particles in the USDA classification have a diameter of less than 0.002 mm. Therefore, to represent the clay aggregates, and in the same time, allow for the non-aggregate representation of sand and silt, the value of $D = 0.01$ mm is selected. In the second plot, with the gradation of 57% sand, 17% silt and 26% clay, we used the value of 0.05 for D .

Using a time interval of 2 minutes, the model computed the total soil loss at the middle, and at the end of a 60-minute storm period. The soil losses computed, for different values of n , for the two sites are shown in Figures 7.1 and 7.2, respectively. The value of n required to produce the measured soil loss is also shown.

Examination of the model results on Figures 7.1 and 7.2 indicates that in order to achieve a value of soil loss comparable to that obtained from field measurements, the value of Manning's n has to be around 0.085 for clay and over 0.2 for sandy clay. Given the surface condition, as a bare slope, and comparing with the estimates produced by Ree et al. (30), those n values, especially for the sandy clay, may be too high. However, the values of n for overland flow in general, and for bare slopes in particular, are not yet well established.

It is possible, however, that the model tends to underestimate the soil loss, because of the approximation used in the side slope failure mechanism, as explained in Section 5.2.3. It is difficult, though, to determine the specific source of discrepancy between the field measurements and the model results, because of the factors discussed in the introduction to this chapter. Therefore, it seems inevitable that a proper verification of the present model requires specific surface preparation and measurements.

7.2 Effect of Slope Gradient

The slope gradient of a soil surface is one of the most important factors which control the process of slope erosion. Investigators, since the earliest erosion studies, have always attempted to determine the relation between the slope steepness and the amount of soil eroded. Experimental as well as theoretical studies agree that soil erosion increases with slope gradient. A unique relation, however, is not yet well established (See Li et al. (19)).

In testing the effect of slope gradient in the present model, the erosion rate is computed for four plots with slopes of 5, 10, 15 and 20 degrees, respectively. Figure 7.3 shows the change of erosion rate with time for the four cases.

The results on Figure 7.3 indicate that steeper slopes result in larger erosion rates. The relation between slope gradient and erosion rate is time-dependent, as shown in Figure 7.4. This

behavior may provide a possible explanation for the differences in the results of experimental studies on the effect of slope gradient on the erosion rate.

7.3 Effect of Slope Length

Since this overland flow tends to increase downslope, longer slopes result in longer and deeper rills. Therefore, the slope length can be expected to have a significant influence on the rill-interrill erosion features.

The relation between the erosion rate and time is computed for three plots of lengths 0.73, 2.29 and 3.85 meters, respectively. These values correspond to values of NY of 10, 30 and 50, respectively, as shown in Figure 7.5. To achieve a value of $NY = 50$, NX is reduced to 39 throughout this test.

The model's results, as shown in Figure 7.5, indicate that the erosion rate decreases with the increase of slope length. This behavior contradicts empirical models in general (see Reference 19). Determination of the mechanism responsible for such behavior requires additional investigation.

The effect of the slope length on the rill-interrill erosion features is very important, since transport and detachment capacities of rills increase with distance downslope. Figure 7.6 shows the relation between rill-interrill erosion ratio with time for the same plots. It is clear that the contribution of

rills increases with slope length. This means that rill erosion increases with distance down slope. Such behavior has been confirmed in many studies (24, 25, 26).

7.4 Effect of Rainfall Intensity

Rainfall characteristics, such as intensity, angle of incidence, spatial, and temporal distribution, have variable impact on the erosion process. The present model is concerned only with the effect of rainfall intensity.

The test area is subjected to three storms of 50, 25 and 12.5 mm/hr rainfall intensity, respectively. The erosion rate is computed for the test periods of 3, 6 and 12 hours, respectively. This means that at the end of each test, all plots would have received the same amount of rainfall, which is 150 mm ($\approx$ 6 inches). Each of the three storms is applied to three plots of slopes of 5, 10 and 20 degrees, respectively. Results of the three storms are shown in Figures 7.7, 7.8 and 7.9.

As expected, storms of larger intensity result in higher values of erosion rate at all times. The relation between rainfall intensity and erosion rate seems to be dependent on the average slope gradient of the plot, as shown from Figure 7.10.

7.5 Evaluation of Eroding Surfaces

The purpose of this section is to illustrate the temporal and spatial changes in the surface geometry under erosion, as simulated by this model.

The shape of the original random surface generated by the model (i.e., prior to erosion) is shown in Figure 7.11. Subsequent changes in the surface geometry are shown in Figures 7.12 and 7.13 at times 200, and 400 minutes, respectively. For the constant rainfall intensity of 50 mm/hr, the total amount of rain at the end of the test is 333 mms ($\approx$ 13.1 inches).

Observation of the figures illustrates the growth of rill size with time. Moreover, we can see the effect of the random surface elevations on development of nonuniform rill pattern. The results are in qualitative agreement with observed rilling on slopes.

It is important to emphasize that the rill pattern developed in the above test is only one of many probable realizations whose occurrence depends on the generated random surface. All those realizations, however, are supposed to have the same statistical properties.

Figure 7.1 Soil Loss from the Clay Site

Figure 7.2 Soil Loss from the Sandy Clay Site

Figure 7.3 Effect of slope gradient on erosion rate

Figure 7.4 Effect of time on the slope gradient - Erosion rate relation

Figure 7.5 Effect of slope length on erosion rate

Figure 7.6 Effect of slope length on R/I erosion ratio

Figure 7.7 Effect of Rainfall intensity on erosion rate;
RNL = 50 mm/hr

Figure 7.8 Effect of Rainfall intensity on erosion rate;
RNL = 25 mm/hr

Figure 7.9 Effect of Rainfall intensity on erosion rate;
RNL = 12.5 mm/hr

Figure 7.10 Relationship between Rainfall Intensity, Slope Gradient and Erosion Rate

Figure 7.11 Original Surface, $t = 0$

Figure 7.12 Eroded Surface; $t = 200$ minutes

Figure 7.13 Eroded Surface, $t = 400$ minutes

CHAPTER VIII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary and Conclusions

The review of literature on soil erosion reveals the need to consider the effect of the random rill patterns which develop as a result of the surface irregularities. An attempt has been made in this study to simulate the erosion process on the basis of the rill-interrill characteristics as they change with space and time.

The measured roughness of a surface is analyzed and used in generating random surfaces for the simulation process. The rill pattern developing on the random surface is approximated by a hexagonal mesh which covers the test area. Erosion computations are then carried out over a number of time intervals, according to the specified rainfall and infiltration characteristics. During each time interval, computations are made assuming a steady state condition. Changes in the surface geometry, due to erosion, during any time interval are considered in the subsequent interval. The model uses simplified mechanisms to simulate ponding, deposition, and failure of side slopes of rills.

A sensitivity analysis of the model was made to examine the effect of important parameters and mechanisms. The length

of time intervals is important because of the cumulative effect of the elevation-updating procedure. Therefore, shorter time intervals give better estimates of erosion rate.

Part of the sensitivity analysis was directed to the study of the influence of the parameters in the erosion equation on the model results. The erosion rate increases with the increase of the value of Manning's coefficient, n . The difference in transport capacity of flow in rills and over interrill areas is mainly expressed in the value of the constants ASR and ASH. The value of ASR does not have significant effect on the total erosion rate. However, an increase in its value produces higher rill-interrill erosion ratio. The model is more sensitive to the value of ASH. An increase in its value increases the erosion rate and, at the same time, decreases rill-interrill erosion ratio. The model is sensitive to the exponent p in Kalinske's bed load equation, Equation (4.10). A lower value of p results in a higher erosion rate, and higher R/I ratio as well.

The randomness incorporated in the generation of the simulated surface has a significant effect on reducing the erosion rate. This means that surfaces with more random variations experience smaller erosion rates.

As part of the sensitivity analysis, a preliminary study was made to investigate the potential difference in the model behavior when using a random mesh to simulate the rill pattern.

The distribution of rill flow in the uniform pattern results has more variations than that of the random pattern. However, the study was not conclusive because of the small sample size used in the analysis.

The results of the model were compared with some data from field experiments. The results are of the right order of magnitude, but it is not possible to determine the extent of agreement between the two results since many parameters and data, including the original surface roughness, were not available.

The effect of the slope gradient on the model results was studied. Steeper slopes result in faster erosion rates. Moreover, the relationship between slope gradient and erosion rate is found to be time-dependent.

The length of the slope has a significant effect on rill characteristics. According to the model results, longer slopes result in larger contribution of rills to the erosion process. However, the total erosion rate seems to decrease for longer slopes. This behavior is not in agreement with the results of existing empirical models.

The influence of rainfall intensity on the erosion rate was also studied. For the same accumulative amount of rainfall, the model showed that the higher the rainfall intensity, the faster the erosion rate. However, the effect of increasing the rainfall intensity is found to be more significant for steeper slopes.

8.2 Recommendations for Further Research

Because this is a first step in stochastic simulation of the erosion process, numerous problems both in formulation and in documentation have been encountered. Consequently, many simplifications were made. The structure of the simulation model, however, allows for sufficient flexibility in refining different submodels and mechanisms when feasible.

Proper verification of the model requires field experiments which meet the model requirements in terms of surface preparation and measurements. Also, more study is needed to determine appropriate values for the parameters of the erosion model, such as Manning's n , the constant a_s , and the exponent p , as they are related to the overland flow problem.

The erosion model can be further improved by considering the detachment and the transport capacity of the rill flow separately. Moreover, the computation of rill flow can be modified so that the continuity of energy at nodal points is satisfied. Such consideration is expected to improve the mechanisms of ponding and deposition.

The use of only one wave component out of the spectrum of the surface roughness to determine the shape of the rill pattern may be too simplistic. The possibility of constructing a rill pattern using a combination of wave components which have comparable contributions to the surface variations warrants further effort.

The study on the use of random rill patterns was not concluded. The use of the method of zero crossing analysis seems to provide a good starting point in that regard.

It is important to notice that the stochastic aspect of the model is based only on the random characteristics of the surface roughness. Other factors such as rainfall distribution, soil properties, and infiltration, are also random in nature, and contribute to the overall behavior. Recently, Freeze (10) presented a simulation model to account for some of those factors in computing overland flow. A similar technique can be used so that the model uses random values for those parameters as they change with time and/or with space.

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APPENDIX A

COMPARISON OF RILL EROSION EQUATION WITH FIELD MEASUREMENTS

Meyer et al. (25) presented some results of some simulated rainfall field investigations on erosion in rills. A number of artificial rills were prepared in a Russell silt loam field. The rills were 4.6 m long and had bed slope of 6% and side slopes of 25%. The present comparison is made for the case of 64 mm/hr rainfall intensity. The test was conducted for several values of base flow, as shown in Table A.1.

To use Equation (4.18), which is derived for rill erosion, several constants and parameters in the equation must be estimated. The silt loam is assumed to aggregate and form larger particles of diameter 0.2 mm. Since the test is on rill erosion, the value of the constant a_s is taken as 300. The exponent p is kept equal to 2.0. For a Manning coefficient of 0.025 and a runoff factor of 0.5, the computed erosion for different base flows is given in Table A.1. The comparison is specifically made between the measured and the computed values of the erosion rate in kg/hr/m length of the rill.

TABLE A.1 COMPARISON BETWEEN MEASURED AND COMPUTED VALUES OF RILL EROSION

Base Flow Q_1 , kg/hr	End Flow Q_2 , kg/hr	MEASURED		COMPUTED FROM EQUATION (4.18)	
		Soil Loss* kg	Erosion Rate kg/hr/m	$m^3 \text{ ER}$ $m^3/\text{sec}/m$	Erosion Rate kg/hr/m
0	114	1.51	0.32	0.031×10^{-6}	0.15
700	732	4.98	1.08	0.53×10^{-6}	2.5
700	712	4.89	1.07	0.53×10^{-6}	2.5
1400	1436	18.45	4.01	0.53×10^{-6}	4.5
1400	1200	9.35	2.03	0.53×10^{-6}	4.5
2000	2053	35.72	7.76	1.31×10^{-6}	6.1
2000	2007	13.20	2.87	1.31×10^{-6}	6.1
2800	2963	37.40	8.13	1.75×10^{-6}	8.15
2800	2885	41.85	9.10	1.75×10^{-6}	8.15

* Values indicated are the net soil loss from rill erosion only. It is computed by deducting the interrill erosion, as estimated by Meyer et al. (25), from the total measured soil loss.

APPENDIX B

LISTING AND SAMPLE OUTPUT
OF THE COMPUTER PROGRAM

[illegible]

NPF: # OF PROFILES

TLEN= TOTAL LENGTH OF MICRORELIEF PROFILE.

DR- DISTANCE BETWEEN TOC/OLENESS DATA MEASUREMENTS

UWT= UNIT WEIGHT OF SOIL - N/CUBIC METER

G* GRAVITY ACCEL. M/SG. SEC

SEC. 5. EFFECT OF GRAVITY ON SOIL

P= EXPONENT IN KALINSKE'S EQUATION

ASH= CONSTANT IN INTERRILL EROSION EQUATION

NY= # OF MESH POINTS IN Y-DIRECTION

RNL: RAINFALL INTENSITY. MLNTR/HR

ANRATE= ANNUAL RATE OF RAIN

NTI: # OF TIME INTERVALS

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WL= WAVELENGTH OF

SH: HORIZONTAL PROJECTION OF SL

DURING A TIME INTERVAL, CUBIC METERS

BY POINT 1 DURING A TIME INTERVAL Δ METERS

V VOLUME OF INTERRILL EROSION PART OF BED THE
 PASSED BY POINT I DURING A TIME INTERVAL C METERS

FIGURE 2. WEIGHT OF TOTAL SEDIMENT ACCUMULATED AT THE
A TIME INTERVAL NEWTONS

[illegible]

RATE= EROSION RATE IN M/SQ. M/HR " " " " " "

[illegible]

FRATIO(NS) = TOTAL RILL/INTERRILL EROSION RATIO

● 2019年12月1日，中国银保监会发布《关于规范商业银行互联网贷款业务的通知》，规定互联网贷款业务应当坚持小额、分散的原则，提高资产分散度，严控集中度风险。同时，要求商业银行应当加强互联网贷款业务的风险管理，建立健全互联网贷款业务管理制度，加强贷前调查、贷中审查和贷后管理，确保贷款资金用途真实、合法。此外，还要求商业银行应当加强互联网贷款业务的合规管理，严格遵守相关法律法规，不得开展违法违规业务。

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1) NP,NPF,CUT,TLEN,DX (SEE FORMAT STATEMENT # 1)

3) DMLM, UWT, RO, G, SC (SEE FORMAT STATEMENT # 3)

6) NX,NY,SLOPE,RNL,RNF,ANRATE (SEE FORMAT STATEMENT)

```

C      6) T1,NT1,NRS          (SEE FORMAT STATMENT # 6)      A00770
C      7) SLIMIT,SSTART      (SEE FORMAT STATMENT # 7)      A00780
C      8) NRUN (15), SEE NOTE # 2                               A00790
C      9) NRUN VALUES OF PARAMETER BEING STUDIED, SEE NOTE # 2 A00800
C      ***** A00810
C      NOTE # 1 A00820
C      ***** A00830
C      THIS PROGRAM USES TWO SUBROUTINES CALLED FFTR AND FFTP FROM A00840
C      THE "IMSL" LIBRARY: A00850
C      FFTR : COMPUTES FOURIER TRANSFORM, AND A00860
C      FFTP : COMPUTES INVERSE FOURIER TRANSFORM. A00870
C      MAKE SURE THEY STILL EXIST IN THE COMPUTER LIBRARY UNDER A00880
C      THE SAME NAME A00890
C      ***** A00900
C      A00910
C      DIMENSION VARPLT(10) A00920
C      DIMENSION XP(200),YP(200),RSD(200) A00930
C      DIMENSION YYP(1000) A00940
C      DIMENSION TBTM(100),RBTM(100),HBTM(100) A00950
C      DIMENSION FTSDT(100),FRSDT(100),FHSdT(100),FRATIO(100),FRATE(100) A00960
C      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ A00970
C      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000) A00980
C      COMMON/QFLOW/QT(2000),QL(2000),QR(2000) A00990
C      COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000) A01000
C      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000) A01010
C      COMMON/HMPP/HMPP(500),KHMP(500),YHMP(500) A01020
C      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500), A01030
C      HMP6(500) A01040
C      COMMON /SAME/TLEN,CUT A01050
C      COMMON /PROP/CAMA,RO,C,SC,RN A01060
C      COMMON NT A01070
C      A01080
C      ***** A01090
C      READ SURFACE ROUGHNESS DATA A01100
C      ***** A01110
C      A01120
C      READ(5,1) NP,NPF,CUT,TLEN,DX A01130
C      NTOTAL=NP*NPF A01140
C      READ(5,2)(YYP(I),I=1,NTOTAL) A01150
C      A01160
C      ***** A01170
C      READ PHYSICAL PARAMETERS A01180
C      ***** A01190
C      A01200
C      READ(5,3) DMLM,UWT,RO,C,SC A01210
C      READ(5,4) RN,P,ASR,ASH A01220
C      A01230
C      ***** A01240
C      READ STORM AND SLOPE DATA A01250
C      ***** A01260
C      A01270
C      READ(5,5) NX,NY,SLOPE,RNL,RNF,ANRATE A01280
C      READ(5,6) T1,NT1,NRS A01290
C      READ(5,7) SLIMIT,SSTART A01300
C      D=DMLM/1000. A01310
C      TTIME=T1*NT1/60. A01320
C      A01330
C      A01340
C      THE FOLLOWING FOUR CARDS ARE TO BE USED ONLY WHEN A01350
C      COMPUTING RESULTS FOR (NRUN) VALUES OF ANY PARAMETER. FOR A01360
C      EXAMPLE, RN, IN THE CASE BELOW A01370
C      READ(5,2000) KRUN A01380
C      READ(5,3000)(VARPLT(I),I=1,KRUN) A01390
C      DO 1000 NRUN=1,KRUN A01400
C      RN=VARPLT(NRUN) A01410
C      WRITE(25) NRUN,VARPLT(NRUN) A01420
C      2000 FORMAT(15) A01430
C      3000 FORMAT(10F8.3) A01440
C      A01450
C      SLPR=TAN(SLOPE*22./7./180.)*100 A01460
C      RAINYR=RNL*TTIME/ANRATE/10. A01470
C      WRITE(6,50) A01480
C      WRITE(6,209) A01490
C      WRITE(6,203) A01500
C      WRITE(6,230) A01510
C      WRITE(6,203) A01520

```

	WRITE(6,209)	A01530
	WRITE(6,310)	A01540
	WRITE(6,315)	A01550
	WRITE(6,320) NPF,NP,DX	A01560
	WRITE(6,330)	A01570
	WRITE(6,315)	A01580
	WRITE(6,340) DMLM,UWT,SG	A01590
	WRITE(6,350) P,ASR,ASH,RN	A01600
	WRITE(6,360)	A01610
	WRITE(6,315)	A01620
	WRITE(6,370) NX,NY,SLOPE,SLPR,RNL,RNF	A01630
	WRITE(6,375) ANRATE,RAINYP	A01640
	WRITE(6,380) TI,TTIME,NRS	A01650
	WRITE(6,390) SLIMIT,SSTART	A01660
	WRITE(6,60)	A01670
	XP(1)=0.0	A01680
	DO 14 I=2,NP	A01690
	XP(I)=XP(I-1)+DX	A01700
14	CONTINUE	A01710
	IF(NRUN.GT.1) GO TO 4000	A01720
	WRITE(6,50)	A01730
	WRITE(6,209)	A01740
	WRITE(6,203)	A01750
	WRITE(6,400)	A01760
	WRITE(6,203)	A01770
	WRITE(6,209)	A01780
C		A01790
C	*****	A01800
C	... DETERMINE THE CHARACTERISTICS OF THE BASIC WAVE	A01810
C	*****	A01820
	CALL CWAVE(XP,YP,YP,NP,NPF,CUT,TLEN,AMP,WL,RSD,	A01830
	RMEAN,STDEV)	A01840
	WRITE(6,300) AMP,WL	A01850
C		A01860
	WRITE(6,305) RMEAN,STDEV	A01870
C	... CONVERT TO METERS	A01880
C		A01890
	AMP=AMP/1000.	A01900
	WL=WL/100.	A01910
	STDEV=STDEV/1000.	A01920
	RMEAN=RMEAN/1000.	A01930
C		A01940
C	*****	A01950
C	... CONSTRUCT THE HEXAGONAL MESH	A01960
C	*****	A01970
	SL=WL/(2.*(3.**0.5))	A01980
	SLP=SLOPE*22./7./100.	A01990
	SH=SL*COS(SLP)	A02000
4000	CONTINUE	A02010
	DO 3007 I=1,NMAX	A02020
	X(I)=0.	A02030
	Y(I)=0.	A02040
	CODE(I)=0	A02050
	NAJ(I)=0	A02060
	KPND(I)=0	A02070
3007	CONTINUE	A02080
	CALL HDGMESH	A02090
	TAREA=Y(NY)*X(NMAX)	A02100
	FSHAPE=X(NMAX)/Y(NY)	A02110
	PL=Y(NY)	A02120
	PW=X(NMAX)	A02130
	WRITE(6,40) PL,PW	A02140
	WRITE(6,30) TAREA,FSHAPE	A02150
	WRITE(6,60)	A02160
	CAMA=RO*C/9.81	A02170
C		A02180
C	*****	A02190
C	... COMPUTE PARAMETERS OF EROSION EQUATIONS	A02200
C	*****	A02210
	CALL PARAM(D,P,ASR,ASH,RCH,HCH,EX)	A02220
C		A02230
C	... START DO LOOP 200 FOR DIFFERENT RANDOM SURFACES	A02240
		A02250
		A02260
		A02270


```

C      DO 200 NS=1,NRS
      DO 201 I=1,NMAX
      ELV(I)=0.0
      DH(I)=0.0
201    HHMP(I)=0.0
      DO 202 I=1,NRS
      FTSDT(I)=0.0
      FRSDT(I)=0.0
      FHSDT(I)=0.0
      FRATIO(I)=0.0
202    FRATE(I)=0.0
C      ... ASSIGN ORIGINAL ELEVATIONS TO ALL MESH POINTS
C      CALL          ELEVIN(SLOPE,AMP,RMEAN,STDEV,NS)
C      ... ASSIGN CALL NUMBERS,COORDINATES ,AND ELEVATIONS TO ALL HUMPS
C      CALL          HUMP(RMEAN,STDEV,SLOPE,AMP,NHUMP)
      WRITE(6,204)
      WRITE(6,203)
      WRITE(6,205)  NS
      WRITE(6,203)
      WRITE(6,209)
      WRITE(6,206)
      WRITE(6,207)
      WRITE(6,208)
C      ... START DO LOOP 100 FOR THE SEQUENCE OF TIME INTERVALS FOR THE
C      RANDOM SURFACE UNDER CONSIDERATION
C      DO 100 NT=1,NTI
      DO 101 I=1,NMAX
      SDT(I)=0.0
      TRE(I)=0.0
      TIRE(I)=0.0
      QL(I)=0.0
      QR(I)=0.0
      QT(I)=0.0
      IF(Y(I).EQ.0.0.AND.KPND(I+1).EQ.0) DH(I)=DH(I+1)
      ELV(I)=ELV(I)-DH(I)
      DH(I)=0.0
101    CONTINUE
      CALL          SFILR(SLIMIT,SSTART)
      CALL          POND
      CALL          ACJNT
888    FORMAT(3(15,F15.5,15))
C      ... STORE INITIAL ELEVATIONS OF ALL POINTS ON FILE # 35
C      IF(NT.GT.1) GO TO 635
      REWIND 35
      CALL          STORE(NNOD,NHUMP)
635    CONTINUE
C      *****
C      ... COMPUTE STEADY STATE FLOW AT MESH POINTS DURING A TIME INTERVAL
C      *****
C      CALL          FLOW(RNL,RNF)
      NVOID=0
      DO 70 LL=1,NY
      KK=NY+(1-LL)
      DO 70 I=KK,NMAX,NY
      IF(Y(I).EQ.0.0) GO TO 75
      IF(CODE(I)-1) 75,80,85
C      *****
C      ... COMPUTE EROSION FOR RILL SEGMENTS WITH UPSTREAM POINT HAVING
C      CODE=1.
C      *****
80    CALL  ERSN1(I,QT(I-1),ECH,RCH,EX,TI)
      GO TO 70

```

A02280
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 A02990
 A03000
 A03010
 A03020
 A03030

```

C *****
C ... COMPUTE EROSION FOR RILL SEGMENTS WITH UPSTREAM POINT HAVING
C CODE=2.
C *****
C
85 CALL ERSN2(1,QL(1),QR(1),ECH,RCH,EX,T1)
75 IF(CODE(1).EQ.0.0) NVOID=NVOID+1
70 CONTINUE
777 FORMAT(3(15,2F15.5))
DO 105 I=1,NHUMP
999 FORMAT(15,7F15.5)
105 HMP(I)=(HMP1(I)+HMP2(I)+HMP3(I)+HMP4(I)+HMP5(I)+HMP6(I))/6.
TTBTM=0.0
TRBTM=0.0
THBTM=0.0
DO 110 K=1,NX
J=1+(K-1)* NY
TBTM(K)=SDT(J)*UWT
TTBTM=TTBTM+TBTM(K)
RBTM(K)=TRE(J)*UWT
TRBTM=TRBTM+RBTM(K)
HBTM(K)=TIRE(J)*UWT
THBTM=THBTM+HBTM(K)
110 CONTINUE
RATIO=TRBTM/THBTM
RATE=TTBTM*60/TAREA/T1
C
C ... STORE EROSION RATE RESULTS ON FILE # 25
C
XPLT=T1*NT
YPLT=RATE
ZPLT=RATIO
WRITE(25) XPLT,YPLT,ZPLT
FTSDT(NS)=FTSDT(NS)+TTBTM
FRSDT(NS)=FRSDT(NS)+TRBTM
FHSdT(NS)=FHSdT(NS)+THBTM
FRATIO(NS)=FRSDT(NS)/FHSdT(NS)
FRATE(NS)=FTSDT(NS)*60.0/TAREA/T1/NT
WRITE(6,210) NT,TTBTM,RATIO,RATE,FTSDT(NS),FRATIO(NS),FRATE(NS)
260 FORMAT(130(' '),/,130(' '))
100 CONTINUE
NNOD=NMAX-NVOID
C
C ... STORE FINAL ELEVATIONS OF ALL POINTS ON FILE # 35
C
CALL STORE(NNOD,NHUMP)
END FILE 35
C
C ... CHECK DATA STORED ON FILE # 35
C
REVIND 35
C625 READ(35,END=600)NY,NNOD,NHUMP
C WRITE(6,630) NY,NNOD,NHUMP
C630 FORMAT(3I10)
C READ(35)XMAX,YMAX
C WRITE(6,612)XMAX,YMAX
C612 FORMAT(2F20.5)
C605 READ(35,END=600) XXX,YYY,ZZZ
C WRITE(6,610) XXX,YYY,ZZZ
C IF(XXX.GT.88887.) GO TO 625
C GO TO 605
C600 CONTINUE
C610 FORMAT(3F20.5)
C
200 CONTINUE
WRITE(6,220)
WRITE(6,211)
WRITE(6,212)
WRITE(6,215)(1,FTSDT(1),FRSDT(1),FHSdT(1),FRATIO(1),FRATE(1),I=1,
NRS)
XPLT=99999.
WRITE(25) XPLT,YPLT,ZPLT
1000 CONTINUE
END FILE 25
C
C ... CHECK DATA STORED ON FILE # 25
C
REVIND 25
C
READ(25) NRUN,VARPLT(NRUN)

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C      WRITE(6,611) NRUN,VARPLT(NRUN)
C611  FORMAT(110,F10.5)
C333  READ(25,END=334)XX,YY
C      WRITE(6,335) XX,YY
C335  FORMAT(2F20.5)
C      GO TO 333
C 334  CONTINUE
C
1     FORMAT(214,3F8.2)
2     FORMAT(10F6.2)
3     FORMAT(5F10.4)
4     FORMAT(4F10.4)
5     FORMAT(215,4F10.3)
6     FORMAT(F10.3,215)
7     FORMAT(2F10.4)
30    FORMAT(///,10X,'TEST AREA =',F10.3,' SQ. METERS',///,10X,
      'SHAPE FACTOR =',F10.3)
40    FORMAT(///,10X,'PLOT LENGTH=',F10.3,' METERS',///,10X,
      'PLOT WIDTH =',F10.3,' METERS')
50    FORMAT(1H1,5X,110('*'),///)
60    FORMAT(///,5X,110('*'))
203   FORMAT(T23,'*',T54,'*',/,T23,'*',T54,'*')
204   FORMAT(1H1,///,23X,30('*'))
205   FORMAT(T23,'*',T29,'RANDOM SURFACE NO.',13,T54,'*')
206   FORMAT(///,T11,'RESULTS OF EACH INTERVAL',T51,'CUMULATIVE RESULTS'
      '///,T11,24('-',T51,18('-'))
207   FORMAT(///,3X,'INTRVL #',T13,'TTL SDMT',T23,'R/I RATIO',T34,
      'ERSN RATE',T47,'TTL SDMT',T57,'R/I RATIO',T69,'ERSN RATE')
208   FORMAT(T15,'( N)',T33,'( N/SM/HR)',T49,'( N)',T68,'( N/SM/HR)')
209   FORMAT(23X,30('*'))
210   FORMAT(///,2X,15,2X,3F10.2,'*',3F10.2)
211   FORMAT(///,T4,'NRS',T9,'TTL SDMT',T22,'R. ERSN.',T30,
      'I. ERSN.',T40,'R/I RATIO',T50,'ERSN. RATE')
212   FORMAT(T9,'( N)',T23,'( N)',T33,'( N)',T50,'( N/SM/HR)',///)
215   FORMAT(15,3F10.3,/)
220   FORMAT(1H1,///,15X,'FINAL RESULTS FOR ALL RANDOM SURFACES',/,
      15X,36('*'))
305   FORMAT(///,10X,'MEAN OF NORMAL DIST.',F8.3,' MLMTR',///,
      10X,'STAND. DEVIATION OF NORMAL DIST.',F8.3,' MLMTR')
300   FORMAT(///,10X,'AMPLITUDE OF REPRESENTATIVE WAVE',F8.3,2X,'MLMR',
      '///,10X,'LENGTH OF REPRESENTATIVE WAVE',F8.3,2X,'CM')
230   FORMAT(T23,'*',T29,'I N P U T D A T A',T54,'*')
310   FORMAT(///,10X,'GROUP # 1',10X,'SURFACE ROUGHNESS DATA')
315   FORMAT(10X,11('*'),10X,22('*'),/,10X,11('*'))
320   FORMAT(///,15X,'NO. OF ELEVATION TRACES =',15,/,15X,
      'NO. OF POINTS PER TRACE =',15,
      '///,15X,'SPACING',F5.2,3X,'CM')
330   FORMAT(///,10X,'GROUP # 2',10X,'PROBLEM PARAMETERS')
340   FORMAT(///,15X,'SOIL PARTICLE DIAMETER',F5.3,3X,'MLMTR',
      '///,15X,'SOIL UNIT WEIGHT',F6.0,3X,'N/C. METER',
      '///,15X,'SOIL SPECIFIC WEIGHT',F5.2)
350   FORMAT(///,15X,'EXPONENT OF KALINSKE EQN.',F5.2,
      '///,15X,'EQN. CONSTANT FOR RILLS',F5.1,
      '///,15X,'EQN. CONSTANT FOR HUMPS',F5.1,
      '///,15X,'MANNING CONSTANT',F5.3)
360   FORMAT(///,10X,'GROUP # 3',10X,'STORM AND SLOPE DATA')
370   FORMAT(///,15X,'NO. OF MESH POINTS IN CROSS-DIRECTION =',15,
      '///,15X,'NO. OF MESH POINTS IN LONGT-DIRECTION =',15,
      '///,15X,'AVERAGE SLOPE',F5.1,
      3X,'DEGREES',/,T54,'*',F7.2,3X,'PERCENT',
      '///,15X,'RAINFALL INTENSITY',F5.1,
      3X,'MLMTR/HR',/,15X,'RUNOFF COEFFICIENT',F5.2)
375   FORMAT(///,T16,'ANNUAL RAINFALL RATE',T54,'*',F5.1,T64,'CNTMTR',
      '///,T16,'EQUIVALENT YEARS OF RAIN',T54,'*',F5.2,T64,'YEARS')
380   FORMAT(///,15X,'TIME INTERVAL',F5.1,3X,
      'MINUTES',/,15X,'TOTAL RAIN PERIOD',F5.2,
      3X,'HOURS',/,15X,'NO. OF RANDOM SURFACES',15,/)
390   FORMAT(15X,'FAILURE LIMIT FOR SIDE SLOPE',9X,'*',F5.2,
      '///,15X,'STARTING LIMIT FOR SIDE SLOPE',9X,'*',F5.2,/)
400   FORMAT(T23,'*',T26,'SPECTRAL ANALYSIS RESULTS',T54,'*')
250   STOP
      END

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SUBROUTINE STORE(NNOD,NHUMP)
COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
COMMON/HMPP/HMPP(500),XHMP(500),YHMP(500)
WRITE(35) NY,NNOD,NHUMP
WRITE(35) X(NMAX),Y(NY),SL
DO 505 I=1,NMAX
IF(CODE(I).LE.0.0) GO TO 505
505 WRITE(35) X(I),Y(I),ELV(I)
CONTINUE
DO 620 I=1,NHUMP
WRITE(35) XHMP(I),YHMP(I),HMPP(I)
620 CONTINUE
XEND=88888.
WRITE(35) XEND,YEND,ZEND
RETURN
END

SUBROUTINE CWAVE(XP,YP,YYP,NP,NPF,CUT,TLEN,AMP,WL,RSD
, RMEAN,STDEV)
*****
THE FUNCTION OF THIS SUBPROGRAM IS:
1) PROCESS SURFACE ROUGHNESS DATA FOR SPECTRAL ANALYSIS, AND
2) IDENTIFY THE BASIC WAVE

COMPUTATIONS ARE BASED ON THE METHOD OF AVERAGE COEFFICIENTS.
*****
REAL*8 FMEAN
REAL*4 XP(1),YP(1),YYP(1)
REAL*8 AN(1000),BN(1000),DPOW(1000),R(1000),C(1000),WLAM(1000)
REAL*8 AAN(1000),BBN(1000),RR(1000),CC(1000),DDPOW(1000)
REAL*4 RSD(1000),YW(1000)
DIMENSION NDEG(1000)
NH1=NP/2+1
DO 401 I=1,NH1
AAN(I)=0.0
BBN(I)=0.0
DDPOW(I)=0.0
RR(I)=0.0
CC(I)=0.0
401 CONTINUE
DO 403 K=1,NPF
DO 404 I=1,NP
M=(K-1)*NP
YP(I)=YYP(M+1)
404 CONTINUE
CALL FILTER(XP,YP,NP,NDEG,AN,BN,DPOW,R,C,WLAM,FMEAN)
C ... COMPUTE AVERAGE VALUES OF AN,BN,...,ETC FOR ALL PROFILES:
C
DO 410 J=1,NH1
AAN(J)=AAN(J)+AN(J)/(1.*NPF)
BBN(J)=BBN(J)+BN(J)/(1.*NPF)
DDPOW(J)=DDPOW(J)+DPOW(J)/(1.*NPF)
RR(J)=RR(J)+R(J)/(1.*NPF)
CC(J)=CC(J)+C(J)/(1.*NPF)
410 CONTINUE
405 CONTINUE
WRITE(6,419)
WRITE(6,421)
WRITE(6,423)
WRITE(6,426) (NDEG(J),AAN(J),BBN(J),DDPOW(J),RR(J),CC(J),
, WLAM(J),J=1,NH1)

C ... DETERMINE THE BASIC WAVE : PICK-UP THE WAVE WITH MAX. POWER IN
C THE "MICRO ROUGHNESS" RANGE.THE MICR. ROUGH. RANGE INCLUDES
C ALL WAVES LENGTH LESS THAN OR EQUAL TO 30.0 CENTIMETERS.
C
PWMAX=0.0
K=0
DO 430 I=1,NH1
IF(WLAM(I).GT.30.) GO TO 430

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B00010
B00020
B00030
B00040
B00050
B00060
B00070
B00080
B00090
B00100
B00110
B00120
B00130
B00140
B00150
B00160
B00170
C00010
C00020
C00030
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C00110
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C00210
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C00520
C00530

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      IF(DDPOW(1).LE.PWMAX) GO TO 430
      PWMAX=DDPOW(1)
      K=1
430  CONTINUE
      AMP=(AAN(K)*AAN(K)+BBN(K)*BBN(K))*0.5
      WL=WLAM(K)
      PSI=2*NDEC(K)*22.0/7.0/TLEN
      DO 460 KK=1,NPF
      DO 450 I=1,NP
      H=(KK-1)*NP
      YP(I)=YYP(H+1)
      XPSI=XP(I)*PSI
      FAZ1=COS(XPSI)
      FAZ2=SIN(XPSI)
      YW(I)=AAN(K)*FAZ1+BBN(K)*FAZ2+FMEAN
      RSD(I)=YP(I)-YW(I)
450  CONTINUE
      CALL RESDL(RSD,NP,RMUE,SIGMA)
      RMEAN=RMEAN+RMUE/(1.*NPF)
      STDEV=STDEV+SIGMA/(1.*NPF)
      WRITE(6,455) (RSD(I),I=1,NP)
C 460  CONTINUE
419  FORMAT( //,10X,'AVERAGE VALUES FOR ALL PROFILES',/)
421  FORMAT(10X,31(' '))
423  FORMAT(///,T6,'DEGREE',T16,'AN',T24,'BN',T32,'POWER',T40,'CONTR.',
      'T48','TOTAL',T56,'L (CM)',/)
425  FORMAT(2(110,2F8.2,F11.3,2F8.4,F8.1,2X))
426  FORMAT(110,2F8.2,F11.3,2F8.4,F8.2)
455  FORMAT(10(2X,F6.2))
      RETURN
      END
      SUBROUTINE FILTER(X,Y,N,NDEC,AN,BN,DPOW,R,C,WLAM,FMEAN)
C *****
C THIS SUBPROGRAM PROCESSES THE DATA BEFORE AND AFTER SPECTRAL ANAL.
C IF MEASUREMENTS ARE NOT EQUALLY SPACED, THE PROGRAM GENERATES
C AN INTERPOLATED PROFILE WITH INTERVAL=DX, USING THE FUNCTION TERP1.
C *****
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 TLEN,CUT
      REAL*4 X(1),Y(1)
      REAL*4 YNS(1000),YORG(1000)
      REAL*4 XX(1000),YTEMP(1000)
      REAL*8 AN(1),BN(1),R(1),C(1)
      DIMENSION NDEC(1)
      DIMENSION F(1000),DPOW(1000),WLAM(1000)
      DIMENSION IL(2000),ILL(2000),ILLL(2000)
      COMPLEX*16 FN(1000)
      EQUIVALENCE (IL(1),ILL(1),ILLL(1))
      COMMON /SAME/TLEN,CUT
C ... INTERPOLATE TO HAVE EQUALLY SPACED DATA
C WRITE(6,720)
C WRITE(6,705) (X(1),Y(1),I=1,N)
C WRITE(6,700)
      DO 9 I=1,N
      YORG(I)=Y(1)
9  CONTINUE
      FINT=0.5
      XX(1)=X(1)
      F(1)=Y(1)
      DELTA=TLEN/(N-1)
      ABS18=X(1)
      DO 11 I=2,N
      ABS18=ABS18+DELTA
      XX(I)=ABS18
11  F(I)=TERP1(ABS18,X,Y,N,FINT)
C WRITE(9,705) (XX(I),F(I),I=1,N)
C ... REMOVE THE MEAN
      SUM=0.
      DO 10 I=1,N
10  SUM=SUM+F(I)
      FMEAN=SUM/N
C WRITE(6,715) FMEAN
      DO 15 I=1,N
15  F(I)=F(I)-FMEAN
C WRITE(6,721)

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 C00690
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 D00390
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 D00430
 D00440
 D00450

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C      WRITE(6,705)(XX(I),F(I),I=1,N)
C      WRITE(6,700)
C ... COMPUTE COMPLEX FOURIER COEFFICIENTS
C      CALL POWER(F,FN,NDEC,AN,BN,DPOW,R,C,WLAM,N)
C ... COMPUTE DATA VECTOR IN TIME DOMAIN
      NH=N/2
      NH1=NH+1
      NH2=NH+2

C ... FILTER OUT HIGH FREQUENCIES
C... SPLIT -FN(1)- AND -FN(NH1)- INTO HALF TO USE FOLLOWING LOGIC
      FN(1)=FN(1)/2.
      FN(NH1)=FN(NH1)/2.
      DO 16 I=2,NH1
      IF(DABS(WLAM(I)).LT.CUT)GO TO 100
16 CONTINUE
100 CONTINUE
      NHIGH=1
      IF(1.EQ.NH1)NHIGH=1+1
      DO 20 I=NHIGH,N
      FN(I)=(0.,0.)
20 CONTINUE
C ... COMPUTE INVERSE FOURIER TRANSFORM
C      CALL FFTP(FN,N,IL,ILL,ILL)
      DO 25 I=1,N
      FN(I)=FN(I)+DCONJG(FN(I))
25 CONTINUE
      DO 26 I=1,N
      F(I)=FN(I)+FMEAN
26 CONTINUE
      DO 30 I=1,N
      YTEMP(I)=F(I)
30 CONTINUE
      DO 35 I=1,N
      ABSIS=X(I)
      Y(I)=TERP1(ABSIS,XX,YTEMP,N,FINT)
35 CONTINUE
C      WRITE(6,700)
C      WRITE(6,722)
C      WRITE(6,705)(XX(I),Y(I),I=1,N)
C... COMPUTE FILTERED-OUT DATA 'YNS'
      DO 36 I=1,N
      YNS(I)=YORG(I)-F(I)
36 CONTINUE
C      WRITE(6,700)
C      WRITE(6,705)(XX(I),YNS(I),I=1,N)
C      WRITE(6,723)
700 FORMAT(////)
705 FORMAT(5(2F10.2,5X))
715 FORMAT(//,' MEAN VALUE =',F10.3,' MLNTR',//)
720 FORMAT(//,55X,'ORIGINAL DATA',//)
721 FORMAT( 55X,'REMOVED-MEAN DATA',//)
722 FORMAT( 55X,'FILTERED DATA',//)
723 FORMAT( 55X,'FILTERED-OUT DATA',//)
      RETURN
      END
      SUBROUTINE POWER(F,FN,NDEC,AN,BN,DPOW,R,C,WLAM,N)
      *****
      THIS SUBPROGRAM PERFORMS SPECTRAL ANALYSIS ON SURFACE ROUGHNESS
      MEASUREMENTS
      *****
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 CUT,TLEN
      DIMENSION F(1),DPOW(1),WLAM(1)
      DIMENSION AN(1000),BN(1000),NDEC(1000),S(1000),C(1000),R(1000)
      DIMENSION IWK(2000)
      COMPLEX*16 GAMN,FN(1)
      COMMON /SAME/TLEN,CUT

C .....
      NH=N/2
      NH1=NH+1
C ... COMPUTE THE VARIANCE OF THE SIGNAL
      VARI=0.
      DO 10 I=1,N
10 VARI=VARI+F(I)**2
      VARI=VARI/N
C ... COMPUTE COMPLEX FOURIER COEFFICIENTS OF -F- BY FFT
      CALL FFTP(F,GAMN,N,IWK)
C ... TAKE CONJUGATE OF OUTPUT AND DIVIDE BY N TO GET INV. FFT
      FN(1)=DCMPLX(F(1),-F(2))/N
      DO 15 I=2,NH

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 E00240
 E00250
 E00260
 E00270

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      I1=2*I
      FN(I)=DCMLPX(F(I1-1),-F(I1))/N
15  FN(N+2-1)=DCONJG(FN(I))
      FN(NH1)=DCONJG(GAMN)/N
C ... COMPUTE -AN- AND -BN- COEFFICIENTS
      AN(I)=FN(I)
      WLMN(I)=9
      DO 16 I=2,NH
      AN(I)=2.*FN(I)
      BN(I)=2.*DIMAG(FN(I))
      WLMN(I)=TLEN/(I-1)
16  CONTINUE
      AN(NH1)=FN(NH1)
      WLMN(NH1)=TLEN/NH
C ... COMPUTE DEGREE POWER, CONTRIBUTION ETC....
      VAR2=0.
      BN(I)=0.
      BN(NH1)=0.
      DO 17 I=1,NH1
      NDEG(I)=I-1
      DPOW(I)=(AN(I)**2+BN(I)**2)/2.D0
      IF(I.EQ.1.OR.I.EQ.NH1)DPOW(I)=2.*DPOW(I)
      VAR2=VAR2+DPOW(I)
      S(I)=VAR2
17  CONTINUE
      SUM=VAR2
      R(I)=0.
      C(I)=0.
      DO 20 I=2,NH1
      R(I)=DPOW(I)/VAR2
      C(I)=S(I)/VAR2
20  CONTINUE
C      WRITE(6,700)
C      WRITE(6,705)(NDEG(I),AN(I),BN(I),DPOW(I),R(I),C(I),WLMN(I),I=1,NH1
C      *)
C      DPOW(I)=FN(I)*DCONJG(FN(I))
C      WRITE(6,710)VAR1,VAR2
C .. FIND THE POWER FROM COMPLEX FOURIER COEFF. TO CHECK THE RESULT
      DO 25 I=2,NH
      DPOW(I)=2.*(FN(I)*DCONJG(FN(I)))
      DPOW(NH1)=FN(NH1)*DCONJG(FN(NH1))
25  CONTINUE
C      WRITE(9,700)
C      WRITE(9,705)(NDEG(I),AN(I),BN(I),DPOW(I),R(I),C(I),WLMN(I),I=1,NH1
C      *)
700  FORMAT(///,T6,'DEGREE',T16,'AN',T24,'BN',T32,'POWER',T40,'CONTR.',
* T48,'TOTAL',T56,'L (CM)',T69,'DEGREE',T79,'AN',T87,'BN',T95,'POWER
* ',T103,'CONTR.',T111,'TOTAL',T119,'L (CM)',/)
705  FORMAT(2(I10,2F8.2,F11.3,2F8.4,F8.1,2X))
710  FORMAT(/30X,'TOTAL POWER IN TIME DOMAIN=',F17.5,' MLNTR**2',/,30X,
* 'TOTAL POWER IN FREQ.DOMAIN=',F17.5,' MLNTR**2',/)
3  RETURN
END
FUNCTION TERP1(X,XI,Y1,N,F)
*****
THIS SUBPROGRAM PRODUCES AN EQUALLY SPACED PROFILE (IF
MEASUREMENTS WERE NOT SO)
*****
IMPLICIT REAL*8(A-H,O-Z)
REAL*4 XI(1),Y1(1)
X IS THE INDEPENDENT VARIABLE
XI IS AN ARRAY OF VALUES OF THE INDEPENDENT VARIABLE
Y1 IS AN ARRAY OF CORRESPONDING VALUES OF DEPENDENT VARIABLE
N IS THE SIZE OF THE ARRAYS
F IS A FACTOR FOR THE END SEGMENTS; BALANCE OF FIRST OND SECOND
ORDER INTERPOLATION
ALL VALUES OUTSIDE THE LIMITS OF THE ARRAY ARE COMPUTED BY
FIRST ORDER EXTRAPOLATION
FUNCTION RETURNS INTERPOLATED VALUE OF DEPENDENT VARIABLE
DIMENSION P(2),E(2),IS(4,2)
LOGICAL OUT
DATA IS /-1.0,-2,-1.0,1,-1.0/
OUT = .FALSE.
J=1

```

E00280
E00290
E00300
E00310
E00320
E00330
E00340
E00350
E00360
E00370
E00380
E00390
E00400
E00410
E00420
E00430
E00440
E00450
E00460
E00470
E00480
E00490
E00500
E00510
E00520
E00530
E00540
E00550
E00560
E00570
E00580
E00590
E00600
E00610
E00620
E00630
E00640
E00650
E00660
E00670
E00680
E00690
E00700
E00710
E00720
E00730
E00740
E00750
E00760
E00770
E00780
E00790
E00800
F00010
F00020
F00030
F00040
F00050
F00060
F00070
F00080
F00090
F00100
F00110
F00120
F00130
F00140
F00150
F00160
F00170
F00180
F00190
F00200
F00210
F00220

1	IF (N-2) 1,12,3	F00230
	TERP1=YI(J)	F00240
	RETURN	F00250
3	KPL=1	F00260
	KPU=2	F00270
	DO 4 J=1,N	F00280
7	IF (XI(J) - X) 4,1,6	F00290
4	CONTINUE	F00300
	J = N	F00310
	GO TO 2	F00320
6	IF (J-2) 12,8,9	F00330
8	KPL =2	F00340
	GO TO 10	F00350
9	IF (J - N) 10,11,2	F00360
12	J=2	F00370
2	OUT=.TRUE.	F00380
11	KPU=1	F00390
10	AL = (X-XI(J-1)) / (XI(J)-XI(J-1))	F00400
	TERP1=AL*YI(J)+(1.0-AL)*YI(J-1)	F00410
	IF (OUT) RETURN	F00420
	DO 16 KP=KPL,KPU	F00430
	P(KP)=0.0	F00440
	DO 15 K=1,3	F00450
	J0=J+KP + K - 4	F00460
	X0=XI(J0)	F00470
	Y0=YI(J0)	F00480
	J1=J+IS(K,KP)	F00490
	J2=J+IS(K+1,KP)	F00500
15	P(KP)=P(KP)+Y0*(X-XI(J1))/(X0-XI(J1))	F00510
*	*(X-XI(J2))/(X0-XI(J2))	F00520
	IF (KPL .NE. KPU) GO TO 16	F00530
	J1=3-KPL	F00540
	P(J1)=TERP1+F*(P(KP)-TERP1)	F00550
C	...	F00560
C	BE CAREFUL FOR FOLLOWING CARDS IF ..ABS..OR ..DABS...	F00570
	E(J1)=DABS(P(J1)-TERP1)	F00580
16	E(KP)=DABS(P(KP)-TERP1)	F00590
	IF (E(1)+E(2) .EQ. 0.0) RETURN	F00600
	TERP1=((E(1)*AL)*P(2)+(E(2)*(1.0-AL))*P(1)) /	F00610
*	((E(1)*AL) + (E(2)*(1.0-AL)))	F00620
	RETURN	F00630
	END	F00640
	SUBROUTINE RESDL(RSD,NP,RMEAN,STDEV)	C00010
C	*****	C00020
C	THIS SUBPROGRAM COMPUTES THE MEAN AND THE STANDARD DEVIATION OF	C00030
C	THE NORMALLY DISTRIBUTED RESIDUAL DATA.	C00040
C	*****	C00050
C		C00060
	DIMENSION RSD(200)	C00070
C	... COMPUTE MEAN	C00080
	SUM=0.0	C00090
	DO 101 I=1,NP	C00100
	SUM=SUM+RSD(I)	C00110
101	CONTINUE	C00120
	RMEAN=SUM/NP	C00130
C	... COMPUTE THE VARIANCE	C00140
	SUMV=0.0	C00150
	DO 102 I=1,NP	C00160
	SUMV=SUMV+(RSD(I)-RMEAN)*(RSD(I)-RMEAN)	C00170
102	CONTINUE	C00180
	VARV=SUMV/NP	C00190
	SD=VARV**0.5	C00200
	STDEV=ABS(SD)	C00210
	RETURN	C00220
	END	C00230


```

C      SUBROUTINE PARAM(D,P,ASR,ASH,RCH,HCH,EXD
C      *****
C      THIS SUBPROGRAM USES THE PROBLEM PARAMETERS TO COMPUTE THE MAIN
C      COEFFICIENTS IN EROSION EQUATIONS.
C      CAMA = UNIT WEIGHT OF SOIL
C      SC   = SPECIFIC WEIGHT OF SOIL
C      RO   = WATER DENSITY
C      G    = GRAVITY ACCELERATION
C      RN   = MANNING'S COEFFICIENT OF FRICTION
C      *****
C      COMMON /PROP/CAMA,RO,G,SC,RN
C      Z=((SC-1.)*G)**P*(D**(P-1))
C      RBETA=ASR/Z
C      HBETA=ASH/Z
C      X=(1.+2.*P)/2.
C      RCH=RBETA*(1.+2.*P)/2./RO**X
C      HCH=HBETA*(1.+2.*P)/2./RO**X
C      EX=(2.*P-1.)/2.
C      RETURN
C      END
C
C      SUBROUTINE RANDU(IX,IY,R)
C      *****
C      THIS SUBPROGRAM GENERATES A RANDOM NUMBER WITH VALUE 0.0 TO 1.0
C      FROM A UNIFORM DISTRIBUTION
C      *****
C      IY=IX*65539
C      IF(IY)5,6,6
C      IY=IY+2147483647+1
C      R=IY
C      R=R*.465613E-9
C      RETURN
C      END
C
C      SUBROUTINE RANORM(NMAX,RMEAN,STDEV,RY,NS)
C      *****
C      IT GENERATES NORMALLY DISTRIBUTED RANDOM NUMBERS FOR THE GIVEN
C      MEAN AND STANDARD DEVIATION
C      *****
C      DIMENSION RY(2000)
C      IF(NS.CT.1) GO TO 800
C      IX=123456789
C      DO 810 I=1,NMAX
C      SUM=0.0
C      DO 820 K=1,12
C      CALL RANDU(IX,IY,R)
C      IX=IY
C      SUM=SUM+R
C      820 CONTINUE
C      X=(SUM-6.0)*STDEV+RMEAN
C      RY(I)=X
C      810 CONTINUE
C      WRITE(6,12)(I,RY(I),I=1,NMAX)
C      12  FORMAT(15,5X,F10.6)
C      RETURN
C      END
C
C      SUBROUTINE EXMESH
C      *****
C      THIS SUBPROGRAM CALCULATES THE COORDINATES AND ASSIGNS CODES
C      FOR NODAL POINTS OF THE HEXAGONAL MESH
C      FOR BIFURCATION POINTS, CODE=2
C      FOR NON-BIFURCATION POINTS , CODE=1, AND
C      FOR OTHER POINTS CODE=0
C      THE X-Y PLANE COINCIDES WITH THE SLOPE SURFACE.
C      MESH DIMENSIONS ARE BASED ON CHARACTERISTICS OF BASIC WAVE
C      *****
C      DIMENSION XX(2000)
C      COMMON /MESH/NX,NY,NMAX,SL,SH,WL,QQ
C      COMMON /NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
C      ... COMPUTE X AND Y COORDINATES OF NODAL POINTS
C      NMAX=NX*NY
C      J=1
C      XX(J)=0

```

```

H00010
H00020
H00030
H00040
H00050
H00060
H00070
H00080
H00090
H00100
H00110
H00120
H00130
H00140
H00150
H00160
H00170
H00180
H00190
H00200
H00210
I00010
I00020
I00030
I00040
I00050
I00060
I00070
I00080
I00090
I00100
I00110
I00120
I00130
J00010
J00020
J00030
J00040
J00050
J00060
J00070
J00080
J00090
J00100
J00110
J00120
J00130
J00140
J00150
J00160
J00170
J00180
J00190
J00200
J00210
J00220
J00230
K00010
K00020
K00030
K00040
K00050
K00060
K00070
K00080
K00090
K00100
K00110
K00120
K00130
K00140
K00150
K00160
K00170
K00180

```

```

      NS=1
      NE=NY
11    DO 10 I=NS,NE,2
      K=I+1
      IF(1.EQ.1) GO TO 15
      IF(1.EQ.NS) GO TO 16
      IF(K.GT.NE) GO TO 17
      Y(I)=Y(I-1)+ SL
      Y(K)=Y(I)+2*SL
      X(K)=XX(J)
      X(I)=XX(J)
      GO TO 10
15    Y(1)=0
      Y(2)=Y(1)+2*SL
      X(1)=XX(J)
      X(2)=XX(J)
      GO TO 10
16    Y(NS)=0
      Y(NS+1)=Y(NS)+2*SL
      X(NS)=XX(J)
      X(NS+1)=XX(J)
      GO TO 10
17    Y(1)=Y(I-1)+ SL
      X(1)=X(I-1)
10    CONTINUE
      J=J+1
      IF(J.GT.NX) GO TO 1000
      XX(J)=XX(J-1)+WL/2.
      NE=NE+NY
      NS=NS+NY
      IF(NE.GT.NMAX) GO TO 1000
      GO TO 11
1000  M=NY
C ... ASSIGN CODES TO NODAL POINTS
      MAX=2*NY
      K=1
      DO 30 J=K,M,4
      DO 30 I=J,NMAX,MAX
      CODE(I)=2
30    CONTINUE
      M=2*NY
      K=NY+3
      DO 40 J=K,M,4
      DO 40 I=J,NMAX,MAX
      CODE(I)=2
40    CONTINUE
      M=NY
      K=2
      DO 50 J=K,M,4
      DO 50 I=J,NMAX,MAX
      CODE(I)=1
50    CONTINUE
      M=2*NY
      K=NY+4
      DO 60 J=K,M,4
      DO 60 I=J,NMAX,MAX
      CODE(I)=1
60    CONTINUE
      RETURN
      END

SUBROUTINE ELEVIN(SLOPE,AMP,RMEAN,STDEV,NS)
*****
THIS SUBPROGRAM CALCULATES THE ORIGINAL (PRE-EROSION) ELEVATIONS
OF NODAL POINTS
ELEVATION OF EACH NODAL POINT IS COMPUTED AS THE SUM OF THE
FOLLOWING COMPONENTS
1) FROM THE AVERAGE SLOPE
2) FROM THE BASIC WAVE,WY
3) RESIDUAL COMPONENT GENERATED RANDOMLY ,RY
*****
DIMENSION RY(2000)
COMMON/NEBH/NX,NY,NMAX,SL,SH,WL,QQ
COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
PI=22.0/7.0
THETA=SLOPE*PI/180

```

K00190
 K00200
 K00210
 K00220
 K00230
 K00240
 K00250
 K00260
 K00270
 K00280
 K00290
 K00300
 K00310
 K00320
 K00330
 K00340
 K00350
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 K00370
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 K00390
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 L00080
 L00090
 L00100
 L00110
 L00120
 L00130
 L00140
 L00150
 L00160
 L00170

	L=1	155
	PHI=PI*(1./6.)	L00180
	WY=AMP*SIN(PHI)*COS(THETA)	L00190
	DO 700 I=1,NMAX	L00200
700	RY(I)=0.0	L00210
	CALL RANORM(NMAX,RMEAN,STDEV,RY,NS)	L00220
C	CALL RANORM(NMAX,RMEAN,STDEV,RY,NS)	L00230
	DO 710 M=NY,NMAX,NY	L00240
	DO 720 I=L,M,4	L00250
	ELV(I)=Y(I)*SIN(THETA)-WY+RY(I)	L00260
	IF(Y(I).EQ.Y(NY)) GO TO 730	L00270
	ELV(I+1)=Y(I+1)*SIN(THETA)-WY+RY(I+1)	L00280
	IF(Y(I+1).EQ.Y(NY)) GO TO 730	L00290
	ELV(I+2)=Y(I+2)*SIN(THETA)+WY+RY(I+2)	L00300
	IF(Y(I+3).EQ.Y(NY)) ELV(I+3)=Y(I+3)*SIN(THETA)+WY+RY(I+3)	L00310
730	IF(Y(I).EQ.0) GO TO 720	L00320
	ELV(I-1)=Y(I-1)*SIN(THETA)+WY+RY(I-1)	L00330
720	CONTINUE	L00340
	L=L+NY	L00350
	WY=-WY	L00360
710	CONTINUE	L00370
C	WRITE(6,790)(I,X(I),Y(I),RY(I),ELV(I),I=1,NMAX)	L00380
790	FORMAT(10X,15,4F10.6)	L00390
	RETURN	L00400
	END	L00410
	SUBROUTINE HUMP(RMEAN,STDEV,SLOPE,AMP,NHUMP)	L00420
C	*****	M00010
C	THIS SUBPROGRAM COMPUTES COORDINATES AND ELEVATIONS OF CIRCULAR	M00020
C	HUMPS' CENTERS.	M00030
C	*****	M00040
C		M00050
	DIMENSION RHY(500)	M00060
	COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ	M00070
	COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)	M00080
	COMMON/HMPP/HMPP(500),XHMP(500),YHMP(500)	M00090
	COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),	M00100
	HMP6(500)	M00110
C		M00120
C ...	DETERMINE THE TOTAL NUMBER OF HUMPS ,NHUMP	M00130
	NZ=NY+1	M00140
	M1=NZ/4	M00150
	RM1=1.*NZ/4	M00160
	DM1=RM1-M1	M00170
	IF(DM1.GT.0.AND.DM1.LE.0.5) GO TO 1210	M00180
	GO TO 1220	M00190
1210	NHUMP=M1*NX	M00200
	GO TO 1225	M00210
1220	N1=NX/2	M00220
	RN1=1.*NX/2.0	M00230
	DN1=RN1-N1	M00240
	IF(DM1.EQ.0) GO TO 1230	M00250
	IF(DN1.EQ.0) GO TO 1231	M00260
	NHUMP=2*M1*N1+N1+M1	M00270
	GO TO 1225	M00280
1231	NHUMP=N1*(2*M1+1)	M00290
	GO TO 1225	M00300
1230	IF(DN1.EQ.0) GO TO 1235	M00310
	NHUMP=2*N1*M1-N1+M1-1	M00320
	GO TO 1225	M00330
1235	NHUMP=N1*(2*M1-1)	M00340
	GO TO 1225	M00350
1225	CONTINUE	M00360
C		M00370
C ...	COMPUTE X AND Y COORDINATES	M00380
	K=1	M00390
	DO 1250 I=1,NMAX	M00400
	IF(CODE(I)-1) 1260,1270,1270	M00410
1270	GO TO 1250	M00420
1260	IF(CODE(I-1).NE.0) GO TO 1250	M00430
	IF(Y(I-1).EQ.Y(NY)) GO TO 1250	M00440
	XHMP(K)=X(I)	M00450
	YHMP(K)=(Y(I)+Y(I-1))/2.0	M00460
	K=K+1	M00470
1250	CONTINUE	M00480
C		M00490
C ...	COMPUTE ELEVATIONS	M00500
	CALL RANORM(NHUMP,RMEAN,STDEV,RHY)	M00510
C	CALL RANORM(NHUMP,RMEAN,STDEV,RHY)	M00520
		M00530

```

      A=AMP*COS(SLOPE*22./7./180.)
      DO 1280 I=1,NHUMP
        HHMP(I)=(YHMP(I)+2.*SL)*SIN(SLOPE*22./7./180.)+A +RHY(I)
1280  CONTINUE
C      WRITE(6,1290)(I,XHMP(I),YHMP(I),HHMP(I), I=1,NHUMP)
1290  FORMAT(15,3F20.6)
C
C ... COMPUTE "FICTICIOUS" ELEVATIONS OF THE HUMP CENTER FOR EACH OF
C THE SIX SIDES OF THE "PYRAMID"
      DO 1295 I=1,NHUMP
        HMP1(I)=HHMP(I)
        HMP2(I)=HHMP(I)
        HMP3(I)=HHMP(I)
        HMP4(I)=HHMP(I)
        HMP5(I)=HHMP(I)
        HMP6(I)=HHMP(I)
1295  CONTINUE
      RETURN
      END
      SUBROUTINE 1DHMP(NY,I,IDL,IDR,IDC)
C *****
C THIS SUBPROGRAM IDENTIFIES THE HUMPS ASSOCIATED WITH DIFFERENT
C RILL SEGMENTS
C IDL=CALL# OF HUMP LEFT OF I
C IDR=CALL# OF HUMP RIGHT OF I
C IDC=CALL# OF HUMP BELOW I (IF CODE(I)=2)
C NC= # COMPLETE MESH COLUMNS BEFORE I
C NHB=# OF HUMPS BELOW I
C *****
      COMMON NT
      NZ=NY+1
      M=NZ/4
      RM=1.*NZ/4.
      DM=RM-M
      KD=DM*4+1
      NC=I/NY
      RNC=(1.*I)/(1.*NY)
      IF(RNC.GT.NC) GO TO 1501
      NC=NC-1
1501  NHB=((1+NC+1)-(NC*NZ))/4
      IF(1.LT.NY) GO TO 1505
      INC=NC/2
      RRNC=1.*NC/2.
      IF(RRNC.EQ.INC) GO TO 1505
      GO TO (1510,1515,1515,1520),KD
1510  IDL=(NC-1)/2*M+(NC-1)/2*(M-1)+NHB
      GO TO 1530
1515  IDL=(NC-1)*M+NHB
      GO TO 1535
1520  IDL=(NC-1)/2*(M+1)+(NC-1)/2*M+NHB
      GO TO 1540
1530  IDR=(NC+1)/2*M+(NC+1)/2*(M-1)+NHB
      GO TO 1550
1535  IDR=(NC+1)*M+NHB
      GO TO 1555
1540  IDR=(NC+1)/2*(M+1)+(NC+1)/2*M+NHB
      GO TO 1560
1550  IDC=(NC/2+1)*(M-1)+(NC/2)*M+NHB
      GO TO 1595
1555  IDC=NC*M+NHB
      GO TO 1595
1560  IDC=(NC/2+1)*M+NC/2*(M+1)+NHB
      GO TO 1595
1565  GO TO (1570,1575,1575,1580),KD
1570  IDL=((NC-1)/2+1)*(M-1)+(NC-1)/2*M+NHB+1
      GO TO 1573
1575  IDL=(NC-1)*M+NHB+1
      GO TO 1578
1580  IDL=((NC-1)/2+1)*M+(NC-1)/2*(M+1)+NHB+1
      GO TO 1585
1573  IDR=((NC+1)/2+1)*(M-1)+(NC+1)/2*M+NHB+1

```

N00540
 N00550
 N00560
 N00570
 N00580
 N00590
 N00600
 N00610
 N00620
 N00630
 N00640
 N00650
 N00660
 N00670
 N00680
 N00690
 N00700
 N00710
 N00720
 N00010
 N00020
 N00030
 N00040
 N00050
 N00060
 N00070
 N00080
 N00090
 N00100
 N00110
 N00120
 N00130
 N00140
 N00150
 N00160
 N00170
 N00180
 N00190
 N00200
 N00210
 N00220
 N00230
 N00240
 N00250
 N00260
 N00270
 N00280
 N00290
 N00300
 N00310
 N00320
 N00330
 N00340
 N00350
 N00360
 N00370
 N00380
 N00390
 N00400
 N00410
 N00420
 N00430
 N00440
 N00450
 N00460
 N00470
 N00480
 N00490
 N00500
 N00510
 N00520
 N00530

```

      GO TO 1574
1578 IDR=(NC+1)*M+NHB+1
      GO TO 1579
1585 IDR=((NC+1)/2+1)*M+(NC+1)/2*(M+1)+NHB+1
      GO TO 1590
1574 IDC=(NC/2)*M+(NC/2)*(M-1)+NHB
      GO TO 1595
1579 IDC=NC*M+NHB
      GO TO 1595
1590 IDC=(NC/2)*(M+1)+(NC/2)*M+NHB
1595 CONTINUE
      RETURN
      END
      SUBROUTINE FLOW(RNL,RNF)
      *****
      FLOW RATE IN A RILL SEGMENT IS THE SUM OF :
      1) DIRECT RAINFALL ON SURFACES OF RILL AND INTERRILL AREAS ,AND
      2) FLOW ARRIVING FROM AREA UPSLOPE

      AT A BIFURCATION POINT THE FLOW IS DEVIDED BETWEEN THE LEFT AND
      THE RIGHT BRANCH ACCORDING TO THE RELATIVE MAGNITUDES OF BED
      SLOPES RAISED TO THE POWER OF 0.5 .

      QT(1) IS THE AMOUNT OF WATER ACCUMULATED AT POINT 1
      QR(1) IS THE AMOUNT OF WATER BRANCHING OUT FROM POINT 1
      QL(1) IS THE AMOUNT OF WATER BRANCHING OUT FROM POINT 1
      FLOW QUANTITY IS IN CUBIC METERS/SEC.

      IF A "LOW" HUMP OCCURS, THE FLOW IS REDISTRIBUTED IN (RDISTB).
      *****

      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)
      COMMON/HMPP/BHMP(500),XHMP(500),YHMP(500)
      COMMON/QFLOW/QT(2000),QL(2000),QR(2000)
      COMMON NT

      COMPUTE RAINFALL FLOW RATE / UNIT TIME / UNIT AREA :

      QQ=(RNF*RNL)/(3.6*10**6)
      DQ IS THE AMOUNT OF WATER DRAINED TO A RILL SEGMENT FROM BOTH SIDES
      PER UNIT TIME.
      DQ=2.*QQ*SL*SL*(3.**0.5)

      COMPUTE TOTAL FLOW RATE AT EACH NODAL POINT :

      DO 901 L=1,NY
      K=NY+(1-L)
      DO 901 I=K,NMAX,NY
      IF(CODE(I)-1) 902,903,904

      POINTS WITH CODE=0 :

902 QR(1)=0
      QL(1)=0
      QT(1)=0
      GO TO 901

      POINTS WITH CODE=1 :

903 IF(Y(1).LT.Y(NY)) GO TO 905
      GO TO 902
905 IF(X(1).EQ.0) GO TO 915
      SLL=(ELV(1-NY+1)-ELV(1))/2.0/SH
      IF(X(1).EQ.X(NMAX)) GO TO 907
915 SLR=(ELV(1+NY+1)-ELV(1))/2.0/SH
      IF(X(1).EQ.0) GO TO 906
      IF(X(1).GE.X(NMAX)) GO TO 907
      IF(SLL.LE.0.AND.SLR.LE.0) GO TO 908
      IF(SLL.LE.0.AND.SLR.GT.0) GO TO 909
      IF(SLL.GT.0.AND.SLR.LE.0) GO TO 910
      QT(1)=QT(1)+QR(1-NY+1)+QL(1+NY+1)+2*DQ
      CALL RDISTB(1,CODE(1))
      GO TO 901
908 QT(1)=0

```

N00540
 N00550
 N00560
 N00570
 N00580
 N00590
 N00600
 N00610
 N00620
 N00630
 N00640
 N00650
 N00660
 000010
 000020
 000030
 000040
 000050
 000060
 000070
 000080
 000090
 000100
 000110
 000120
 000130
 000140
 000150
 000160
 000170
 000180
 000190
 000200
 000210
 000220
 000230
 000240
 000250
 000260
 000270
 000280
 000290
 000300
 000310
 000320
 000330
 000340
 000350
 000360
 000370
 000380
 000390
 000400
 000410
 000420
 000430
 000440
 000450
 000460
 000470
 000480
 000490
 000500
 000510
 000520
 000530
 000540
 000550
 000560
 000570
 000580
 000590
 000600
 000610
 000620
 000630

```

GO TO 901                                000640
909 QT(I)=QT(I)+QR(I-NY+1)+DQ             000650
    CALL RDISTB(I, CODE(I))               000660
GO TO 901                                000670
910 QT(I)=QT(I)+QL(I+NY+1)+DQ             000680
    CALL RDISTB(I, CODE(I))               000690
GO TO 901                                000700
906 IF(SLR.LE.0.0) GO TO 911              000710
    QT(I)=QT(I)+QL(I+NY+1)+DQ             000720
    CALL RDISTB(I, CODE(I))               000730
GO TO 901                                000740
911 QT(I)=0.0                             000750
GO TO 901                                000760
907 IF(SLL.LE.0.0) GO TO 911              000770
    QT(I)=QT(I)+QR(I-NY+1)+DQ             000780
    CALL RDISTB(I, CODE(I))               000790
GO TO 901                                000800
C C C POINTS OF CODE=2 (BIFURCATION POINTS) : 000810
904 IF(Y(I).EQ.Y(NY)) GO TO 902           000820
    SLM=(ELV(I+1)-ELV(I))/2.0/SH          000830
    IF(SLM.GT.0) GO TO 916                000840
    QT(I)=0                               000850
    GO TO 902                              000860
916 IF(X(I).EQ.0) GO TO 930               000870
    IF(X(I).EQ.X(NMAX)) GO TO 940         000880
    QT(I)=QT(I)+QT(I+1)+DQ               000890
    SLL=(ELV(I)-ELV(I-NY-1))/2.0/SH      000900
    SLR=(ELV(I)-ELV(I+NY-1))/2.0/SH      000910
    IF(SLL.LE.0.AND.SLR.LE.0) GO TO 920   000920
    IF(SLL.GT.0.AND.SLR.GT.0) GO TO 921   000930
    IF(SLL.GT.0.AND.SLR.LT.0) GO TO 922   000940
    SLL1=(ELV(I-NY-1)-ELV(I-NY-2))/2.0/SH 000950
    SLR2=(ELV(I+NY-1)-ELV(I+NY-2))/2.0/SH 000960
    SLAV=(SLL+SLL1)/2.                   000970
    IF(SLAV.LT.0.0) SLAV=0.0              000980
    SRAV=(SLR+SLR1)/2.                   000990
    IF(SRAV.LT.0.0) SRAV=0.0              001000
    SQR=SLAV**0.5+ SRAV**0.5              001010
    QL(I)=QL(I)+QT(I)*((SLAV**0.5)/SQR)   001020
    QR(I)=QR(I)+QT(I)*((SRAV**0.5)/SQR)   001030
    CALL RDISTB(I, CODE(I))               001040
GO TO 901                                001050
920 QL(I)=0                               001060
    QR(I)=0                               001070
GO TO 901                                001080
921 QL(I)=0                               001090
    QR(I)=QR(I)+QT(I)                    001100
    CALL RDISTB(I, CODE(I))               001110
GO TO 901                                001120
922 QR(I)=0                               001130
    QL(I)=QL(I)+QT(I)                    001140
    CALL RDISTB(I, CODE(I))               001150
GO TO 901                                001160
930 QT(I)=QT(I)+QT(I+1)+DQ               001170
    SLR=(ELV(I)-ELV(I+NY-1))/2.0/SH      001180
    SLL=0.0                               001190
    QL(I)=0.0                             001200
    IF(SLR.GT.0) GO TO 932                001210
    QR(I)=0.0                             001220
GO TO 901                                001230
932 QR(I)=QR(I)+QT(I)                    001240
    CALL RDISTB(I, CODE(I))               001250
GO TO 901                                001260
940 QT(I)=QT(I)+QT(I+1)+DQ               001270
    SLL=(ELV(I)-ELV(I-NY-1))/2.0/SH      001280
    SLR=0.0                               001290
    QR(I)=0.0                             001300
    IF(SLL.GT.0) GO TO 942                001310
    QL(I)=0.0                             001320
GO TO 901                                001330
942 QL(I)=QL(I)+QT(I)                    001340
    CALL RDISTB(I, CODE(I))               001350
901 CONTINUE                             001360
    IF(NT.NE.1) RETURN                    001370
C WRITE(6,990)(I,X(I),Y(I),CODE(I),QR(I),QL(I),QT(I), I=1,NMAX) 001380
990 FORMAT(2X,15,6F20.8)                 001390
RETURN                                     001400
END                                         001410
                                           001420
                                           001430

```

```

C      SUBROUTINE RDISTB(1,CKODE)
C      *****
C      THIS SUBPROGRAM CHECKS THE EXISTANCE OF NEGATIVE SIDE SLOPES
C      RESULT FROM BUMPS DEPRESSED BY FAILURE MECHANISM. THE PROGRAM
C      THEN REDISTRIBUTES THE QUANTITY OF WATER AMONG NODAL POINTS. THIS
C      PROCESS IS REPEATED BEFORE EVERY TIME INTERVAL.
C      *****
C      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
C      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
C      COMMON/HMPP/HMPP(500),XHMP(500),YHMP(500)
C      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)
C      COMMON/QFLOW/QT(2000),QL(2000),QR(2000)
C      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),
C      * HMP6(500)
C      COMMON NT
C      IF(Y(1).EQ.0.0) GO TO 100
C      IF(CKODE-1.0) 100,200,300
200  AELV=(ELV(1)+ELV(1-1))/2.
      SO=(ELV(1)-ELV(1-1))/2./SH
      CALL IDHMP(NY,1,IDL,IDR,IDC)
      IF(X(1).EQ.0.0) GO TO 210
      IF(X(1).EQ.X(NMAX)) GO TO 220
      S1=(HMP4(IDL)-AELV)/SH/3.**0.5
      S2=(HMP1(IDR)-AELV)/SH/3.**0.5
20  FORMAT(/,' SLOPES :',15,3F20.6)
      AS1=ABS(S1)
      AS2=ABS(S2)
      IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 100
      IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 215
      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 225
1  CONTINUE
      NK=1-2*NY
      NV=1
      F=0.5
      KK=1
      HHH=(ELV(NK)+ELV(NK-1))/2.
      IF(HHH.GT.HMP1(IDL)) QT(NV)=0.0
      GO TO 2000
211  NK=1+2*NY
      NV=1
      F=0.5
      KK=2
      GO TO 2000
215  IF(SO.GE.AS1) GO TO 290
      NK=1-2*NY
      NV=1
      F=1.0
      KK=2
      HHH=(ELV(NK)+ELV(NK-1))/2.
      IF(HHH.GT.HMP1(IDL)) QT(NV)=0.0
      GO TO 2000
225  IF(SO.GE.AS2) GO TO 290
      NK=1+2*NY
      NV=1
      F=1.0
      KK=2
      GO TO 2000
210  S2=(HMP1(IDR)-AELV)/SH/3.**0.5
      AS2=ABS(S2)
      IF(S2.LE.0.0) GO TO 225
      GO TO 100
220  S1=(HMP4(IDL)-AELV)/SH/3.**0.5
      AS1=ABS(S1)
      IF(S1.LE.0.0) GO TO 215
      GO TO 100
2000  QT(NK)=QT(NK)+F*QT(NV)
      IF(KK.EQ.1) GO TO 211
      QT(NV)=0.0
290  IF(SO.LE.0.0) GO TO 100
      NAJ(1)=NAJ(1)-1
      NAJ(1-1)=NAJ(1-1)-1
      GO TO 100
300  CALL IDHMP(NY,1,IDL,IDR,IDC)
10  FORMAT(/,15,3F20.8,/)
      IF(X(1).EQ.0.0) GO TO 400
      AELV=(ELV(1)+ELV(1-NY-1))/2.

```

P00010
P00020
P00030
P00040
P00050
P00060
P00070
P00080
P00090
P00100
P00110
P00120
P00130
P00140
P00150
P00160
P00170
P00180
P00190
P00200
P00210
P00220
P00230
P00240
P00250
P00260
P00270
P00280
P00290
P00300
P00310
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P00330
P00340
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P00360
P00370
P00380
P00390
P00400
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P00500
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P00620
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P00640
P00650
P00660
P00670
P00680
P00690
P00700
P00710
P00720
P00730
P00740
P00750
P00760
P00770

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SOL=(ELV(1)-ELV(1-NY-1))/2./SH
S2=(HMP2(IDC)-AELV)/SH/3.**0.5
IF(Y(1).EQ.Y(NY)) HMP5(IDL)=HMP2(IDC)
S1=(HMP5(IDL)-AELV)/SH/3.**0.5
AS1=ABS(S1)
AS2=ABS(S2)
IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 400
IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 315
IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 325
NK=1-NY+2
NV=1
IF(Y(NV).GE.Y(NY-1)) NK=NHAX+5
IF(X(NV).EQ.X(NY+1)) NK=NHAX+5
F=0.5
KK=1
HHH=(ELV(NK)+ELV(NK-NY-1))/2.
IF(HHH.GT.HMP2(IDL)) QL(NV)=0.0
GO TO 3000
NK=1+NY-2
NV=1
F=0.5
KK=2
GO TO 3000
IF(SOL.GE.AS1) GO TO 390
NK=1-NY+2
NV=1
IF(Y(NV).GE.Y(NY-1)) NK=NHAX+5
IF(X(NV).EQ.X(NY+1)) NK=NHAX+5
F=1.0
KK=2
HHH=(ELV(NK)+ELV(NK-NY-1))/2.
IF(HHH.GT.HMP2(IDL)) QL(NV)=0.0
GO TO 3000
IF(SOL.GE.AS2) GO TO 390
NK=1+NY-2
NV=1
F=1.0
KK=2
QL(NK)=QL(NK)+F*QL(NV)
QL(NV)=0.0
IF(KK.EQ.1) GO TO 311
IF(SOL.LE.0.0) GO TO 400
NAJ(1)=NAJ(1)-1
NAJ(1-NY-1)=NAJ(1)-1
IF(X(1).EQ.X(NMAX)) GO TO 100
IF(Y(1).EQ.Y(NY)) HMP6(IDR)=HMP3(IDC)
AELV=(ELV(1)+ELV(1+NY-1))/2.
SOR=(ELV(1)-ELV(1+NY-1))/2./SH
S1=(HMP3(IDC)-AELV)/SH/3.**0.5
S2=(HMP6(IDR)-AELV)/SH/3.**0.5
AS1=ABS(S1)
AS2=ABS(S2)
IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 100
IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 415
IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 425
NK=1-NY-2
NV=1
IF(Y(NV).GE.Y(NY-1)) NK=NHAX+5
IF(X(NV).EQ.X(NY+1)) NK=NHAX+5
F=0.5
KK=1
GO TO 4000
NK=1+NY+2
NV=1
IF(Y(NV).GE.Y(NY-1)) NK=NHAX+5
IF(X(NV).EQ.X(NY+1)) NK=NHAX+5
F=0.5
KK=2
HHH=(ELV(NK)+ELV(NK+NY-1))/2.
IF(HHH.GT.HMP3(IDR)) QR(NV)=0.0
GO TO 4000
IF(SOR.GE.AS1) GO TO 490
NK=1-NY-2
NV=1
F=1.0
KK=2
GO TO 4000

```

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P00780
P00790
P00800
P00810
P00820
P00830
P00840
P00850
P00860
P00870
P00880
P00890
P00900
P00910
P00920
P00930
P00940
P00950
P00960
P00970
P00980
P00990
P01000
P01010
P01020
P01030
P01040
P01050
P01060
P01070
P01080
P01090
P01100
P01110
P01120
P01130
P01140
P01150
P01160
P01170
P01180
P01190
P01200
P01210
P01220
P01230
P01240
P01250
P01260
P01270
P01280
P01290
P01300
P01310
P01320
P01330
P01340
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P01370
P01380
P01390
P01400
P01410
P01420
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P01440
P01450
P01460
P01470
P01480
P01490
P01500
P01510
P01520
P01530
P01540

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425 IF(SOR.GE.AS2) GO TO 490
    NK=I+NY+2
    NV=1
    IF(Y(NV).GE.Y(NY-1)) NK=NMAX+5
    IF(X(NV).EQ.X(NY+1)) NK=NMAX+5
    F=1.0
    KK=2
    HHH=(ELV(NK)+ELV(NK+NY-1))/2.
    IF(HHH.GT.HMP3(IDR)) QR(NV)=0.0
4000 QR(NK)=QR(NK)+F*QR(NV)
    QR(NV)=0.0
    IF(KK.EQ.1) GO TO 411
490 IF(SOR.LE.0.0) GO TO 100
    NAJ(1)=NAJ(1)-1
    NAJ(I+NY-1)=NAJ(I+NY-1)-1
100 CONTINUE
500 FORMAT(/,120(' '),/)
990 FORMAT(2X,15,6F20.8)
    RETURN
END
SUBROUTINE SFAILR(SLIMIT,SSTART)
*****
C THIS SUBPROGRAM CHECKS THE STABILITY OF SIDESLOPES OF ALL RILL
C SEGMENTS BEFORE EVERY TIME INTERVAL.
C SLIMIT=THE UPPER LIMIT A SIDESLOPE CAN REACH BEFORE FAILURE
C SSTART= THE STARTING VALUE OF THE SIDESLOPE AFTER FAILURE
C DSDT= THE VOLUME OF THE SOIL CHUNK SEPARATED DUE TO FAILURE
C NOTE: AT THE PRESENT STAGE DSDT IS NOT ADDED TO THE AMOUNT OF
C SOIL ERODED . I. E. DSDT=0.
C *****
COMMON/MESH/NX,NY,NMAX,SL,SH,WL,GQ
COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
COMMON/HMPP/HMPP(500),XHMP(500),YHMP(500)
COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),
    HMP6(500)
COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)
COMMON NT
16 FORMAT(15,2F20.6,/)
10 FORMAT(15,3F10.5)
15 FORMAT(15,F10.5)
1000 FORMAT(3110,2F10.5,/)
    BETA=ATAN(SSTART)
    PHI=ATAN(SLIMIT)-BETA
    DY=SH*(SLIMIT-SSTART)*3.**0.5*COS(BETA)
    DSDT=SH*SH*SH*(SLIMIT-SSTART)
    DSDT=0.0
    DO 100 J=1,NY
        K=NY+(1-J)
        DO 100 I=K,NMAX,NY
            IF(Y(1).EQ.0.0) GO TO 100
            IF(CODE(1)-1) 100,200,300
200 AELV=(ELV(1)+ELV(1-1))/2.
            CALL IDHMP(NY,1,IDL,IDR,IDC)
            IF(X(1).EQ.0.0) GO TO 210
            IF(X(1).EQ.X(NMAX)) GO TO 220
            S1=(HMP4(IDL)-AELV)/SH/(3.**0.5)
            S2=(HMP1(IDR)-AELV)/SH/(3.**0.5)
230 IF(S1.LT.SLIMIT) GO TO 205
            HMP4(IDL)=HMP4(IDL)-(S1-SSTART)*SH*3.**0.5
            SDT(1)=SDT(1)+DSDT
            TIRE(1)=TIRE(1)+DSDT
205 IF(S2.LT.SLIMIT) GO TO 100
            HMP1(IDR)=HMP1(IDR)-(S2-SSTART)*SH*3.**0.5
            SDT(1)=SDT(1)+DSDT
            TIRE(1)=TIRE(1)+DSDT
            GO TO 100
210 S2=(HMP1(IDR)-AELV)/SH/3.**0.5
            S1=S2
            GO TO 230
220 S1=(HMP4(IDL)-AELV)/SH/3.**0.5
            S2=S1
            GO TO 230

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```

50  KPND(1)=2
    GO TO 10
45  KPND(1)=11
    GO TO 10
35  DZR=ELV(1)-ELV(1+NY-1)
    IF(DZR.GT.0.0) GO TO 10
    GO TO 45
40  DZL=ELV(1)-ELV(1-NY-1)
    IF(DZL.GT.0.0) GO TO 10
    GO TO 45
10  CONTINUE
    RETURN
    END
SUBROUTINE ACJNT
C *****
C THIS SUBPROGRAM COMPUTES THE NUMBER OF RILL SEGMENTS AT EACH
C NODAL POINT
C *****
COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)
COMMON NT
DO 10 I=1,NMAX
  IF(CODE(I)-1) 10,20,30
20  IF(Y(I).EQ.Y(NY)) GO TO 15
  IF(X(I).EQ.0.0.OR.X(I).EQ.X(NMAX)) GO TO 25
  NAJ(I)=3
  GO TO 10
15  NAJ(I)=1
  GO TO 10
25  NAJ(I)=2
  GO TO 10
30  IF(Y(I).EQ.0.0) GO TO 15
  IF(Y(I).EQ.Y(NY)) GO TO 35
  IF(X(I).EQ.X(NMAX).OR.X(I).EQ.0.0) GO TO 25
  NAJ(I)=3
  GO TO 10
35  IF(X(I).NE.0.0.AND.X(I).NE.X(NMAX)) GO TO 25
  GO TO 15
10  CONTINUE
C  WRITE(6,5)(I,X(I),Y(I),          CODE(I),KPND(I),NAJ(I),I=1,NMAX)
5  FORMAT(15,3F20.5,2I5)
    RETURN
    END
SUBROUTINE CSEC(SL,Q,S1,S2,S0,H,B,C1)
C *****
C THIS SUBPROGRAM COMPUTES DEPTH AND BREADTH OF THE FLOW AT ANY
C NODAL POINT. COMPUTATIONS ARE BASED ON MANNING'S FORMULA.
C FLOW MEAN VELOCITY AND VELOCITY HEAD ARE ALSO COMPUTED HERE.
C *****
COMMON /PROP/GAMA,RO,G,SG,RN
COMMON NT
THETA1=ATAN(S1)
THETA2=ATAN(S2)
C1=1/S1+1/S2
C2=1/SIN(THETA1)+1/SIN(THETA2)
C3=C1/C2
CC=2.**(5./3.)*RN/C1/C3**(2./3.)
H=(CC/S0**0.5)**0.375*Q**0.375
C
C CHECK FOR OVERFLOW
HM1=S1*SL*(3.**0.5)
HM2=S2*SL*(3.**0.5)
IF(HM1.LT.HM2) GO TO 1710
HMAX=HM2
GO TO 1720
1710 HMAX=HM1
1720 IF(B.GT.HMAX) H=HMAX
    B=H*C1
    RH=0.5*B*C3
    V=1./RN *(RH**(2./3.)) * S0**0.5
    EC=V*V/2./G
C  WRITE(6,10) V,EC
10  FORMAT(/,10X,'VELOCITY=',F12.8,10X,'ENERGY=',F12.8,/)
    RETURN
    END

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```

C      SUBROUTINE RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,T1,TE,DE)
C      *****
C      THIS SUBPROGRAM COMPUTES THE AMOUNT OF MATERIAL ERODED FROM
C      A RILL SEGMENT (RILL EROSION).
C      COMPUTATIONS ARE BASED ON THE ASSUMPTION OF UNIFORM RILL FLOW.
C      K A L I N S K E 'S BED LOAD FORMULA IS USED AS THE SEDIMENT
C      PICK-UP CRITERION.
C      DE = THE REDUCTION IN BED ELEVATION DUE TO EROSION.
C      *****
C      REAL*4 TE,DE
C      COMMON /PROP/CAMA,RO,G,SG,RN
C      COMMON NT
C      TAU1=CAMA*C1*SO*H1*H1/2.
C      TAU2=CAMA*C1*SO*H2*H2/2.
C      XL=2.*SL
C      E= RCH*(TAU2-TAU1)/XL*((TAU2+TAU1)/2.)*EX*60
C ... E= EROSION RATE IN CUBIC METERS/METER LENGTH/MINUTE
C      TE=E*XL*T1
C ... TE IS DEDUCTED UNIFORMLY ALONG THE RILL LENGTH
C      KF=2
C      WD=2.*SL*3.**0.5
30    BB=(B1+B2)/2.*KF
      IF(BB.GT.0.0) GO TO 40
      DE=0.0
      RETURN
40    IF(BB.GT.WD) GO TO 35
      DE=2.*TE/SH/BB
      GO TO 50
35    KF=KF-1
      IF(KF.LT.1) KF=1
      GO TO 30
50    RETURN
      END
C      SUBROUTINE HERSN(QQ,SL,EM,EH,HCH,B1,B2,H1,H2,EX,T1,TEH)
C      *****
C      THIS SUBPROGRAM COMPUTES THE AMOUNT OF MATERIAL ERODED FROM SIDE
C      HUMPS OF ANY RILL SEGMENT (INTERRILL AREAS).
C      COMPUTATIONS ARE BASED ON THE ASSUMPTION OF UNIFORM SHEET FLOW
C      OVER AN EQUIVALENT RECTANGULAR AREA.
C      K A L I N S K E 'S BED LOAD FORMULA IS USED AS THE SEDIMENT
C      PICK-UP CRITERION.
C      *****
C      REAL*4 EM,EH,TEH
C      COMMON /PROP/CAMA,RO,G,SG,RN
C      COMMON NT
C      ZRO=1/(10.**20.)
C      IF(B1.GE.1000..AND.B2.GE.1000.) GO TO 30
C      XH=SL*(3.**0.5)
C      HH=EH-EM
C      SO=(EH-EM)/XH
C      THETA=ATAN(SO)
C      ZL=HH/SIN(THETA)
C      HAV=(H1+H2)/2.
C      RL=ZL-HAV/SIN(THETA)
C      IF WATER OVERFLOWS ON THIS SIDE ,THEN N EROSION WILL TAKE
C      PLACE ON IT.
C      IF(RL.LE.0.0) GO TO 100
C      YL=2.*RL*SL/ZL
C      XL=RL/2.
50    Q=QQ*XL
      Y=(RN*Q/SO**0.5)**0.6
      TAU=CAMA*Y*SO
      E=HCH*TAU/XL*(TAU/2.)*EX*60.
      TEH=E*XL*YL*T1
10    FORMAT(7F15.8)
      RETURN
100   TEH=0.0
      RETURN
30    SO=ABS(H1)
      IF(SO.LE.ZRO) RETURN
      XL=0.5*SL
      YL=2.*SL
      GO TO 50
      END

```

```

C      SUBROUTINE ERSN(I,QTT,ECH,NCH,EX,TI)
C      *****
C      THIS SUBPROGRAM PERFORMS EROSION COMPUTATIONS ON RILL SEGMENTS
C      WITH UP-STREAM POINT HAVING CODE=1 .
C      S1 = SLOPE OF THE LEFT SIDE OF THE RILL SIDE WALLS
C      S2 = SLOPE OF THE RIGHT SIDE OF THE RILL SIDE WALLS
C      Q1 = FLOW RATE AT UPSTREAM END OF THE RILL SEGMENT
C      Q2 = FLOW RATE AT DOWNSTREAM END OF THE RILL SEGMENT
C      SDT(I),TRE(I),TIRE(I) ARE DEFINED IN MAIN PCM
C      DH(I) = CHANGE IN ELEVATION OF I AT THE END OF A TIME INTERVAL
C      *****
C      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
C      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
C      COMMON/HMPP/HMPP(500),XHMP(500),YHMP(500)
C      COMMON/POND/KPND(2000),NAJ(2000),DH(2000)
C      COMMON/SDMT/SDT(2000),TRE(2000),TIRE(2000)
C      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),
C      HMP6(500)
C      COMMON /PROP/GAMA,RO,G,SG,RN
C      COMMON NT
C      ZRO=1.0/(10.0**20.)
C      KODE=1
C      DE=0.0
C      TE=0.0
C      E1=ELV(I)
1015 E2=ELV(I-1)
C      AELV=(E1+E2)/2.
C
C      ... IDENTIFY HUMPS ON LEFT AND ON RIGHT
C      CALL IDHMP(NY,1,IDL,IDR,NDUMY)
C      IF(X(1).EQ.0) GO TO 1020
C      IF(X(1).EQ.X(NMAX)) GO TO 1030
C
C      ... COMPUTATIONS FOR RILL SEGMENTS NOT ON THE BOUNDARIES
C      *****
C      S1=(HMP4(IDL)-AELV)/SH/3.**0.5
C      S2=(HMP1(IDR)-AELV)/SH/3.**0.5
C      SO=(E1-E2)/2./SH
C      IF(SO.LE.ZRO) GO TO 1065
10 CONTINUE
C      DQ=2.*QQ*SL*SL*(3.**0.5)
C      Q2=QTT
C      Q1=Q2-DQ
C      IF(Q1.LT.0.0) Q1=0.0
C      IF(Q2.LT.0.0) Q2=0.0
C
C      ... CHECK FOR NEGATIVE SIDE SLOPES
C      IF(S1.LE.ZRO.OR.S2.LE.ZRO) GO TO 1025
11 CONTINUE
C
C      ... COMPUTE DEPTH AND WIDTH OF THE FLOW AT THE TWO END POINTS
C      CALL CSEC(SL,Q1,S1,S2,SO,H1,B1,C1)
C      CALL CSEC(SL,Q2,S1,S2,SO,H2,B2,C1)
C
C      ... COMPUTE EROSION FROM NEIGHBORING HUMPS
C      CALL HERSN(QQ,SL,AELV,HMP4(IDL),ECH,B1,B2,H1,H2,EX,TI,TEHL)
C      CALL HERSN(QQ,SL,AELV,HMP1(IDR),ECH,B1,B2,H1,H2,EX,TI,TEHR)
C
C      ... CHECK FOR PONDING . IF IT OCCURS, DEPOSIT SEDIMENT LOAD AT
C      DESIGNATED POINTS(SEE NEXT COMMENT STATEMENT).
C      IF(KPND(I-1).NE.11) GO TO 1017
C      TDP=SDT(I)+TEHL+TEHR
C
C      ... SEDIMENT LOAD AT I IS DEPOSITED ON RILL SEGMENTS OF SIX MESH
C      "BACK STEPS" (BETWEEN I-1 AND I+3) .
C      DD1,....,DD5 ARE DEPTHS OF MATERIAL DEPOSITED AT DIFFERENT
C      BACK STEPS.
29 CONTINUE
C      KF=2
C      WD=WL
30 BB=(B1+B2)/2.*KF
C      IF(BB.GT.WD) GO TO 35
C      DD1=2.5/29.*2.*TDP/SH/BB
C      GO TO 40
35 KF=KF-1
C      IF(KF.LT.1) KF=1

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W00010
 W00020
 W00030
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 W00110
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 W00750
 W00760
 W00770

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40 GO TO 30
DD2=0.8*DD1
DD3=0.6 *DD1
DD4=0.4* DD1
DD5=0.2* DD1
DH(I-1)=DH(I-1)-1.*DD1
DH(I)=DH(I)-1.*DD2
IF((I+NY+1).LT.Y(1)) GO TO 200
IF((I+NY+1).GT.NMAX) GO TO 20
DH(I+NY+1)=DH(I+NY+1)-1.*DD3
20 IF((I-NY+1).LE.0) GO TO 21
DH(I-NY+1)=DH(I-NY+1)-1.*DD3
21 IF((I+NY+2).LT.Y(1+NY+1)) GO TO 200
IF((I+NY+2).GT.NMAX) GO TO 22
DH(I+NY+2)=DH(I+NY+2)-1.*DD4
22 IF((I-NY+2).LE.0) GO TO 23
DH(I-NY+2)=DH(I-NY+2)-1.*DD4
23 IF((I+3).LT.Y(1)) GO TO 200
DH(I+3)=DH(I+3)-1.*DD5
IF((I+2*NY+3).GT.NMAX) GO TO 24
DH(I+2*NY+3)=DH(I+2*NY+3)-1.*DD5
24 IF((I-2*NY+3).LE.0) GO TO 200
DH(I-2*NY+3)=DH(I-2*NY+3)-1.*DD5
200 CONTINUE
SDT(I-1)=0.0
TRE(I-1)=0.0
TIRE(I-1)=0.0
1021 RETURN
1017 CONTINUE
C
C ... COMPUTE RILL EROSION
CALL RERSN(S0,SL,SH,RCH,C1,H1,H2,EX,B1,B2,T1,TE,DE)
C
C ... COMPUTE CHANGE IN ELEVATION OF TWO END POINTS
DH(I)=DH(I)+DE/(NAJ(I)*1.)
DH(I-1)=DH(I-1)+DE/(NAJ(I-1)*1.)
C
C ... COMPUTE SEDIMENT DISCHARGE AT NODAL POINTS
SDT(I-1)=SDT(I-1)+SDT(I)+TE+TEHL+TEHR
TRE(I-1)=TRE(I-1)+TRE(I)+TE
TIRE(I-1)=TIRE(I-1)+TIRE(I)+TEHR+TEHL
RETURN
C
C ... COMPUTATIONS FOR RILL SEGMENTS WITH NEGATIVE SIDE SLOPE(S).
C NO RILL EROSION IN THIS CASE.
1025 B1=1000.
B2=1000.
C ... LARGE VALUES OF B1 AND B2(1000) IS FOR IDENTIFICATION ONLY
CALL HERSN(QQ,SL,AELV,HMP4(IDL),HCH,B1,B2,S1,H2,EX,T1,TE1)
CALL HERSN(QQ,SL,AELV,HMP1(IDR),HCH,B1,B2,S2,H2,EX,T1,TE2)
C
C ... REDISTRIBUTE THE SEDIMENT LOAD WHEN EITHER SIDE SLOPES IS -VE.
CALL SNECTV(I,S1,S2,TE1,TE2,KODE,T,R,H,NBRCH)
RETURN
C
C ... COMPUTATIONS FOR RILL SEGMENTS ON THE BOUNDARIES
C *****
C ... RILL SEGMENTSON THE BOUNDARY ARE ASSUMED TO HAVE SYMMETRICAL
C SIDE SLOPES
C THE SAME SEQUENCE OF COMPUTATION IS FOLLOWED
1020 S=(HMP1(IDR)-AELV)/SH/3.**0.5
EH=HMP1(IDR)
GO TO 1040
1030 S=(HMP4(IDL)-AELV)/SH/3.**0.5
S1=S
S2=S
EH=HMP4(IDL)
1040 SO=(ELV(I)-ELV(I-1))/2./SH
IF(S0.LE.ZRO) GO TO 1065
12 CONTINUE
AELV=(ELV(I)+ELV(I-1))/2.
DQ=2.*QQ*SL*SL*(3.**0.5)
Q2=QTT
Q1=Q2-DQ
IF(Q1.LT.0.0) Q1=0.0
IF(Q2.LT.0.0) Q2=0.0
IF(S.LE.ZRO) GO TO 1035

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W00990
W01000
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W01390
W01400
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W01470
W01480
W01490
W01500
W01510
W01520
W01530
W01540

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13  CONTINUE
    CALL CSEC(SL,Q1,S,S,SO,H1,B1,C1)
    CALL CSEC(SL,Q2,S,S,SO,H2,B2,C1)
    CALL HERSN(QQ,SL,AELV,EH,ECH,B1,B2,H1,H2,EX,T1,TEH)
    IF(KPND(I-1).NE.11) GO TO 1016
    TDP=SDT(I)+TEH
    GO TO 29
1016 CONTINUE
    CALL RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,T1,TE,DE)
    DH(I)=DH(I)+DE/(NAJ(I)*1.)
    DH(I-1)=DH(I-1)+DE/(NAJ(I-1)*1.)
    SDT(I-1)=SDT(I-1)+SDT(I)+TE+TEH
    TRE(I-1)=TRE(I-1)+TRE(I)+TE
    TIRE(I-1)=TIRE(I-1)+TIRE(I)+TEH
    RETURN
1035 B1=1000.
    B2=1000.
    CALL HERSN(QQ,SL,AELV,EH,ECH,B1,B2,S,H2,EX,T1,TE)
    CALL SNEGTV(1,S,S,TE,TE,KODE,T,R,S,NBRANCH)
    RETURN
1065 CONTINUE
C  WRITE(6,1070)1,SO
1070 FORMAT(/,10X,'PONDING OCCURED AT PT. ',15.5X,'SO=',F12.6)
    RETURN
    END
    SUBROUTINE ERSN2(1,QLL,QRR,ECH,RCH,EX,T1)
    *****
    THIS SUBPROGRAM PERFORMS EROSION COMPUTATIONS ON RILL SEGMENTS
    WITH UP-STREAM POINT HAVING CODE=2 .

    S1 = SLOPE OF THE LEFT SIDE OF THE RILL SIDE WALLS
    S2 = SLOPE OF THE RIGHT SIDE OF THE RILL SIDE WALLS
    Q1 = FLOW RATE AT UPSTREAM END OF THE RILL SEGMENT
    Q2 = FLOW RATE AT DOWNSTREAM END OF THE RILL SEGMENT
    SDT(I),TRE(I),TIRE(I) ARE DEFINED IN MAIN PGM
    DH(I) = CHANGE IN ELEVATION OF I AT THE END OF A TIME INTERVAL
    *****

    COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
    COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)
    COMMON/HMPP/HMPP(500),XEMP(500),YHMP(500)
    COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
    COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)
    COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),
    * HMP6(500)
    COMMON /PROP/GAMA,RO,C,SG,RN
    COMMON NT
    ZRO=1.0/(10.0**20.)
    KODE=2
    DE=0.0
    TE=0.0
    DQ=2.*QQ*SL*SL*(3.**0.5)

C  ... IDENTIFY THE THREE NEIGHBORING HUMPS
C  CALL IDHMP(NY,1,IDL,IDR,IDC)
    SOL=(ELV(1)-(ELV(1-NY-1)))/2./SH
    SOR=(ELV(1)-(ELV(1+NY-1)))/2./SH
    IF(X(1).EQ.0) GO TO 1110
    IF(X(1).EQ.X(NMAX)) GO TO 1120
    IF(SOL.LE.ZRO.AND.SOR.LE.ZRO) GO TO 1170
    IF(SOL.LE.ZRO.AND.SOR.GT.ZRO) GO TO 1110
    IF(SOL.GT.ZRO.AND.SOR.LT.ZRO) GO TO 1120
201 CONTINUE

C  ... SEDIMENT LOAD IS DEVIDED BETWEEN THE TWO BRANCHES ACCORDING TO
C  THE RELATIVE MAGNITUDES OF BED SLOPES RAISED TO THE POWER OF 1.25
    SOL2=(ELV(1-NY-1)-ELV(1-NY-2))/2./SH
    SOR2=(ELV(1-NY-1)-ELV(1-NY-2))/2./SH
    SAVL=(SOL+SOL2)/2.
    IF(SAVL.LT.0.0) SAVL=0.0
    SAVR=(SOR+SOR2)/2.
    IF(SAVR.LT.0.0) SAVR=0.0
    SS=SAVL**1.25+SAVR**1.25
    IF(SS.LE.0.0) GO TO 210
    STL=SDT(I)*(SAVL**1.25)/SS
    RENL=TRE(I)*(SAVL**1.25)/SS
    HRENL=TIRE(I)*(SAVL**1.25)/SS
    GO TO 220

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167

W01550
 W01560
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 W01690
 W01700
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 X00010
 X00020
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 X00500
 X00510
 X00520
 X00530

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210 STL=0.5*SDT(I)
RENL=0.5*TRE(I)
HRENL=0.5*TIRE(I)
220 CONTINUE
C
C ... COMPUTATIONS FOR RILL SEGMENT ON THE LEFT
C *****
C
K=1
GO TO 1140
1120 K=2
IF(SOL.IE.0.0) GO TO 1170
STL=SDT(I)
RENL=TRE(I)
HRENL=TIRE(I)
1140 SO=SOL
AELV=(ELV(I)+ELV(I-NY-1))/2.
S2=(HMP2(IDC)-AELV)/SH/3.**0.5
HP5=HMP5(IDL)
C
C ... RILL SEGMENTS ON THE BOUNDARY ARE ASSUMED TO HAVE SYMMETRICAL
C SIDE SLOPES
IF(Y(I).EQ.Y(NY)) HP5=HMP2(IDC)
S1=(HP5-AELV)/SH/3.**0.5
Q1=QLL
IF(Q1.LT.0.0) Q1=0.0
Q2=Q1+DQ
C
C ... CHECK FOR NEGATIVE SIDE SLOPES
IF(S1.LE.ZRO.OR.S2.LE.ZRO) GO TO 1145
202 CONTINUE
C
C ... COMPUTE DEPTH AND WIDTH OF THE FLOW AT THE TWO END POINTS
CALL CSEC(SL,Q1,S1,S2,SO,H1,B1,C1)
CALL CSEC(SL,Q2,S1,S2,SO,H2,B2,C1)
C
C ... COMPUTE EROSION FROM NEIGHBORING HUMPS
CALL HERSN(QQ,SL,AELV,HP5,HCH,B1,B2,H1,H2,EX,T1,TEHL)
CALL HERSN(QQ,SL,AELV,HMP2(IDC),HCH,B1,B2,H1,H2,EX,T1,TEHLC)
C
C ... CHECK FOR PONDING . IF IT OCCURS, DEPOSIT SEDIMENT LOAD AT
C DESIGNATED POINTS(SEE NEXT COMMENT STATEMENT).
IF(KPND(I-NY-1).NE.11) GO TO 1115
C
C ... SEDIMENT LOAD AT I IS DEPOSITED ON RILL SEGMENTS OF SIX MESH
C "BACK STEPS"
TDP=STL+TEHL+TEHLC
KF=2
WD=WL
30 BB=(B1+B2)/2.*KF
IF(BB.GT.WD) GO TO 35
C
C DD1,....,DD5 ARE DEPTHS OF MATERIAL DEPOSITED AT DIFFERENT
C BACK STEPS.
DD1=2.5/35.*2.*TDP/SH/BB
GO TO 40
35 KF=KF-1
IF(KF.LT.1) KF=1
GO TO 30
40 DD2=0.8*DD1
DD3=0.6*DD1
DD4=0.4*DD1
DD5=0.2*DD1
DH(I-NY-1)=DH(I-NY-1)-1.*DD1
DH(I)=DH(I)-1.*DD2
IF((I-2*NY).LE.0) GO TO 10
DH(I-2*NY)=DH(I-2*NY)-1.*DD2
10 IF(Y(I+1).LT.Y(I)) GO TO 100
DH(I+1)=DH(I+1)-1.*DD3
IF((I-2*NY+1).LE.0) GO TO 11
DH(I-2*NY+1)=DH(I-2*NY+1)-1.*DD3
11 IF(Y(I+NY+2).LT.Y(I)) GO TO 100
IF((I+NY+2).GT.NMAX) GO TO 12
DH(I+NY+2)=DH(I+NY+2)-1.*DD4
12 DH(I-NY+2)=DH(I-NY+2)-1.*DD4
IF((I-3*NY+2).LE.0) GO TO 13
DH(I-3*NY+2)=DH(I-3*NY+2)-1.*DD4

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X00540
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X01280
X01290
X01300


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13 IF(Y(I+NY+3).LT.Y(I)) GO TO 100 X01310
IF((I+NY+3).GT.NMAX) GO TO 14 X01320
DH(I+NY+3)=DH(I+NY+3)-1.*DD5 X01330
14 IF((I-NY+3).LE.0) GO TO 15 X01340
DH(I-NY+3)=DH(I-NY+3)-1.*DD5 X01350
15 IF((I-3*NY+3).LE.0) GO TO 100 X01360
DH(I-3*NY+3)=DH(I-3*NY+3)-1.*DD5 X01370
100 CONTINUE X01380
1021 RETURN X01390
1115 CONTINUE X01400
C X01410
C ... COMPUTE RILL EROSION X01420
CALL HERSN(SO,SL,SH,BCH,C1,H1,H2,EX,B1,B2,T1,TE,DE) X01430
C X01440
C ... COMPUTE CHANGE IN ELEVATION OF TWO END POINTS X01450
DH(I)=DH(I)+DE/(1.*NAJ(I)) X01460
DH(I-NY-1)=DH(I-NY-1)+DE/(1.*NAJ(I-NY-1)) X01470
C X01480
C ... COMPUTE SEDIMENT DISCHARGE AT NODAL POINTS X01490
SDT(I-NY-1)=SDT(I-NY-1)+STL+TE+TEHL+TEHLC X01500
TRE(I-NY-1)=TRE(I-NY-1)+REN+TE X01510
TIRE(I-NY-1)=TIRE(I-NY-1)+HREN+TEHL+TEHLC X01520
C X01530
C ... CHECK FOR -VE. SIDE SLOPES X01540
1145 IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 1150 X01550
NBRNCH=1 X01560
B1=1000. X01570
B2=1000. X01580
C NOTE: THE LARGE VALUES OF B1, AND B2 (1000.) ARE USED ONLY AS FLAGS X01590
C X01600
C ... COMPUTATIONS FOR RILL SEGMENTS WITH NEGATIVE SIDE SLOPE(S). X01610
C NO RILL EROSION IN THIS CASE. X01620
CALL HERSN(QQ,SL,DNY1,DNY2,BCH,B1,B2,S2,H2,EX,T1,TE2) X01630
CALL HERSN(QQ,SL,DNY1,DNY2,BCH,B1,B2,S1,H2,EX,T1,TE1) X01640
KODE=2 X01650
C X01660
C ... REDISTRIBUTE THE SEDIMENT LOAD WHEN EITHER SIDE SLOPES IS -VE. X01670
CALL SNECTV(I,S1,S2,TE1,TE2,KODE,STL,REN,HREN,NBRNCH) X01680
1150 IF(K.EQ.1) GO TO 1160 X01690
RETURN X01700
C X01710
C ... COMPUTATIONS FOR RILL SEGMENT ON THE RIGHT X01720
C ***** X01730
C X01740
C THE SAME SEQUENCE OF COMPUTATIONS IS FOLLOWED X01750
1110 IF(SOR.LE.0) GO TO 1170 X01760
STL=0 X01770
REN=0.0 X01780
HREN=0.0 X01790
1160 STR=SDT(I)-STL X01800
RENH=TRE(I)-REN X01810
HRENH=TIRE(I)-HREN X01820
SO=SOR X01830
AELV=(ELV(I)+ELV(I+NY-1))/2. X01840
S1=(HMP3(IDC)-AELV)/SH/3.**0.5 X01850
HP6=HMP6(IDC) X01860
IF(Y(I).EQ.Y(NY)) HP6=HMP3(IDC) X01870
S2=(HP6-AELV)/SH/3.**0.5 X01880
Q1=QRR X01890
IF(Q1.LT.0.0) Q1=0.0 X01900
Q2=Q1+DQ X01910
IF(S1.LE.ZRO.OR.S2.LE.ZRO) GO TO 1155 X01920
203 CONTINUE X01930
CALL CSEC(SL,Q1,S1,S2,SO,H1,B1,C1) X01940
CALL CSEC(SL,Q2,S1,S2,SO,H2,B2,C1) X01950
CALL HERSN(QQ,SL,AELV,HP6,HCH,B1,B2,H1,H2,EX,T1,TEHR) X01960
CALL HERSN(QQ,SL,AELV,HP6,HCH,B1,B2,H1,H2,EX,T1,TEHRC) X01970
IF(KPND(I+NY-1).NE.11) GO TO 1116 X01980
TDP=STL+TEHR+TEHRC X01990
KF=2 X02000
WD=WL X02010
60 BB=(B1+B2)/2.*KF X02020
IF(BB.GT.WD) GO TO 65 X02030
DD1=2.5/35.*2.*TDP/SH/BB X02040
GO TO 70 X02050
65 KF=KF-1 X02060
IF(KF.LT.1) KF=1 X02070

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```

70  GO TO 60
    DD2=0.8*DD1
    DD3=0.6*DD1
    DD4=0.4*DD1
    DD5=0.2*DD1
    DH(I+NY-1)=DH(I+NY-1)-1.*DD1
    DH(I)=DH(I)-1.*DD2
    IF((I+2*NY).GT.NMAX) GO TO 20
    DH(I+2*NY)=DH(I+2*NY)-1.*DD2
20  IF(Y(I+1).LT.Y(I)) GO TO 200
    DH(I+1)=DH(I+1)-1.*DD3
    DH(I+2*NY+1)=DH(I+2*NY+1)-1.*DD3
    IF(Y(I+NY+2).LT.Y(I)) GO TO 200
    IF((I+NY+2).GT.NMAX) GO TO 21
    DH(I+NY+2)=DH(I+NY+2)-1.*DD4
21  IF((I+3*NY+2).GT.NMAX) GO TO 22
    DH(I+3*NY+2)=DH(I+3*NY+2)-1.*DD4
22  IF((I-NY+2).LT.0) GO TO 23
    DH(I-NY+2)=DH(I-NY+2)-1.*DD4
23  IF(Y(I+3*NY+3).LE.Y(I)) GO TO 200
    IF((I+3*NY+3).GT.NMAX) GO TO 24
    DH(I+3*NY+3)=DH(I+3*NY+3)-1.*DD5
24  IF((I+NY+3).GT.NMAX) GO TO 25
    DH(I+NY+3)=DH(I+NY+3)-1.*DD5
25  IF((I-NY+3).LE.0) GO TO 200
    DH(I-NY+3)=DH(I-NY+3)-1.*DD5
200 CONTINUE
    SDT(I+NY-1)=0.0
    TRE(I+NY-1)=0.0
    TIRE(I+NY-1)=0.0
1023 RETURN
1116 CONTINUE
    CALL HERSN(S0,SL,SH,RCH,C1,H1,H2,EX,B1,B2,T1,TE,DE)
    DH(I)=DH(I)+DE/(1.*NAJ(I))
    DH(I+NY-1)=DH(I+NY-1)+DE/(1.*NAJ(I+NY-1))
    SDT(I+NY-1)=SDT(I+NY-1)+STR+TE+TEHR+TEHRC
    TRE(I+NY-1)=TRE(I+NY-1)+RENR+TE
    TIRE(I+NY-1)=TIRE(I+NY-1)+HRENR+TEHR+TEHRC
    RETURN
1155 IF(S1.GT.ZRO.AND.S2.GT.ZRO) RETURN
204 CONTINUE
    NBRNCH=2
    B1=1000.
    B2=1000.
    CALL HERSN(QQ,SL,DHY1,DHY2,HCH,B1,B2,S1,H2,EX,T1,TE1)
    CALL HERSN(QQ,SL,DHY1,DHY2,HCH,B1,B2,S2,H2,EX,T1,TE2)
    KODE=2
    CALL SNECTV(1,S1,S2,TE1,TE2,KODE,STR,RENR,HRENR,NBRNCH)
    RETURN
1170 CONTINUE
C  WRITE(6,1175) 1,SOL,SOR
1175 FORMAT(/,10X,'PONDING OCCURED AT PT. ',15,5X,'SOL=',F12.0,
    * 5X,'SOR=',F12.0)
    RETURN
    END
    SUBROUTINE SNECTV(1,S1,S2,TE1,TE2,KODE,T,R,H,NBRNCH)
C  *****
C  THIS SUBPROGRAM MODIFIES THE EROSION COMPUTATIONS WHEN EITHER
C  SIDESLOPES OF A RILL SEGMENT IS NEGATIVE.
C
C  NV= LOCATION OF SEDIMENT LOAD BEFORE MODIFICATION
C  NK= LOCATION OF SEDIMENT LOAD AFTER MODIFICATION
C  TE1= VOLUME OF SOIL ERODED FROM LEFT SIDESLOPE
C  TE2= VOLUME OF SOIL ERODED FROM RIGHT SIDESLOPE
C  *****
    COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ
    COMMON/HMPP/HMP(500),XMP(500),YMP(500)
    COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),
    * HMP6(500)
    COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)
    COMMON/SDMT/SDT(2000),TRE(2000),TIRE(2000)
    COMMON NT
    1  FORMAT(/,' POINT # ',13,5F20.8,/)
    E1=TE1
    E2=TE2
    CALL IDHMP(NY,1,IDL,1DR,1DC)

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```

X02080
X02090
X02100
X02110
X02120
X02130
X02140
X02150
X02160
X02170
X02180
X02190
X02200
X02210
X02220
X02230
X02240
X02250
X02260
X02270
X02280
X02290
X02300
X02310
X02320
X02330
X02340
X02350
X02360
X02370
X02380
X02390
X02400
X02410
X02420
X02430
X02440
X02450
X02460
X02470
X02480
X02490
X02500
X02510
X02520
X02530
X02540
X02550
X02560
X02570
X02580
X02590
X02600
X02610
X02620
Y00010
Y00020
Y00030
Y00040
Y00050
Y00060
Y00070
Y00080
Y00090
Y00100
Y00110
Y00120
Y00130
Y00140
Y00150
Y00160
Y00170
Y00180
Y00190
Y00200
Y00210
Y00220

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	GO TO (100,200),KODE	Y00230
100	S0=(ELV(1)-ELV(1-1))/2./SH	Y00240
	IF(X(1).EQ.0.0) GO TO 120	Y00250
	IF(X(1).EQ.X(NMAX)) GO TO 110	Y00260
	IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 110	Y00270
	IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 120	Y00280
	NK=1-2*NY-1	Y00290
	NV=1	Y00300
	IF(X(NV).LE.X(NY+1)) NK=NMAX+5	Y00310
	F=0.5	Y00320
	KK=1	Y00330
	E2=0.0	Y00340
	HHH=(ELV(NK)+ELV(NK+1))/2.	Y00350
	IF(HHH.GT.HMP1(IDL)) GO TO 105	Y00360
	GO TO 1000	Y00370
105	F=0.0	Y00380
	E1=0.0	Y00390
	E2=0.0	Y00400
	GO TO 1000	Y00410
111	NK=1+2*NY-1	Y00420
	NV=1	Y00430
	IF(X(NV).GE.X(NMAX-NY)) NK=NMAX+5	Y00440
	F=0.5	Y00450
	KK=2	Y00460
	E2=TE2	Y00470
	E1=0.0	Y00480
	HHH=(ELV(NK)+ELV(NK+1))/2.	Y00490
	IF(HHH.GT.HMP4(IDR)) GO TO 105	Y00500
	GO TO 1000	Y00510
110	NK=1-2*NY-1	Y00520
	NV=1	Y00530
	F=1.0	Y00540
	KK=2	Y00550
	IF(X(NV).LE.X(NY+1)) NK=NMAX+5	Y00560
	AS1=ABS(S1)	Y00570
	IF(S0.GE.AS1) GO TO 117	Y00580
	HHH=(ELV(NK)+ELV(NK+1))/2.	Y00590
	IF(HHH.GT.HMP1(IDL)) GO TO 115	Y00600
	GO TO 1000	Y00610
115	F=0.0	Y00620
	E1=0.0	Y00630
	E2=0.0	Y00640
	GO TO 1000	Y00650
117	F=0.0	Y00660
	E=E2	Y00670
	E2=0.0	Y00680
	KK=3	Y00690
	GO TO 1000	Y00700
120	NK=1+2*NY-1	Y00710
	NV=1	Y00720
	IF(X(NV).GE.X(NMAX-NY)) NK=NMAX+5	Y00730
	F=1.0	Y00740
	KK=2	Y00750
	HHH=(ELV(NK)+ELV(NK+1))/2.	Y00760
	IF(HHH.GT.HMP4(IDR)) GO TO 115	Y00770
	AS2=ABS(S2)	Y00780
	IF(S0.GE.AS2) GO TO 127	Y00790
	GO TO 1000	Y00800
127	F=0.0	Y00810
	E=E1	Y00820
	E1=0.0	Y00830
	KK=3	Y00840
	GO TO 1000	Y00850
1000	SDT(NK)=SDT(NK)+F*SDT(NV)+E1+E2	Y00860
	TRE(NK)=TRE(NK)+F*TRE(NV)	Y00870
	TIRE(NK)=TIRE(NK)+F*TIRE(NV)+E1+E2	Y00880
	IF(KK.EQ.1) GO TO 111	Y00890
	IF(KK.EQ.3) GO TO 1500	Y00900
	GO TO 1700	Y00910
1500	SDT(NV-1)=SDT(NV-1)+SDT(NV)+E	Y00920
	TRE(NV-1)=TRE(NV-1)+TRE(NV)	Y00930
	TIRE(NV-1)=TIRE(NV-1)+TIRE(NV)+E	Y00940
1700	CONTINUE	Y00950
	RETURN	Y00960
200	CALL IDHMP(NY,1,IDL,IDR,IDC)	Y00970
	IF(NBRNCH.EQ.2) GO TO 300	Y00980
	IF(X(1).EQ.0.0) GO TO 300	Y00990

	SOL=(ELV(1)-ELV(1-NY-1))/2./SH	Y01000
	AS1=ABS(S1)	Y01010
	AS2=ABS(S2)	Y01020
	IF (S1.LE.0.0.AND.S2.GT.0.0) GO TO 210	Y01030
	IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 220	Y01040
	NK=1-2*NY+1	Y01050
	IF(Y(1).GE.Y(NY-1)) NK=NMAX+5	Y01060
	IF(X(1).EQ.X(NY+1)) NK=NMAX+5	Y01070
	F=0.5	Y01080
	KK=1	Y01090
	E2=0.0	Y01100
	HHH=(ELV(NK)+ELV(NK+NY+1))/2.	Y01110
	IF(HHH.GT.HMP2(IDL)) GO TO 205	Y01120
	GO TO 2000	Y01130
205	F=0.0	Y01140
	E1=0.0	Y01150
	E2=0.0	Y01160
	GO TO 2000	Y01170
211	NK=1-3	Y01180
	IF(Y(1).EQ.Y(3)) NK=1+NY-2	Y01190
	F=0.5	Y01200
	KK=2	Y01210
	E2=TE2	Y01220
	E1=0.0	Y01230
	HHH=(ELV(NK)+ELV(NK+NY+1))/2.	Y01240
	IF(HHH.GT.HMP5(IDC)) GO TO 205	Y01250
	GO TO 2000	Y01260
210	NK=1-2*NY+1	Y01270
	IF(Y(1).GE.Y(NY-1)) NK=NMAX+5	Y01280
	IF(X(1).EQ.X(NY+1)) NK=NMAX+5	Y01290
	F=1.0	Y01300
	KK=2	Y01310
	IF(SOL.GT.AS1) GO TO 217	Y01320
	HHH=(ELV(NK)+ELV(NK+NY+1))/2.	Y01330
	IF(HHH.GT.HMP2(IDL)) GO TO 205	Y01340
	GO TO 2000	Y01350
217	F=0.0	Y01360
	E=E2	Y01370
	E2=0.0	Y01380
	KK=3	Y01390
	GO TO 2000	Y01400
220	NK=1-3	Y01410
	IF(Y(1).EQ.Y(3)) NK=1+NY-2	Y01420
	F=1.0	Y01430
	KK=2	Y01440
	IF(SOL.GT.AS2) GO TO 227	Y01450
	IF(X(1).EQ.X(NMAX)) GO TO 2000	Y01460
	HHH=(ELV(NK)+ELV(NK+NY+1))/2.	Y01470
	IF(HHH.GT.HMP5(IDC)) GO TO 205	Y01480
	GO TO 2000	Y01490
227	F=0.0	Y01500
	E=E1	Y01510
	E1=0.0	Y01520
	KK=3	Y01530
2000	SDT(NK)=SDT(NK)+F*T+E1+E2	Y01540
	TRE(NK)=TRE(NK)+F*R	Y01550
	TIRE(NK)=TIRE(NK)+F*H+E1+E2	Y01560
	IF(KK.EQ.1) GO TO 211	Y01570
	IF(KK.EQ.3) GO TO 2500	Y01580
	GO TO 2700	Y01590
2500	SDT(1-NY-1)=SDT(1-NY-1)+T+E	Y01600
	TRE(1-NY-1)=TRE(1-NY-1)+R	Y01610
	TIRE(1-NY-1)=TIRE(1-NY-1)+H+E	Y01620
2700	CONTINUE	Y01630
4	FORMAT(6F20.10, /)	Y01640
	RETURN	Y01650
300	IF(X(1).EQ.X(NMAX)) RETURN	Y01660
	SOR=(ELV(1)-ELV(1+NY-1))/2./SH	Y01670
	AS2=ABS(S2)	Y01680
	AS1=ABS(S1)	Y01690

	IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 310	Y01700
	IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 320	Y01710
	NK=1+2*NY+1	Y01720
	IF(Y(1).GE.Y(NY-1)) NK=NMAX+5	Y01730
	IF(X(1).EQ.X(NMAX-NY)) NK=NMAX+5	Y01740
	F=0.5	Y01750
	KK=1	Y01760
	E1=0.0	Y01770
	HHH=(ELV(NK)+ELV(NK-NY+1))/2.	Y01780
	IF(HHH.GT.HMP3(IDR)) GO TO 305	Y01790
	GO TO 3000	Y01800
305	F=0.0	Y01810
	E1=0.0	Y01820
	E2=0.0	Y01830
	GO TO 3000	Y01840
311	NK=1-3	Y01850
	IF(Y(1).EQ.Y(3)) NK=1-NY-2	Y01860
	F=0.5	Y01870
	KK=2	Y01880
	E1=TE1	Y01890
	E2=0.0	Y01900
	HHH=(ELV(NK)+ELV(NK-NY+1))/2.	Y01910
	IF(HHH.GT.HMP6(IDC)) GO TO 305	Y01920
	GO TO 3000	Y01930
310	NK=1+2*NY+1	Y01940
	IF(Y(1).GE.Y(NY-1)) NK=NMAX+5	Y01950
	IF(X(1).EQ.X(NMAX-NY)) NK=NMAX+5	Y01960
	F=1.0	Y01970
	KK=2	Y01980
	IF(SOR.GT.AS1) GO TO 317	Y01990
	HHH=(ELV(NK)+ELV(NK-NY+1))/2.	Y02000
	IF(HHH.GT.HMP6(IDC)) GO TO 305	Y02010
	GO TO 3000	Y02020
317	F=0.0	Y02030
	E=E1	Y02040
	E1=0.0	Y02050
	KK=3	Y02060
	GO TO 3000	Y02070
320	NK=1-3	Y02080
	IF(Y(1).EQ.Y(3)) NK=1-NY-2	Y02090
	F=1.0	Y02100
	KK=2	Y02110
	IF(SOR.GT.AS2) GO TO 327	Y02120
	IF(X(1).EQ.0.0) GO TO 3000	Y02130
	HHH=(ELV(NK)+ELV(NK-NY+1))/2.	Y02140
	IF(HHH.GT.HMP3(IDR)) GO TO 305	Y02150
	GO TO 3000	Y02160
327	F=0.0	Y02170
	E=E1	Y02180
	E1=0.0	Y02190
	KK=3	Y02200
3000	SDT(NK)=SDT(NK)+F*T+E1+E2	Y02210
	TRE(NK)=TRE(NK)+F*R	Y02220
	TIRE(NK)=TIRE(NK)+F*H+E1+E2	Y02230
	IF(KK.EQ.1) GO TO 311	Y02240
	IF(KK.EQ.3) GO TO 3500	Y02250
	GO TO 3700	Y02260
3500	SDT(1+NY-1)=SDT(1+NY-1)+T+E	Y02270
	TRE(1+NY-1)=TRE(1+NY-1)+R	Y02280
	TIRE(1+NY-1)=TIRE(1+NY-1)+H+E	Y02290
3700	CONTINUE	Y02300
	RETURN	Y02310
	END	Y02320

```

*****
*                                     *
*               INPUT DATA          *
*                                     *
*****

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GROUP # 1 :

SURFACE ROUGHNESS DATA

NO. OF ELEVATION TRACES = 7
NO. OF POINTS PER TRACE = 100
SPACING = 2.00 CM

GROUP # 2 :

PROBLEM PARAMETERS

SOIL PARTICLE DIAMETER = 0.010 MLNTR
SOIL UNIT WEIGHT = 16660. N/C. METER
SOIL SPECIFIC WEIGHT = 2.65

EXPONENT OF KALINSKE EQN. = 1.50
EQN. CONSTANT FOR RILLS = 400.0
EQN. CONSTANT FOR HUMPS = 20.0
MANNING CONSTANT = 0.040

GROUP # 3 :

STORM AND SLOPE DATA

NO. OF MESH POINTS IN CROSS-DIRECTION = 65
NO. OF MESH POINTS IN LONGT-DIRECTION = 30
AVERAGE SLOPE = 20.0 DEGREES
= 36.41 PERCENT
RAINFALL INTENSITY = 50.0 MLNTR/HR
RUNOFF COEFFICIENT = 0.50

ANNUAL RAINFALL RATE = 100.0 CMYR
EQUIVALENT YEARS OF RAIN = 0.25 YEARS

TIME INTERVAL = 10.0 MINUTES
TOTAL RAIN PERIOD = 5.00 HOURS
NO. OF RANDOM SURFACES = 1

FAILURE LIMIT FOR SIDE SLOPE = 1.40
STARTING LIMIT FOR SIDE SLOPE = 1.10

 *
 *
 * SPECTRAL ANALYSIS RESULTS *
 *
 *

AVERAGE VALUES FOR ALL PROFILES

DEGREE	AN	BN	POWER	CONTR.	TOTAL	L (CM)
0	0.00	0.0	0.000	0.0	0.0	0.0
1	-3.73	5.08	26.373	0.1021	0.1021	198.00
2	5.14	3.01	28.660	0.1213	0.2234	99.00
3	-7.44	0.03	51.573	0.2030	0.4263	66.00
4	-1.39	2.23	6.368	0.0257	0.4520	49.50
5	0.08	1.61	4.803	0.0207	0.4727	39.60
6	-0.23	-0.25	5.473	0.0236	0.4963	33.00
7	-0.36	-0.94	3.866	0.0160	0.5123	28.29
8	0.36	1.16	3.864	0.0166	0.5290	24.75
9	-0.40	0.26	4.253	0.0187	0.5477	22.00
10	0.30	0.35	4.087	0.0156	0.5632	19.80
11	3.00	-2.23	10.397	0.0429	0.6061	18.00
12	-1.62	1.22	4.259	0.0171	0.6232	16.50
13	-0.30	0.51	4.770	0.0200	0.6432	15.23
14	1.00	0.25	3.735	0.0163	0.6595	14.14
15	0.55	1.08	3.243	0.0143	0.6737	13.20
16	0.72	-0.42	5.569	0.0217	0.6955	12.38
17	0.21	0.02	4.153	0.0173	0.7127	11.65
18	-1.22	-1.19	3.580	0.0147	0.7274	11.00
19	-0.53	-0.57	1.665	0.0066	0.7339	10.42
20	2.32	-0.62	3.820	0.0161	0.7501	9.90
21	0.24	-1.47	2.547	0.0102	0.7602	9.43
22	-0.46	0.80	2.371	0.0099	0.7702	9.00
23	1.96	-0.24	4.659	0.0179	0.7881	8.61
24	-1.05	-0.07	2.347	0.0094	0.7974	8.25
25	-0.73	0.83	5.703	0.0242	0.8217	7.92
26	0.18	0.37	1.808	0.0067	0.8283	7.62
27	0.07	0.11	2.606	0.0105	0.8388	7.33
28	0.98	-1.07	3.876	0.0160	0.8548	7.07
29	1.45	0.56	4.067	0.0167	0.8715	6.83
30	1.12	-0.42	1.495	0.0061	0.8776	6.60
31	0.36	0.02	0.577	0.0025	0.8801	6.39
32	1.12	-0.06	2.610	0.0105	0.8906	6.19
33	-0.22	0.12	1.397	0.0058	0.8964	6.00
34	0.50	-0.34	1.149	0.0044	0.9008	5.82
35	1.08	0.05	1.901	0.0074	0.9082	5.66
36	0.25	-0.47	1.384	0.0056	0.9137	5.50
37	0.59	-0.29	1.515	0.0061	0.9198	5.35
38	0.99	-0.94	2.421	0.0096	0.9294	5.21
39	1.17	0.19	2.047	0.0088	0.9382	5.08
40	0.52	0.51	3.057	0.0121	0.9504	4.95
41	0.23	0.33	1.819	0.0072	0.9576	4.83
42	0.75	0.78	1.401	0.0062	0.9638	4.71
43	0.00	0.25	1.030	0.0042	0.9680	4.60
44	0.48	-0.15	1.208	0.0047	0.9727	4.50
45	0.01	0.34	0.861	0.0037	0.9763	4.40
46	-0.16	0.76	1.333	0.0057	0.9820	4.30
47	0.57	0.07	1.139	0.0047	0.9867	4.21
48	0.01	-0.56	1.196	0.0048	0.9914	4.13
49	-0.22	-0.22	1.079	0.0043	0.9958	4.04
50	-0.17	0.0	0.993	0.0042	1.0000	3.96

AMPLITUDE OF REPRESENTATIVE WAVE= 3.740 MLNR
LENGTH OF REPRESENTATIVE WAVE = 18.000 CM
MEAN OF NORMAL DIST. = 4.719 MLNTR
STAND. DEVIATION OF NORMAL DIST.= 15.906 MLNTR

PLOT LENGTH= 2.286 METERS
PLOT WIDTH = 5.760 METERS

TEST AREA = 13.169 SQ. METERS
SHAPE FACTOR = 2.519