PRE-MINING HYDROLOGIC ANALYSIS USING MODELING AND GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

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(ABSTRACT)

Surface mining activities are known to affect the quantity and quality of stormwater runoff. This can create flooding and water quality degradation of receiving streams. The Surface Mining Control and Reclamation Act (SMCRA) of 1977 provides regulations intended to produce environmentally acceptable results from mining operations.

The SMCRA requires that extensive pre-mining monitoring be carried out to assist in determining the probable hydrologic consequences (PHC) of mining. The Finite Element Storm Hydrograph Model (FESHM) was used to demonstrate the utility of hydrologic modeling concepts in simulating runoff volumes and peak flows. Guidelines were proposed for using this methodology to simulate selected pre-mining hydrologic conditions.

The use of geographic information system (GIS) technology as a tool for improving data management and modeling efficiency was demonstrated. The required input watershed characteristics were digitized, stored, and manipulated using a computerized GIS. Appropriate software was developed to integrate the GIS with FESHM.

The ability of FESHM to simulate runoff events in an ungaged context was evaluated using an experimental watershed. First, simulations were conducted using

two separate data bases, "lumped" and "detailed", in order to evaluate the effect of limited data availability, as expected in mining regions, on FESHM's predictive ability. The "lumped" data base produced better simulation results, however, more thorough and detailed research is needed to determine the level of data resolution necessary for a given level of simulation accuracy. Next, significant runoff events from 17-years of the historical record were simulated using data from the "lumped" data base. Statistical analyses were used to make judgments on parameter estimation and model usage. Regression methodology was used to assess expected error and model bias. Simulation bias was found to be related to the input rainfall intensity levels. The results suggest that either spatial variability or parameter values were not adequately defined and that some form of calibration is needed.

Two additional drainage basins were used to evaluate FESHM's predictive capabilities in situations considered representative of mining regions. The results indicated that more thorough investigations of watershed characteristics must be made, that calibration procedures should be performed for each watershed, and that FESHM does not adequately model the physical processes involved in forest hydrology.

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1.0 INTRODUCTION

1.1 BACKGROUND

Coal is one of the major energy resources in the United States. Each year approximately 100,000 acres of land are surface mined (CSMRC, 1981). Surface mining and reclamation operations can greatly affect the quantity and quality of surface runoff. In the Appalachian region, surface mine drainage has polluted thousands of miles of streams (Curtis, 1972).

The lack of availability of oil and natural gas will require an increase in coal production and utilization (Hamon, 1979). Haan and Barfield (1978) stressed the need for increased surface mined coal in the United States in order to attain energy self-sufficiency. Along with the need for increased coal production, the strip mining industry is faced with stringent environmental controls. Therefore, there is an increased need for and use of environmental information on mining activities (Hamon, 1979).

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 established regulations to minimize environmental degradation caused by coal mining activities. Mining activities must be planned and conducted to minimize changes in the hydrologic balance of both the permit and adjacent areas (Hunt, 1985). The act requires the determination of the Probable Hydrologic Consequences (PHC) of proposed surface mining and reclamation operations. This assessment of the effects of surface mining on the prevailing hydrologic regime requires extensive pre-mining analysis. This pre-mining analysis involves a description of existing geology, hydrology, water quantity and quality. There is no precise methodology for the preparation of PHC. Both water monitoring programs and computer modeling techniques have been used. A good surface water monitoring program should include

flow measurements and chemical analyses of water samples for a period of six months (Virginia DMLR, 1981). Computer modeling techniques also may be included as part of the surface mining permit application (Virginia DMLR, 1979). The use of deterministic watershed models may be the best approach for characterizing watersheds and predicting the consequences of mining.

The purpose of this study is to evaluate the use of hydrologic modeling techniques to simulate various pre-mining hydrologic characteristics. These techniques are not intended to eliminate the required six month monitoring period, but to supplement available hydrologic data. It is envisioned that future modeling studies which include the simulation of all the required hydrologic characteristics could significantly reduce the tedious and costly monitoring requirements.

1.2 RESEARCH OBJECTIVES

The objectives of this study were to:

1) Evaluate the Finite Element Storm Hydrograph Model (FESHM) for simulating peak flow rates and total runoff volumes from mining areas in an ungaged context.
2) Demonstrate the use of the model on selected watersheds from mining regions in an ungaged context.
3) Demonstrate the use of geographic information system (GIS) technology as a possible tool for improving data management and modeling efficiency.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The available literature relating to this project are discussed in the following order: surface mining regulations, hydrologic modeling techniques, and geographic information systems (GIS). The review of surface mining regulations is limited to rules and guidelines related to PHC. In the next section, modeling techniques, hydrologic model uses, available models, and methods of model verification are reviewed. Finally, the use of GIS technology in the computer modeling of hydrologic processes is discussed.

2.2 SURFACE MINING REGULATIONS

The SMCRA of 1977 was the first national attempt to control coal mining to produce environmentally acceptable operations (Kilpatrick, 1980). The act required the determination of PHC for each proposed mine site (U.S. Congress, 1977). Each surface mining application must contain a description of geology, hydrology, and water quality and quantity of the mine and adjacent area (Virginia DMLR, 1979). In order to determine PHC, a description of baseline or existing hydrologic conditions is essential. Baseline data requirements include seasonal ground water and surface water characteristics (MLRC, 1979).

A description of the surface water hydrology of waters discharging into, or which will receive runoff from the disturbed area is required (Virginia DMLR, 1981). This description usually requires a monitoring program. It is recommended that

surface water monitoring stations be placed on major springs, ponds and receiving streams in the mining area and measurements be taken monthly or more frequently (Genereaux, 1980). The recommended minimum duration of baseline data is six months, provided this period includes appropriate seasonal high and low flow periods (Haynes, 1986; MLRC, 1979). The use of models, where available and applicable, is encouraged (MLRC, 1979).

Surface water characteristics which should be monitored or estimated are (MLRC, 1979):

1) Seasonal stream flow characteristics.
2) Peak flows.
3) Low flows.
4) Flow durations.
5) Chemical water quality.
6) Erosion and sediment.
7) Aquatic biology.

Peak flows for at least two storms during the six month period should be determined at each monitoring point. The return periods for these two storms should be determined from flow frequency relationships or from published sources (MLRC, 1979). The Virginia Division of Mined Land Reclamation (DMLR) (1981) currently recommends the use of a 10-year, 24-hour storm for determination of peak discharge rates. The DMLR is in the process of changing their design storm recommendation to a 25-year, 6-hour storm event (Haynes, 1986).

There are two possible methods for the determination of erosion and sediment characteristics (MLRC, 1979): the prediction of the annual erosion rate and the estimation of stream sediment loads resulting from selected storms. Storm runoff volume, storm discharge peaks, and sediment loads should be determined for equivalent storms.

The SMCRA of 1977 should encourage the development of advanced hydrologic predictive techniques and improve methods of data collection and analysis

(Genereaux, 1980). Kilpatrick (1980) also predicts the expansion of hydrologic data collection and analysis in the coal resource areas as a result of the act. Hamon (1979) stresses the need for studies of the pre-mining, mining, and post-mining phases in order to obtain desired hydrologic and water quality data from watersheds subjected to surface mining.

2.3 HYDROLOGIC SIMULATION MODELS

Methods for estimating hydrologic quantities, such as stream flow, range from simple formulas to complex computer simulation models (Haan and Barfield, 1978). The Office of Technology Assessment (1982) describes mathematical models as being amongst the most sophisticated tools for analyzing water resources issues. They mention that although simulation models are not explicitly required in federal legislation, models are often the method of choice to meet requirements. The SMCRA is listed as one of the major legislative acts promoting mathematical model use.

Novotny and Chesters (1981) mention lumped parameter and distributed parameter as the two possible approaches to modeling nonpoint source pollution. Lumped parameter models treat the watershed as a single unit, while the distributed parameter approach involves the division of a watershed into small homogeneous units. Distributed parameter models are further divided into deterministic and parametric models (Overton and Meadows, 1976). Deterministic models involve the use of measurable physical quantities and require thorough verification. Parametric models aré less rigorous in defining physical quantities and utilize optimization techniques.

According to Jennings (1980), many hydrologists believe deterministic models offer the best approach to characterizing surface mine hydrology. Deterministic

models produce output of an event as single values without introducing an element of chance or possible error (Office of Technological Assessment, 1982; Overton and Meadows, 1976). Advantages of deterministic models include:

1) Realistic characterization of physical and chemical processes.
2) Measurable watershed characteristics can be used instead of long and costly gaged records.
3) Possibility of regionalization of parameters.
4) They can be used to simulate virtually any land use.

The reliability of a deterministic model depends on the extent to which it can be or has been verified (Overton and Meadows, 1976). Verification insures that a simulation model behaves as a researcher intends. Overton and Meadows (1976) state that verification is incomplete without a thorough sensitivity analysis. Sensitivity is a measure of the effect of change in one factor on another factor (McCuen, 1973). A sensitivity analysis is usually performed by holding all but one parameter constant and testing for its effect on model output, then repeating this for all significant input variables. This procedure, although commonly practiced, gives little or no insight into complex parameter interactions.

Validation tests the agreement between the behavior of the simulation model and a real system (Van Horn, 1969). Validation of simulation models involves running the model under various conditions and visually or statistically comparing the results to actual data. Some visual or graphical approaches include plots of simulated and recorded hydrographs, scatter plots of simulated versus observed values with a line of equal value superimposed, and plots showing the effect of variability or error in input on the output (Shanholtz and Carr, 1975). Simple statistical measures for comparing observed and computed values include correlation coefficients, relative error, and comparison of means (Office of Technological Assessment, 1982). Williams et al. (1985) state that it is important for simulation models to produce frequency distributions that are similar to measured frequency distributions. Close agreement between means and standard deviations indicates that the frequency distributions are

similar. Reynolds and Chung (1986) suggest that instead of applying statistical tests to determine whether a model adequately represents the real system, an alternate approach is to estimate the error that will result when the model is used to draw inferences about the real system. They propose the use of regression methodology for estimating this error as a function of the levels of the input variables.

There are many models available for simulating the hydrology of small watersheds. Many of these models also contain sediment and nutrient components. Table 1 lists the names, the types of simulation, the processes simulated, and the references of selected models. Renard et al. (1982) lists forty models currently available for hydrologic applications. Novotny and Chesters (1981) describe eleven nonpoint pollution simulation models. With this many simulation models available, model selection for a particular application is very important. Jackson (1982) defines a technique for model selection which consists of the following five steps:

1) Define the problem and specify information required to reach a decision.
2) Identify available models.
3) Specify the criteria and limits that will be used and define the values for each available model.
4) Estimate cost by item for each model.
5) Rate candidate models and select.

Data requirements for deterministic, distributed parameter simulation modeling vary depending on the model selection. Precipitation is usually considered the driving force for runoff, erosion and sediment processes and is an important input to most models. Watershed characteristics are also essential input data and usually consist of topography, soils and land use information. There are two major approaches to representing watershed characteristics (Smolen, 1983). The first uses a series of regularly spaced discrete points, as exemplified in ANSWERS (Beasley, 1982) and AGNPS (Young, 1986), where watershed characteristics are input into a uniform grid system. The second approach uses spatially independent subsets for which there can be an assumed uniformity of the characteristics. The data is often represented by

Table 1. List of selected hydrologic simulation models.

Model	Simulation Type	Processes Simulated	Reference
ACTMO	continuous	S[1],N[2],P[3],Pest.[4]	Frere et al., 1975
AGNPS	event	S,N,P,COD[5]	Young et al., 1986
ANSWERS	event	S	Beasley and Huggins, 1982
ARDBSN	continuous	S	Stone et al., 1986
ARM	continuous	S,N,P,Pest.	Donigian and Davis, 1978
CREAMS	continuous	S,N,P	Knisel (ed.), 1980
EPIC	continuous	S	Williams et al., 1984
FESHM	event	S	Wolfe, 1982
GAMESP	seasonal	S,P	Rousseau et al., 1985
Gupta	continuous	S	Gupta and Solomon, 1977
HSPF	continuous	S,N,P,Pest.	Johanson et al., 1984
HYMO	event/cont.	S	Arnold et al., 1986
Khanbil-vardi	event	S	Khanbilvardi and Rogowski, 1984
KINEROS	event	S	Smith, 1981
KYERMO	event	S	Hirschi et al., 1983
LANDRUN	continuous	S,P	Novotney et al., 1979
LAVSED	event	S	Julien and Frenette, 1985
NPS	continuous	S,N,P,Pest.	Donigian and Crawford, 1979
PRMS	event	S	Leavesley et al., 1983
SEDEL	event	S	Boyce, 1975
SEDLAB	event	S	Seeley, 1983
SEDIMOT II	event	S	Wilson et al., 1984
SIMSED	event	S	Cotton and Li, 1985
SWAM	continuous	S,N,P,Pest.	Seeley et al., 1986
SWRRB	contiuuous	S	Williams et al., 1985
TENN II	event	S,N,P	Overton, 1980
WASCH	event	S,Pest.	Bruce et al., 1975
WASED	event	S	Li et al., 1976
WATMOD	event	S	Barfield et al., 1979

[1]Sediment
[2]Nitrogen
[3]Phosporous
[4]Pesticides
[5]Chemical Oxygen Demand

irregular boundaries. SEDLAB (Seeley, 1983) and FESHM (Ross et al., 1978) presently use this form of representation.

Hydrologic modeling concepts have been used extensively in relation to surface mining of coal. Hamon (1979) described an ongoing project with the intent of developing or modifying a computer model to simulate both pre- and post- surface mined conditions. This project involved the monitoring of five watersheds in Ohio.

SEDIMOT and SEDIMOT II have been used in several mining related studies. Barfield et al. (1979) and Wilson et al. (1981) used SEDIMOT II to predict sediment yield from surface mined watersheds.

Basin size, geology and land use characteristics were used in a regression analysis to predict pre-mining discharge from small watersheds in Alabama (Van Haveren, 1980). In conjunction with the same program, the Bureau of Land Management intends to use a small watershed hydrologic model developed by the U.S. Geological Survey to estimate hydrologic parameters for ungaged basins and to assist in predicting hydrologic impacts from surface mining (Van Haveren, 1980).

In Tennessee and Indiana, the U.S. Geological Survey, as part of a broad effort to satisfy hydrologic data needs of the SMCRA, is conducting field studies of thirteen mined and unmined areas which will provide a data base for comparing twelve surface mining hydrologic models (Jennings, 1980). Curwick and Jennings (1980) discuss the testing and evaluation of "state-of-the-art" watershed models that have potential use for characterizing the hydrology of surface mined lands. Among the models tested were ANSWERS, FESHM, KINEROS, CREAMS, and HYSIM. Seven additional models will eventually be evaluated. All preliminary tests were carried out using a hypothetical catchment.

In northwestern Colorado, studies are being conducted to assess present surface and subsurface hydrology of areas where mining is occurring or may occur (Saulinger and Goddard, 1982). Mathematical modeling techniques will be used to simulate present hydrologic conditions and will eventually be used as predictive tools.

The Finite Element Storm Hydrograph Model (FESHM) has been used in

several studies related to surface mining. Smolen and Younos (1980) used the FESHM to simulate the hydrologic response of a reclaimed surface mine. Wolfe (1982) added detachment and transport functions to estimate soil loss from reclaimed mine soils.

2.4 GEOGRAPHIC INFORMATION SYSTEMS

Deterministic hydrologic models require large amounts of land and water based spatial data as input. The use of GIS technology in hydrologic modeling can provide efficient spatial data base management. GISs have emerged as the major tool for solving complex natural resource problems that require extensive geographical data (Nystrom, 1986). Cicone (1977) defines any system that integrates layers of spatially oriented information, whether manually or automatically, as a GIS. A computerized GIS is a computer hardware and software system designed to collect, manage, analyze and display spatially referenced data (Nystrom, 1986).

Jett (1979) emphasizes that, with the flexible storage of data available with GIS technology, one can easily use alternate hydrologic models with a single data base. The organization of data in a GIS also permits the appraisal of nonpoint source pollution over large areas on a repetitive schedule (Walsh, 1985). Recent applications of GIS technology have demonstrated the power, efficiency and value of this approach in hydrologic modeling (Jett, 1979).

Spanner (1983) demonstrated the use of an existing county-wide digital data base for the prediction of soil erosion in Santa Cruz County, California. He concluded that utilizing GIS technology makes it possible to inventory large areas at a substantial savings of both time and money.

Walsh (1985) describes the Oklahoma Geographic Information Retrieval System (OGIRS) and a variety of applications in resource management and regional

planning. The advantages cited include ease of retrieval, variety of output products, data updating capabilities, and evaluation of variable coefficients for predictive models.

Jett (1979) describes the Area Design And Planning Tool (ADAPT) which makes use of the Triangulated Irregular Network (TIN) for data storage. This system has been used for hydrologic simulation in northeast Ohio and for nonpoint source modeling in several states.

In a study concerning the Chesapeake Bay, the Patuxent River Basin in Maryland is being modeled using the Hydrologic Simulation Program-Fortran (HSPF) (Summers, 1986). All data is being assembled into a GIS and includes land use, soils, slopes, streams, cultural features, and watershed boundaries.

Shanholtz et al. (1985) illustrated the use of a GIS in identifying agricultural nonpoint source pollution potential. The approach utilized the Map Analysis Package (MAP) by Tomlin (1980) and support software. The development of the Virginia Geographic Information System (VirGIS) is described in detail by Hession et al. (1985) and Shanholtz et al. (1987). The computerized approach was shown to be more effective, less expensive and holds greater potential for reuse than manual methods.

Gupta and Solomon (1977) and Beasley et al. (1977) used uniform grid systems to store land and stream information for use in hydrologic modeling. A modification of CREAMS (Knisel, 1980) was used by Heatwole et al. (1985) along with a cellular data base to simulate water quality parameters. Young et al. (1986) used a cellular GIS database along with the Agricultural Nonpoint Source Pollution Model (AGNPS) to model nonpoint source pollution from large areas.

Vector and raster data structures represent the two principle strategies for digital representation of paper maps. The vector or polygon structure allows exact representation of data boundaries and is often used in cartography. The raster or grid cell structure requires some data generalization, but has superior analytical capabilities (Jett et al., 1979).

Grid cell data bank techniques are discussed in depth by the Hydrologic

Engineering Center (1978). The grid cell size establishes the digital resolution of the data element, but a trade-off must be made between higher resolution and the costs of computer storage and analysis (Johannsen, 1982).

2.5 SUMMARY

Upon review of related literature a number of areas appear in need of additional research. First, although hydrologic models have been used extensively in mining applications, their use, specifically for pre-mining analysis, has been limited. The use of hydrologic models to simplify and minimize efforts involved in pre-mining analysis should be researched and guidelines for this methodology should be created.

Second, the use of GIS technology to improve modeling efficiency and data management should be investigated. Appropriate software needs to be developed to interface GISs with a variety of hydrologic and water quality models. In addition, more research is needed to determine the effects of data availability and resolution on simulation results.

Finally, the application of hydrologic modeling in a totally ungaged context should be investigated. Extensive research is needed to determine whether model results are reliable under these conditions or if some level of calibration is required.

3.0 THE FINITE ELEMENT STORM HYDROGRAPH MODEL

3.1 INTRODUCTION

The Finite Element Storm Hydrograph Model (FESHM) is a single event hydrologic model that was developed by the Agricultural Engineering Department at Virginia Polytechnic Institute and State University to simulate runoff and stream flow in ungaged watersheds. It is a physically based, distributed parameter model. The basic model, developed by Ross (1975, 1978), combines the concept of simulating runoff hydrographs by the finite element method (Judah, 1973; Judah et al., 1975) and the use of hydrologic response units (HRUs) based on readily available soil and land use characteristics (Li, 1975; Li et al., 1977).

The model was later modified to account for transmission losses from the overland flow plane (Heatwole, 1979; Heatwole et al., 1982). The original version considered rainfall to be the only source of water available for infiltration. In Heatwole's modification, substantial changes were made which affected the computational steps and data input to the model. In 1982, Wolfe (1982) modified the model to include an extended sediment prediction capability.

The validity of the original model has been demonstrated extensively on several natural watersheds (Ross, 1978; Ross et al., 1978; Ross et al., 1979). The version including transmission losses was evaluated, using a theoretical sub-watershed, by comparing simulated results with those of the original model. Wolfe et al. (1981) used field erosion plots to evaluate the hydrology and sediment components of FESHM. The modified versions of FESHM have not been evaluated using natural watersheds in an ungaged context.

The original version of FESHM has been used in numerous studies. For example, the model has been used to evaluate the effect of land use on flood flows

(Ross et al., 1978), to simulate surface mine hydrology (Smolen and Younos, 1980), in comparisons with the ANSWERS model (Beasley et al., 1979), for water resource planning (Ross et al., 1984), and in a systems approach to evaluate water quality oriented land management plans (Trapanese, 1982). The most recent version, with sediment yield prediction, was used to simulate soil loss from reclaimed mine soils (Wolfe, 1982; Wolfe et al., 1983).

3.2 MODEL DESCRIPTION

3.2.1 Concepts

The main concept utilized by FESHM is that a complex watershed can be subdivided, or discretized, into smaller, less complex units for analysis. The results from the analysis of these units can then be combined to simulate overall watershed response.

The model structure includes three separate sub-models and two separate discretization schemes. The first sub-model computes the infiltration rate and rainfall excess generated for each HRU. The second sub-model routes the generated rainfall excess across the overland flow plane and through the channel network. The last sub-model, which was not utilized in this study, computes sediment yield by element. A simplified flow chart for FESHM is shown in Figure 1. All input to FESHM must be provided in English units, therefore, all input parameters are presented in this system of units, although the equations and results are presented in metric units.

3.2.1.1 *Discretization*

The first of the discretization techniques provides for a description of the variation of infiltration capacity throughout a watershed. This method divides the

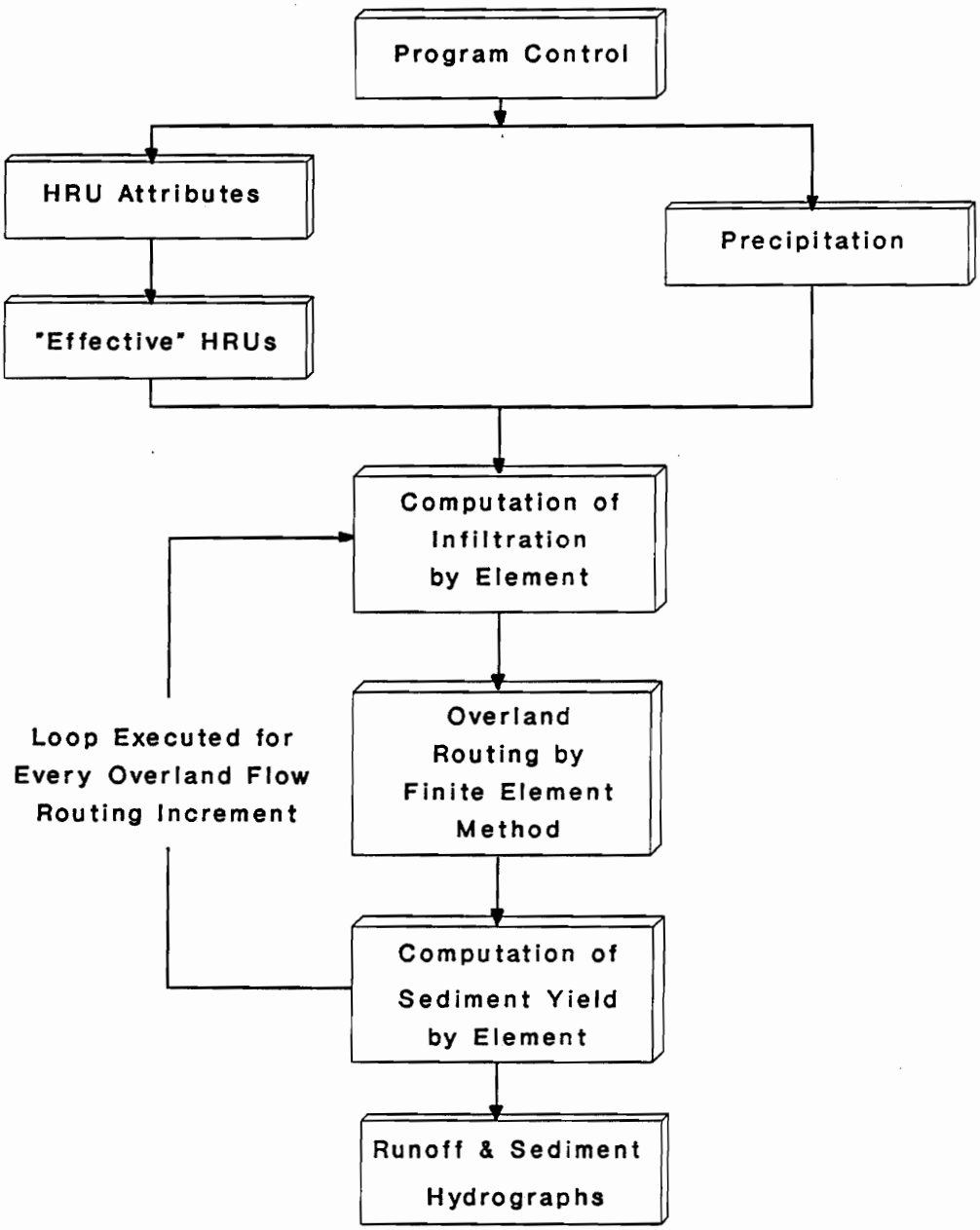

Figure 1. Computational sequence of FESHM.

watershed into previously defined HRUs for computing rainfall excess (Li et al., 1977). Each HRU has uniform soil and land use characteristics which determine it's response to precipitation. These HRUs are delineated by overlaying soil and land use maps, as shown in Figure 2. For example, the 2 soils and 3 land uses shown combine to produce 5 unique HRUs.

The second discretization scheme accounts for variation of drainage and topographic characteristics within a watershed. Different levels of discretization may be used depending on watershed complexity and the resolution of available data. The watershed is first partitioned into sub-watersheds defined by the main tributaries of the drainage network. Each sub-watershed is discretized into overland flow strips which drain into the sub-watershed's channel. The flow strips then can be further divided into sequential overland flow elements that account for the variation of flow characteristics within a flow strip. Each overland flow element then is assigned an index number. The result is a finite element grid structure for the watershed. An example for a rectangular section (Figure 3) depicts a finite element grid structure with two overland flow strips, five elements and two channel sections. The purpose of this discretization is for routing flows through the watershed. The equations of motion are solved independently for each flow strip or channel reach using finite element numerical procedures as described by Judah (1973) and Judah et al. (1975).

These two separate discretization schemes rarely result in common unit boundaries within a watershed. The original model (Ross, 1975; Ross, 1978) resolved this problem by area-weighting HRU rainfall excess values within each element. The most recent version of FESHM (Heatwole, 1979; Heatwole et al., 1982), due to computational differences, requires that elements contain single HRUs or "effective" HRUs. An "effective" HRU must be determined by area-weighting HRUs within each flow element and entered as input to the model. This requirement becomes impractical when modeling complex drainage basins. Therefore, FESHM was modified to provide for internal area-weighting of HRU characteristics within each element, which allowed input to the model to retain the format and requirements of

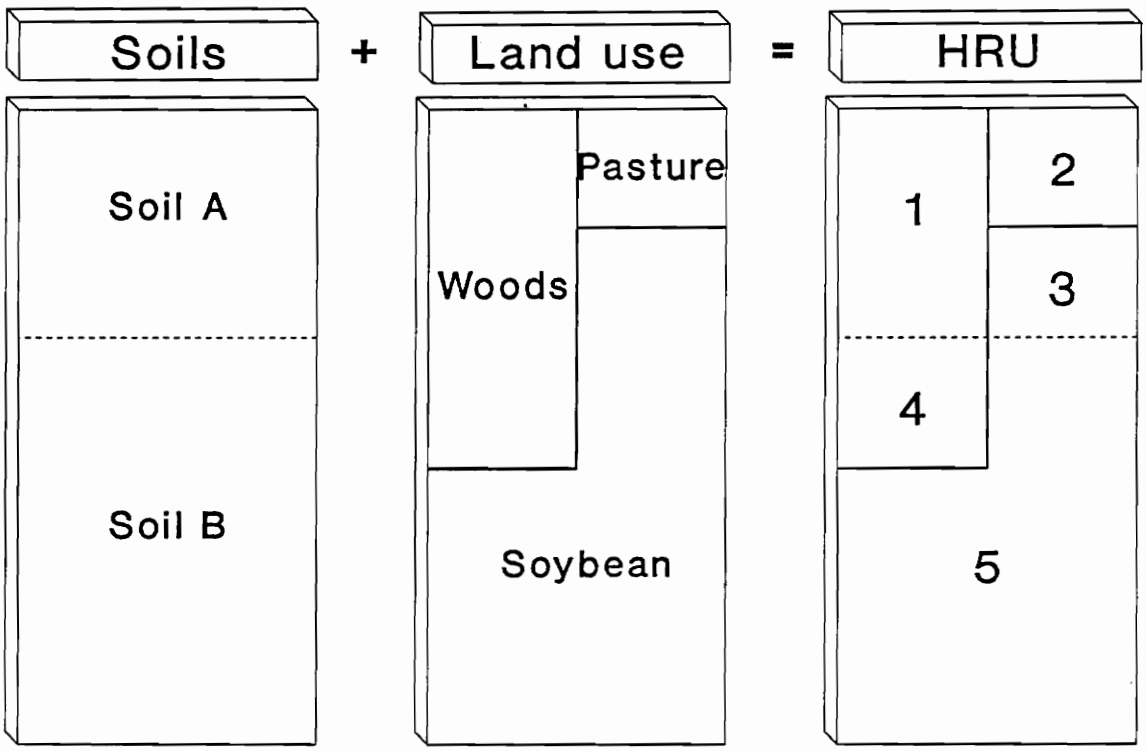

Figure 2. Schematic illustration of the process for determining Hydrologic Response Units (HRUs).

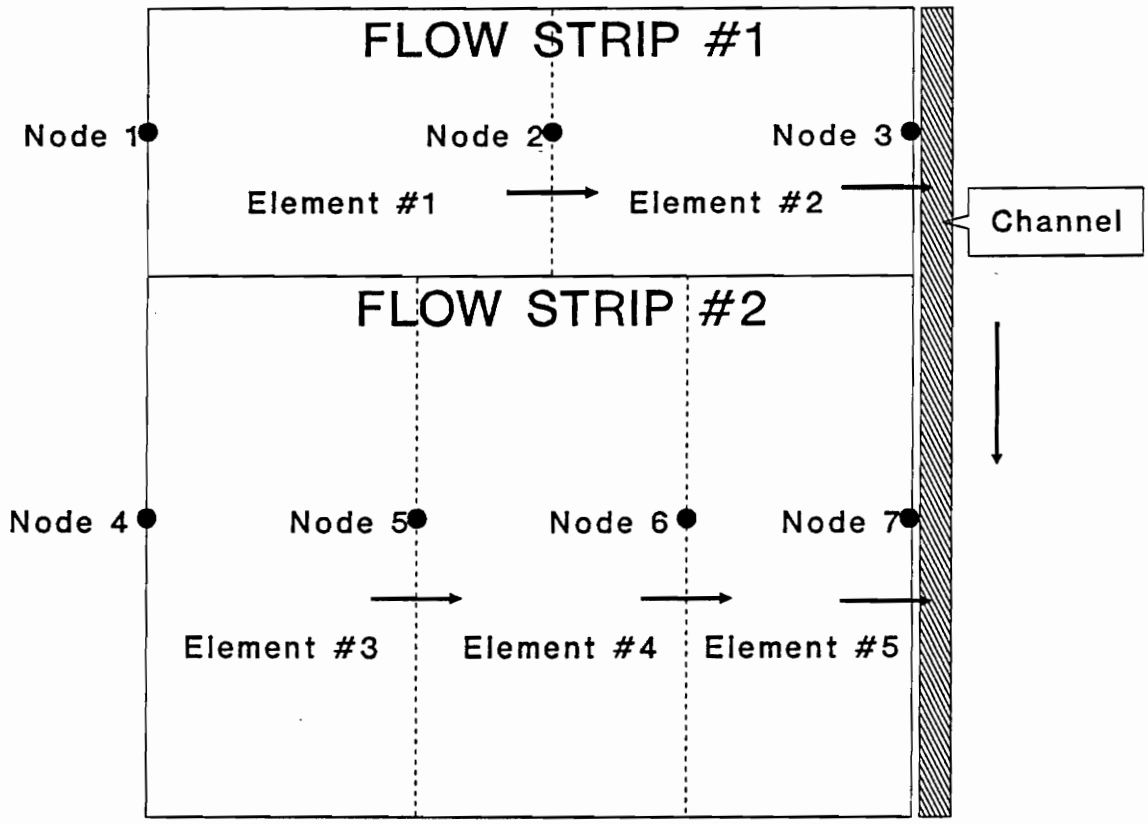

Figure 3. A typical finite element grid structure for an idealized overland flow plane.

the original version of FESHM. The modifications of FESHM are discussed in a later section.

3.2.1.2 *Rainfall Excess*

Rainfall excess is computed using the Holtan infiltration equation (Holtan, 1961). This empirical model was chosen because the equation parameters correspond closely to the criteria used to define HRUs. The Holtan model is expressed as:

$$F = GI * a * S^{n} + F_{c} \qquad [1]$$

where F is the infiltration rate in mm/hr (in/hr), GI is a monthly growth index, a is the land use cover factor, S is unfilled storage space to a restrictive layer in mm (in), n is the ratio of the potential gravitational water to the potential plant available water in the storage layer, and F_c is the final infiltration rate of the restrictive layer in mm/hr (in/hr). A schematic representation of the Holtan infiltration equation is shown in Figure 4.

Using this equation the infiltration capacity and rainfall excess are computed for each HRU, during each rainfall increment of the storm. The unfilled storage space, S, is also computed for each time interval. Depression storage is accounted for using a simple algorithm to abstract initial rainfall excess produced by the HRUs.

3.2.1.3 *Routing Overland and Channel Flow*

In order to accomplish flow routing, the finite element numerical procedure is used to solve the St. Venant equations of continuity and momentum. This procedure is applicable to both overland and channel flow. The continuity equation can be expressed as:

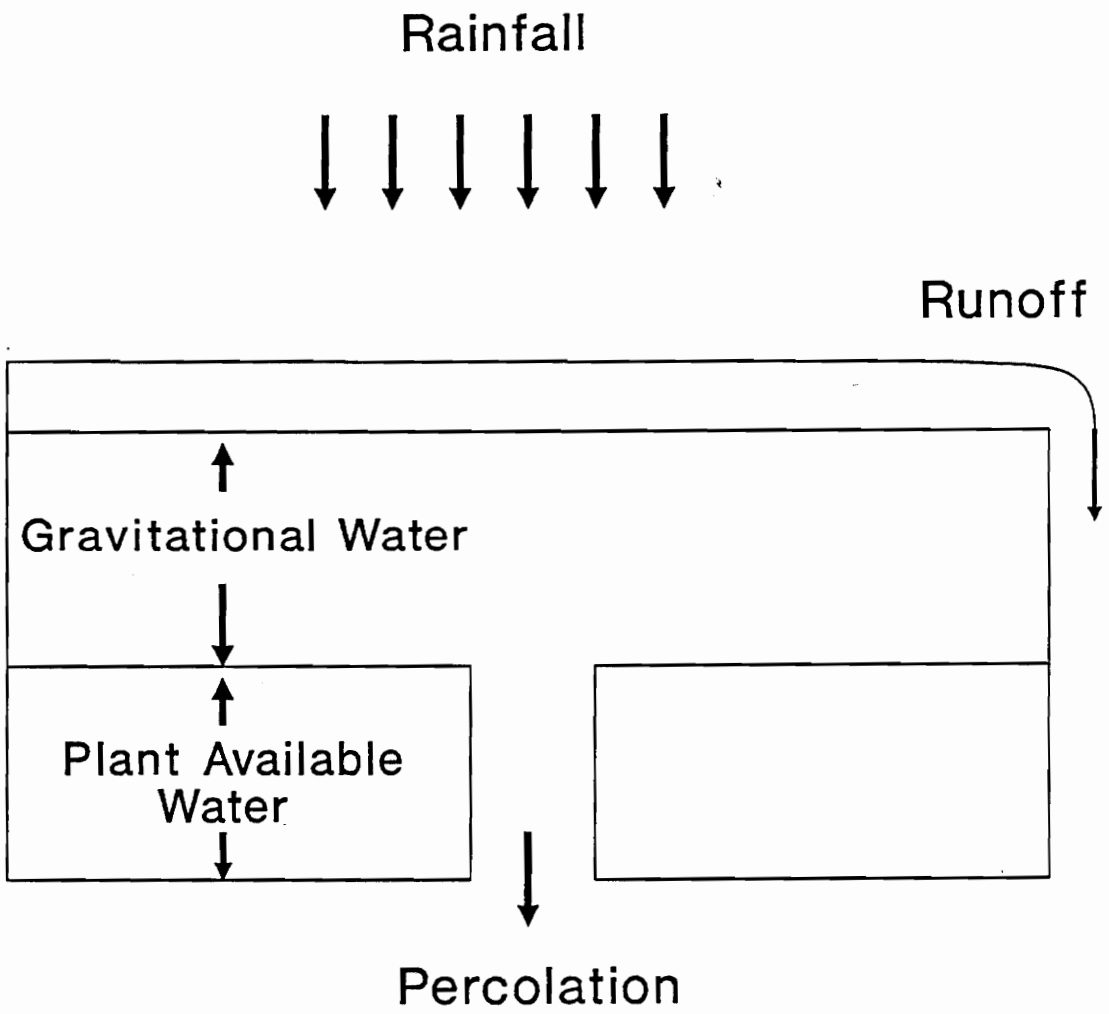

Figure 4. Schematic representation of the Holtan Infiltration equation.

$$\partial Q/\partial x + \partial A/\partial t - q = 0 \qquad [2]$$

where Q is the discharge in m^3/s (ft^3/s), A is the cross-sectional area of flow in m^2 (ft^2), q is the lateral inflow per unit length of flow plane in m^2/s (ft^2/s), x is the distance in the direction of flow in m (ft), and t is time in seconds.

The kinematic wave approximation is used to simplify the momentum equation. This results in a steady flow equation such as the Manning equation (Ross et al., 1978), which can be expressed as:

$$Q = R^{2/3} * S^{1/2} * A / n \qquad [3]$$

where Q is the discharge in m^3/s, R is the hydraulic radius in m, S is the bed slope of the flow plane, A is the cross-sectional area of flow in m^2, and n is the roughness coefficient of the overland surface or channel.

The finite element routing component is structured as a system of linear elements ordered to approximate the response of a watershed. The rainfall excess is considered a lateral input to the overland flow elements. The routed flow from each overland strip is then a lateral input to the receiving channel.

3.2.2 Data Requirements

Requirements and procedures for developing a data base for FESHM are described in great detail by Ross et al. (1978) and Smolen et al. (1984), thus, to avoid repetition, only a brief summary is presented. Data base preparation for specific watersheds used in this research project are discussed in later sections.

The data needs of FESHM can be divided into two major categories: storm event description and watershed characterization. The watershed characterization parameters then can be separated into those used to define HRUs and those used to describe overland and channel elements.

3.2.2.1 *Storm Event*

FESHM requires that rainfall distributions be provided in equal time intervals. If available rainfall data is hourly or daily, the user must assume some distribution. FESHM provides for incorporation of data from several raingages by use of an indexing scheme. A rainfall sequence is entered for each raingage in the watershed, then each overland flow element is assigned to an appropriate raingage.

Since FESHM is an event model, some estimate of initial moisture content is required. This estimate can be provided using three different procedures. A single estimate may be entered as a fraction of the field capacity for the entire watershed, each HRU can be assigned an appropriate fraction, or the initial moisture content of each HRU can be computed internally using an antecedent moisture accounting algorithm. The routine for internally computing antecedent moisture requires the input of a thirty day sequence of daily precipitation and an estimate of average monthly evapotranspiration.

3.2.2.2 *Hydrologic Response Unit Attributes*

As mentioned previously, the HRUs used by FESHM are determined by overlaying land use and soils maps. Consequently, the parameters needed to describe the HRUs can be divided into two categories: land use attributes and soil attributes.

Land use parameters which must be defined for each HRU are: Holtan's vegetative index (AFLU), overland flow roughness coefficient (RCLU) and depression storage (DSLU). Estimates for these factors can be found in Table 2. Additional parameters that are required when simulating sediment losses are the cover-management factor (C) and the practice factor (P) from the Universal Soil Loss Equation (USLE). Guidelines for estimating these parameters can be found in Schwab et al. (1981).

The soil attributes are more difficult to determine, depending on the extent and resolution of the data available for the watershed. The parameters which must be estimated for each soil type are: plant available water (FAW), gravitational water

Table 2. Estimates for land use attributes (Ross et al., 1972).

Land Use Number	Land Use Type	AFLU[1]	RCLU[2]	Depression Storage
1	SMALL GRAIN	0.30	0.08	0.15
2	CORN	0.20	0.08	0.15
3	HAY	0.70	0.25	0.30
4	PASTURE	0.60	0.15	0.40
5	TOBACCO	0.20	0.08	0.10
6	WOODS (LIGHT)	0.80	0.35	0.50
7	WOODS (DENSE)	1.00	0.45	0.50
8	IDLE LAND	0.70	0.25	0.30
9	ROADS	0.00	0.02	0.05
10	SOYBEANS	0.40	0.08	0.15
11	COTTON	0.40	0.08	0.15
12	SORGHUM	0.20	0.08	0.15
13	FALLOW	0.20	0.05	0.80
14	HOMESTEAD	0.50	0.15	0.40
15	CEMETERY	0.80	0.15	0.40
16	BUILDING & LOT	0.50	0.03	0.02
17	POND	0.00	0.01	10.00

[1] Holtan's vegetative index.
[2] Overland flow roughness coefficient.

(FGW), final infiltration rate (F_c) and the depth to controlling soil layer. When modeling sediment losses, the USLE's erodibility factor (K) must be provided which can be found in appropriate county soil surveys.

FAW is defined as the moisture capacity in the soil between field capacity, 33.33 kPa (1/3 bar), and wilting point, 1500 kPa (15 bar). Estimates for this parameter can be found in the physical and chemical property charts of recent county soil surveys and in Table 3 based on soil textural classes. FGW is the moisture capacity between saturation and field capacity. This parameter is not provided in county soil survey reports, but can be estimated from soil textural class, Table 3.

The F_c is an estimate of the final infiltration rate and can be approximated by the saturated hydraulic conductivity of the restrictive layer in the soil profile. It can be estimated as the low end of the range of infiltration capacities specified in soil series descriptions. As an alternative procedure, F_c values can be estimated from hydrologic soil group as shown in Table 4.

The control depth is usually assumed to be the depth of the "A" soil horizon, although this is not always the case. The control depth should be defined as the depth to a restrictive layer. It can be determined from infiltration data if rates are given at several depths of the soil profile, as in Holtan et al. (1968). A dramatic reduction in infiltration rate indicates a restrictive layer. The control depth also can be estimated from data on root penetration and soil color. The absence of roots or the appearance of strong colors is usually an indication of a restrictive layer.

3.2.2.3 *Overland and Channel Element Attributes*

Descriptive information for overland and channel elements are given by sub-watershed to define the element geometry and surface conditions that affect flow. Data required for each overland flow element are: average overland flow length, relief, area and width of the downstream node. This information can be obtained from topographic maps of the watershed or from field surveys.

Channel element description includes the channel length and relief, the

Table 3. Estimates of water storage capacities based on soil texture (England, 1970).

Soil Texture	FAW[1] (in./in.)	FGW[2] (in./in.)	Total Storage Capacity (in./in.)
Coarse Sand	0.067	0.177	0.244
Coarse Sand Loam	0.087	0.153	0.245
Sand	0.133	0.190	0.323
Loamy Sand	0.101	0.269	0.370
Loamy Fine Sand	0.054	0.272	0.326
Sandy Loam	0.123	0.186	0.309
Fine Sandy Loam	0.131	0.235	0.366
Very Fine Sandy Loam	0.117	0.210	0.327
Loam	0.156	0.144	0.300
Silty Loam	0.199	0.114	0.313
Sandy Clay Loam	0.119	0.134	0.253
Clay Loam	0.127	0.130	0.257
Silty Clay Loam	0.119	0.134	0.253
Sandy Clay	0.078	0.116	0.194
Silty Clay	0.123	0.091	0.214
Clay	0.115	0.073	0.188

[1] Plant Available Water Capacity
[2] Gravitational Water Capacity

Table 4. Estimates of final infiltration rate based on hydrologic soil group (Li et al., 1977).

Hydrologic Soil Group	Final Constant Infiltration Rate (in./hr)
A^+	0.450
A	0.400
A^-	0.350
B^+	0.300
B	0.250
B^-	0.200
C^+	0.150
C	0.100
C^-	0.075
D^+	0.050
D	0.025
D^-	0.000
Impervious	0.000

channel roughness coefficient, and a description of the channel cross-section at the downstream node. Each channel resides at the intersection of two overland flow strips, therefore, its length coincides with the width of the last overland flow element in these strips. Estimates for channel roughness coefficients can be determined through visual observation and information given in Chow (1959). The channel geometry is assumed to be triangular and the top width for a 0.61 m (2 ft) depth must be given.

3.2.3 Model Output

All output provided by FESHM is controlled by program options defined at the beginning of program execution. Normal output includes an echo of precipitation input and the simulated runoff hydrograph at the watershed outlet. Runoff information includes discharge rate, channel cross-sectional area, flow velocity, and depth of flow for each time step. The printout time step can be any multiple of the computational time step.

Optional output includes tables that describe the properties of "effective" HRU's, rainfall excess per HRU, and weighted rainfall excess per element. In addition, a listing of overland and channel discharge hydrographs can be obtained at various locations throughout the watershed. If erosion is being simulated, the output would include sediment load, accumulated sediment, and sediment concentration at each time step. A sample output file is shown in Appendix A.

3.3 MODIFICATIONS

3.3.1 Language Modifications

The original model was written using the Fortran 66 programming language. Recent enhancements in the Fortran language are included in the Fortran 77 programming language. The model was not rewritten to the advantage of all enhancements. Some minor modifications, however, were made to allow for generating an executable module with the Fortran 77 compiler. A computer program listing of FESHM is given in Appendix B.

The program also was modified to allow the use of the WATFIV fortran compiler. The WATFIV compiler provides more thorough error messages and diagnostics, and the Fortran 77 compiler generates code with faster execution time.

FESHM uses many large storage arrays during execution. The size requirements for these arrays were not well documented, which created difficulty when using the model with different sized storms and/or different watersheds. When including great spatial detail during the modeling of large watersheds, it is important to dimension arrays correctly because serious problems can result from exceeding computer memory. The Fortran 77 compiler does not provide good error diagnostics when array overflows occur. It is suggested that the first simulation be made using the WATFIV compiler in order to check array dimensioning. The remainder of the simulations should be made with the Fortran 77 compiler, which is much faster and consequently, less expensive. A list of variables and their array size requirements were compiled and included in Appendix C.

3.3.2 Computational Modifications

As mentioned previously, the most recent version of FESHM (Heatwole, 1979) requires elements to contain single HRUs or that HRU parameters be area-weighted prior to input to the model. Watersheds with complex land use and soil type patterns rarely have HRU and element definitions whose boundaries correspond. Therefore, achieving hydraulic continuity requires a redefining of the element grid structure to match the HRU boundaries or creating "effective" HRUs for each element. For most applications on large watersheds, creating "effective" HRUs is the desirable approach. Defining "effective" HRUs manually can be a time consuming and tedious process. Therefore, a subroutine, EFFHRU, was added to FESHM which computes "effective" HRUs internally. The properties for all HRUs are supplied, along with the type and percentage of each HRU within a given overland flow element. The HRU properties are then area-weighted within each element, thereby creating a new set of HRU properties for each element. This creates an "effective" HRU that conforms to the geometric configurations of each element and provides hydraulic continuity between elements. The program listing for this subroutine is included in Appendix B.

Using this technique, input to the FESHM remains the same as described by Ross et al. (1978). However, the original model weighted HRU rainfall excess values within each element, as opposed to weighting HRU characteristics and then calculating rainfall excess (Ross, 1975; Ross 1978). Ross et al. (1978) discussed these two alternatives in detail and found no significant advantage of one method over the other.

4.0 GEOGRAPHIC INFORMATION SYSTEM

4.1 INTRODUCTION

One of the objectives of this study was to use GIS technology to improve data management and modeling efficiency. Data bases were built and software was developed to assist in the process of creating input files for FESHM.

A major disadvantage of using physically based, distributed parameter models, such as FESHM, is the large amount of input data required to describe the spatial detail of a watershed. The creation of such a data base can be difficult and time consuming.

The two discretization schemes used in FESHM can be readily defined using GIS technology. To define HRUs, a soil map and a land use map are overlaid and the unique combinations formed from these two maps are defined as HRUs. After the HRU map is defined, the user assigns appropriate land use and soil attributes to each HRU. This can be a tedious process depending on the resolution and complexity of the soil and land use maps.

The second discretization scheme, which is used to route overland and channel flow, involves subdividing the watershed into a series of sub-watersheds, flow strips, and elements. Because the two schemes usually do not result in polygonal units with matching boundaries, a technique must be used to assure continuity. As previously noted, an "effective" element HRU is determined by weighting HRU characteristics as a function of element area. To accomplish these computations a list of HRUs and their fractional area within the element must be provided as input to the model. To obtain these data the area of each element and it's HRUs must be measured. From this information the fraction of each HRU is computed. This also can be a difficult and time consuming process.

A computerized GIS was developed to simplify and enhance the process of building an input file for simulating watershed hydrology with FESHM. The data base creation and management, and the software development are described in the following sections.

4.2 DATA BASE

A GIS was used to develop the geographic data base for each study area. As described previously, vector and raster data structures are the two principal strategies used for digital representation of paper maps. The raster method was chosen for this study because of cost and equipment constraints.

Figure 5 illustrates the method proposed for developing geographic data bases and interfacing them with FESHM. Topographic, soils, and land use maps were obtained for each study area. The element discretizations were then defined on the topographic maps as described previously in Section 3.2.1.1. Element, soil, and land use data were then interpreted by overlaying the appropriate paper maps with transparent uniform grids and assigning a numeric value to each cell using the majority rule. The resulting grid maps were manually entered into the computer, producing three separate computerized map files. All data were referenced to the Universal Transverse Mercator (UTM) coordinate system.

In addition to the three digital map files, attribute lists for land use and soil types were needed which included characteristics necessary for defining the hydrology of each HRU. The important characteristics for each land use type included; the land use index number, Holtan's vegetative index, roughness coefficient, depression storage, cover factor (C factor in USLE), and practice factor (P factor in USLE). The soil attribute lists contained, for each soil; a soil index number, plant available water holding capacity, gravitational water holding capacity, final

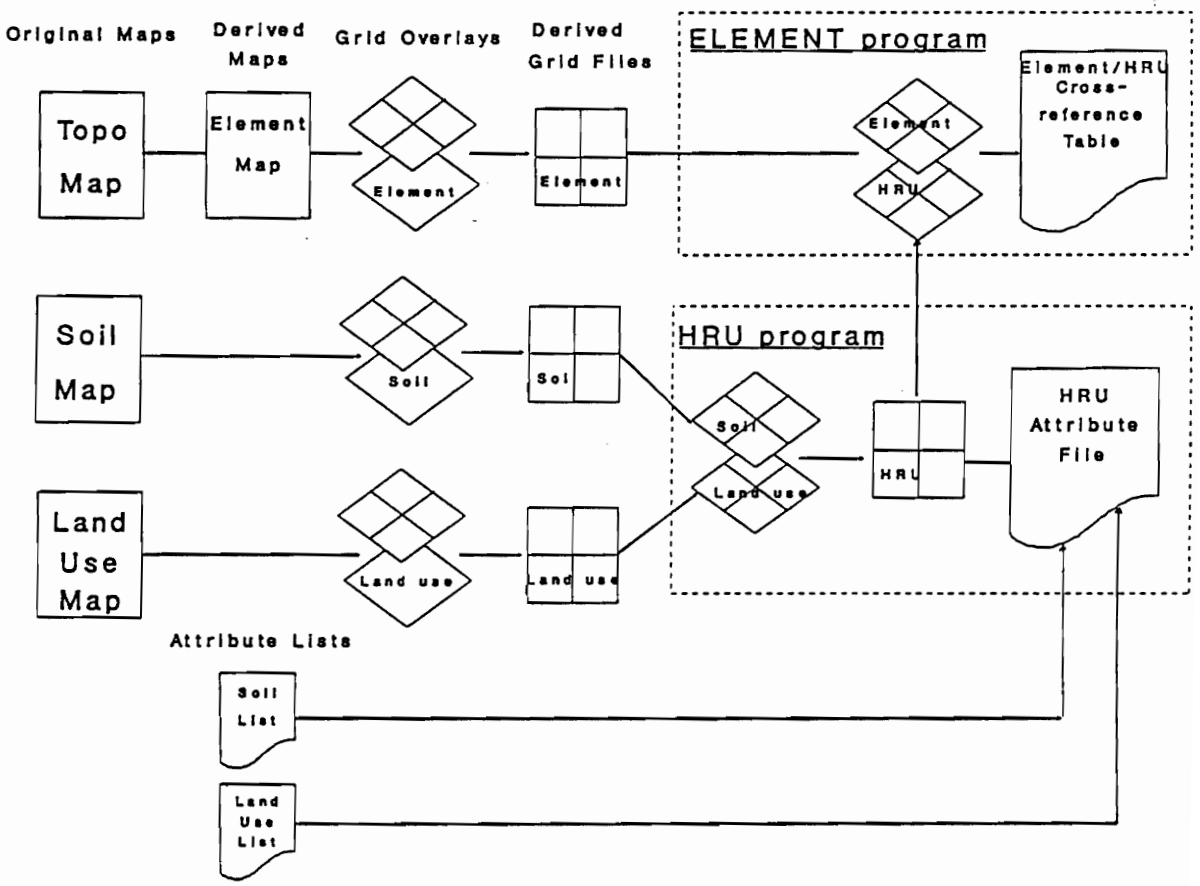

Figure 5. Schematic of procedures and methods used for integrating a computerized GIS with FESHM.

infiltration rate, depth to control layer, and erodibility factor (K factor in USLE).

Each watershed data base includes three data layers and two attribute tables. The element data layer was created to provide a method for organizing the geographic related data by sub-watershed, overland flow strip and element. As previously noted, the HRU data layer must be summarized to match the element grid structure. By computer techniques, the element data layer is overlaid on the HRU data layer (derived from soils and land use) and model parameters are derived for each element. Without the element data layer the spatial orientation of data required by FESHM cannot be automatically determined with the computer. Example digital map files and attribute lists are presented in Appendix D.

4.3 SOFTWARE

Two computer software packages were written in Fortran 77 to use the GIS data bases to produce input files in the format required by FESHM. Using the two programs, HRU.FOR and ELEMENT.FOR, significantly reduced the time and effort required to develop input data bases for FESHM. Figure 5 illustrates the functions performed by the two software packages.

The first program, HRU.FOR, overlays the soil and land use data layers and creates the HRU data layer. The technique, which is illustrated in Figure 2, involved assigning each unique combination of soil type and land use to a different HRU number. The same combination can occur at many locations but would be coded with the same HRU number. This program also uses the soil and land use attribute files along with the HRU data layer to create a HRU attribute list required by FESHM.

The second program, ELEMENT.FOR, determines the fractional area of coverage of HRUs per overland flow element. This involves overlaying the HRU data layer, created by HRU.FOR, and the element data layer. The result is an

element/HRU cross-reference table, which is required by FESHM. This table contains, for each overland flow element, a list of HRU types and their fractional area within the element. Listings of the two software packages are presented in Appendix D.

4.4 DISCUSSION

The GIS does not generate a complete FESHM input file. The system, however, greatly simplifies data management and reduces the difficulty and time involved in setting up data bases required by FESHM. The results of this effort are consistent with Hellmund et al. (1986) who stated that computerized GISs are more effective, less expensive, and hold greater potential for reuse than manual methods. The software can be readily interfaced with cellular type GISs such as the Virginia Geographic Information System (VirGIS) (Shanholtz et al., 1986).

Table 5 lists the different groups of data within a FESHM input file and the method of generation used in this study. These groups of data are illustrated within the sample input file listed in Table 6. Although only groups 3 and 4 are presently generated using GIS technology, these two groups of data represent a major portion of FESHM input files.

No attempt was made to computerize the generation of groups 5 and 6 due to time constraints. It may be feasible to add digital elevation and channel maps to the data bases and develop software that would produce groups 5 and 6 of FESHM input files.

Table 5. FESHM input data groups and methods of generation.

Group[1] Number	Description	Method of Generation
1	Control options	Manual
2	Rainfall distribution	Manual
3	Element/HRU cross-reference	GIS
4	Land use and HRU descriptors	GIS
5	Computation time and index for flow routing	Manual
6	Element descriptors for overland and channel flow	Manual

[1] Group number refers to those indicated in Table 6.

Table 6. FESHM input file with data group designations.

```
   1    1        600        600
 0 0 0 0 0 0 0
 0 0 0 0 0 0 1
DATA BASE
       1          6         10        900       1.00
   1    1    1   87
 0.07000   0.08000   0.10000   0.10000   0.12000   0.13000   0.23000   0.27000
 0.79000   0.78000   0.26000   0.23000   0.16000   0.17000   0.14000   0.11000
 0.12000   0.10000   0.11000   0.08000   0.09000   0.09000   0.08000   0.09000
  .30  0.30  0.30  0.45  0.60  0.80  0.90  0.90  0.75  0.40  0.30  0.30
       2          4          6         18
       2
     1        3
0.8889   0.1111
       2
     1        3
0.7273   0.2727
       4
     1        2        3        4
0.5789   0.2632   0.0789   0.0789
       4
     1        2        5        6
0.1111   0.2222   0.5556   0.1111
    0.30       0.20       0.50       0.80       0.20       1.00       0.90       0.00
    0.40       0.40       0.20       0.10       0.90       0.90       0.90       0.80
    0.00       0.45
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
   00.00       0.00
    0.10       0.10       0.20       0.25       0.10       0.40       0.30       0.02
    0.15       0.15       0.10       0.10       0.35       0.25       0.25       0.02
    0.02       0.25
  4   0.139    0.089    0.335  13.000     A   0.000   0.320 0.00600    0.500     2
  6   0.139    0.089    0.335  13.000     A   0.000   0.320 0.00100    0.500     2
  4   0.139    0.089    0.335  16.000     A   0.000   0.320 0.00600    0.500     1
  6   0.139    0.089    0.335  16.000     A   0.000   0.320 0.00100    0.500     1
  6   0.139    0.089    0.335  10.000     A   0.000   0.320 0.00100    0.500     3
  4   0.139    0.089    0.335  10.000     A   0.000   0.320 0.00600    0.500     3
    150          50
0    0    0    1    1    0    1
2    3
1    4
5    6
0
2
1    1
   300          50       19.8       2750
   600          80       44.5       2750
  2750         210      .1200      45.00
2
1    1
   300          30        2.5        400
   500          45        4.9        400
   400          15      .0900      75.00
```

GROUP 1

GROUP 2

GROUP 3

GROUP 4

GROUP 5

GROUP 6

5.0 DATA PREPARATION

5.1 SITE SELECTION

Three experimental watersheds, with hydrologic records, were chosen to evaluate the capability of FESHM to predict runoff from storm events in an ungaged context. The most recent version of FESHM, which includes transmission loss has not previously been evaluated for its ability to predict storm flows from natural watersheds.

One objective of this study was to evaluate the performance of the model over a wide range of flow conditions. Of particular interest, was the expected range of error for a given storm sequence. Validation, therefore, was a matter of establishing the ability of FESHM to simulate peak flow rate and runoff volume in an ungaged context, thereby, providing more confidence in it's ability to simulate pre-mining hydrologic responses, where historical records rarely exist.

For this study, the Brush Creek watershed located near Floyd, Virginia was selected for an evaluation of FESHM's predictive ability. Nineteen years of rainfall-runoff, land use, and soils data exist for this area, however, only seventeen years of this data were used because data from 1975 and 1976 were not available at the time of this study. Two additional drainage basins, Millstone Branch and Right Fork Sandlick Creek, with limited hydrologic records were selected because they were located within surface mining regions. The periods of record for these watersheds were four and two years, respectively. The simulations of storm runoff from selected storm events were used to evaluate FESHM's simulation capabilities in real world situations. A discussion of the simulations, by watershed, is given in Chapter 7.

5.2 DESIGN STORMS

In order to conduct several objectives of the proposed study a design storm was needed. Although the selection of an appropriate storm can be accomplished in several ways, the approach used in this study was to make use of design recommendations developed by the Virginia DMLR.

The Virginia DMLR recommends the use of a 10-year, 24-hour rainfall event for design considerations, but at the time of this study they were in the process of changing this recommendation to a 25-year, 6-hour rainfall event. With this in mind, both rainfall events were chosen as design storms for the various studies.

The rainfall volumes for these storms, for the various watersheds, were obtained by using the equation developed by Weiss (1962), as described by Schwab et al. (1981), and are listed in Table 7. The rainfall intensity patterns were computed from the Soil Conservation Service (SCS) Type II storm distributions (Kent, 1968).

5.3 BRUSH CREEK WATERSHED

5.3.1 Description of Watershed

The Brush Creek watershed, which is located in Floyd County, Virginia, drains 361 hectares (893 acres), with approximately 68 percent farm land and 32 percent forest land. Total watershed relief is 119 meters (390 feet) with 42 percent of the area having slopes greater than 15 percent. The area is characterized by well drained loam and sandy loam soils.

Precipitation and stream flow were monitored from late 1957 to 1976. Two continuous recording raingages were located in the watershed. Stream flow was

Table 7. Rainfall volumes of the two design storms for each watershed.

Watershed Name	Design Storm Volumes (mm)	
	10-yr., 24-hr.	25-yr., 6-hr.
Brush Creek	135.9	114.3
Millstone Branch	104.0	92.4
Right Fork Sandlick Creek	105.8	92.9

measured using a broad crested Virginia V-notched weir and an FW-1 water level recorder.

5.3.2 Data Base

5.3.2.1 *Introduction*

Detailed geographic surveys of the Brush Creek watershed were available from previous research projects. In most cases, sites undergoing pre-mining analysis would not have such detailed geographic information available. The effect of limited data availability and/or lumping on FESHM's predictive ability was investigated by creating two separate data bases for the Brush Creek watershed. The first, or "detailed" data base utilizes the detailed geographic surveys mentioned previously, while the second, or "lumped" data base ignores these detailed surveys and utilizes sources which would be readily available for most pre-mining analyses.

Geographic data requirements for FESHM were previously described in Chapter 3, and a procedure using GIS technology was given in Chapter 4. Using these procedures the two data bases were assembled.

5.3.2.2 *"Detailed" Data Base*

Detailed soils, land use, and topographic maps were available for this study from a small watershed hydrology program[1]. The first step was to create geographic data layers for each map type. The data layers were created following procedures previously outlined in Chapter 4. To minimize inventory error, the data were digitized at 1/4 hectare (0.62 acre). This cell size is expected to result in less than 2 percent inventory error based on work by Wehde (1982). This procedure resulted in digital data layers of 40 by 62 cells or a total of 2480 cells.

1. A result of a cooperative research agreement between the USDA Agricultural Research Service and the Agricultural Engineering Department at Virginia Polytechnic Institute and State University (no reference available).

Soils: The soil survey of the watershed was conducted by Williamson et al. (1965) and includes 35 soil types. The map scale was 1:7920, which required creating an overlay of square grids measuring approximately 6.35 mm (0.25 in.) on a side. This overlay was overlaid on the soils map and the predominate soil type in each cell was recorded. After recording all data, the information was manually entered into a computer file. A soil attribute list (Table 8) was created based on work by Ross (1978) and manually entered into a computer file.

Land use: Detailed land use surveys were made annually as part of the small watershed hydrology program. Land use remained reasonably constant throughout the duration of the program. For this study, the 1968 land use map was selected for inclusion in the geographic data base. Preparation and data entry were identical to those described for entering soil types. A land use attribute list (Table 2) was created from Ross et al. (1978) and manually entered into a computer file.

Topography: A detailed topographic map of the Brush Creek watershed was used to create a finite element grid (Figure 6) using procedures described in Chapter 3. The grid structure contains 17 subsheds and 64 elements. The map scale was 1:13080, which required creating an overlay of grids measuring 3.81 mm (0.15 in.) on a side. The overlay was overlaid on the finite element map and each grid was assigned an element number using procedures described previously.

HRUs: The distribution of HRUs throughout the watershed is shown in Figure 7. The HRUs were determined with computer program HRU.FOR and the soil and land use digital files as described in Chapter 4. Output included a digital HRU data layer and the HRU attribute section of the FESHM input file (data group 4, Table 5).

Elements: Computer program ELEMENT.FOR, the HRU digital data layer, and the finite element grid digital data layer were then used to create the element/HRU cross-reference section of the input file, or data group 3 (Table 5), and a list of elements and their areas to assist in creating the element attribute section of the input file, or data group 6 (Table 5). An example input file for the "detailed" Brush Creek data base is shown in Appendix E.

Table 8. Brush Creek "detailed" soil parameter list.

Index No.	Soil Type	FAW (in./in.)	FGW (in./in.)	F_c (in./hr)	Depth (in.)
1	125C	.106	.183	.117	25.0
2	125D	.106	.183	.117	21.0
3	125E	.106	.183	.117	16.0
4	11B	.153	.090	.160	20.5
5	11C	.153	.090	.160	15.6
6	11D	.153	.090	.160	14.1
7	116C	.153	.090	.160	15.6
8	116D	.153	.090	.160	14.1
9	49F	.141	.093	.085	10.0
10	12B	.149	.151	.098	25.0
11	12C	.149	.151	.098	16.0
12	121C	.149	.151	.098	16.0
13	44C	.141	.093	.085	19.5
14	44D	.141	.093	.085	14.7
15	70B	.141	.093	.085	20.2
16	70C	.141	.093	.085	15.3
17	124D	.149	.151	.098	12.0
18	123D	.149	.151	.098	12.0
19	126E	.149	.151	.098	8.0
20	127C	.149	.151	.098	4.8
21	118A	.153	.090	.040	22.0
22	18E	.141	.093	.085	17.5
23	18F	.141	.093	.085	12.5
24	28C	.153	.090	.160	14.0
25	30C	.141	.093	.085	19.5
26	30D	.141	.093	.085	14.7
27	30E	.141	.093	.085	13.7
28	98D	.141	.093	.085	18.5
29	98E	.141	.093	.085	17.5
30	119B	.140	.160	.140	18.0
31	119C	.140	.160	.140	13.0
32	119D	.140	.160	.140	12.0
33	4A	.106	.183	.117	16.0
34	7C	.141	.093	.085	10.3
35	111C	.153	.090	.160	15.6

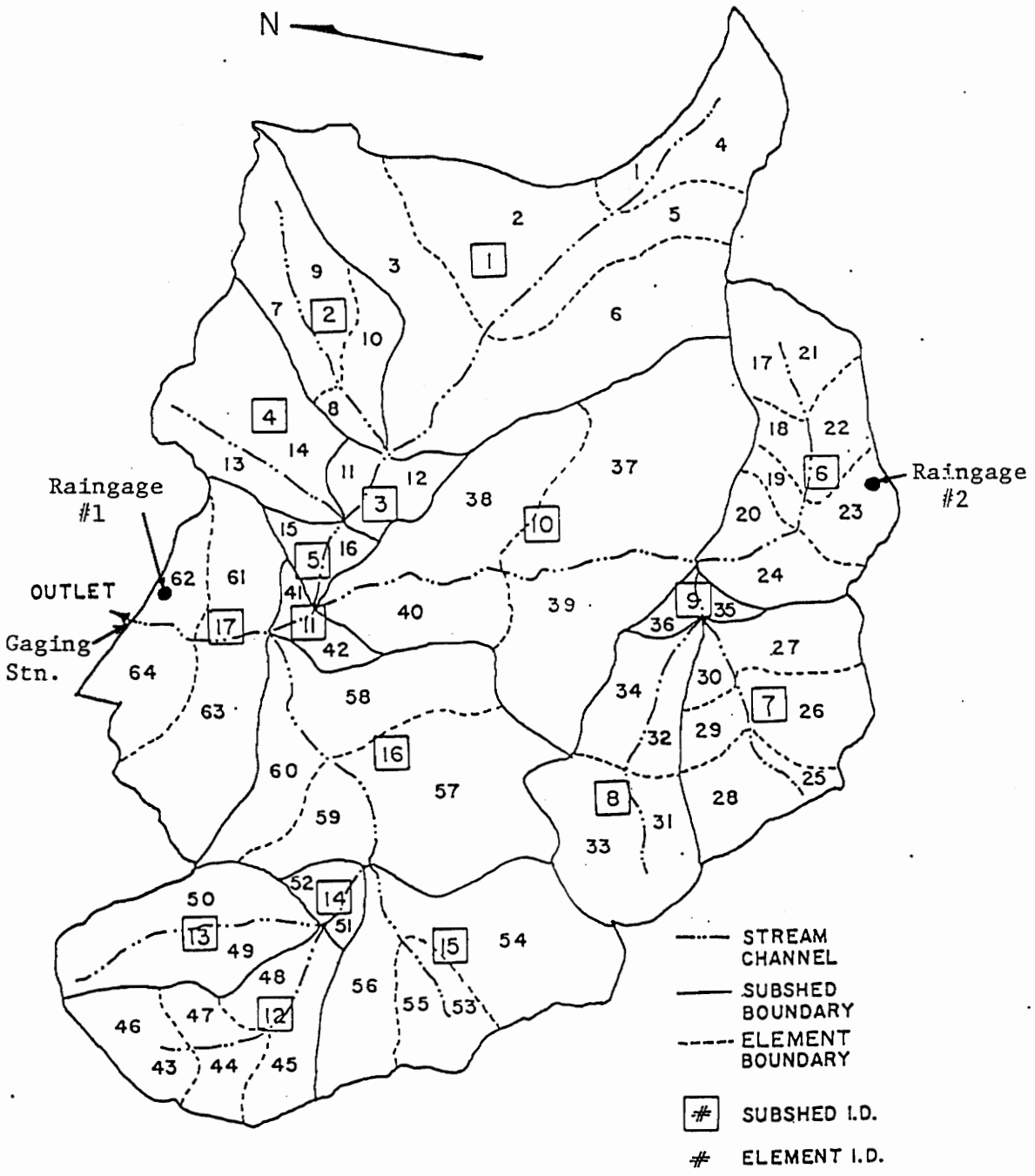

Figure 6. Finite element grid structure for Brush Creek watershed "detailed" data base.

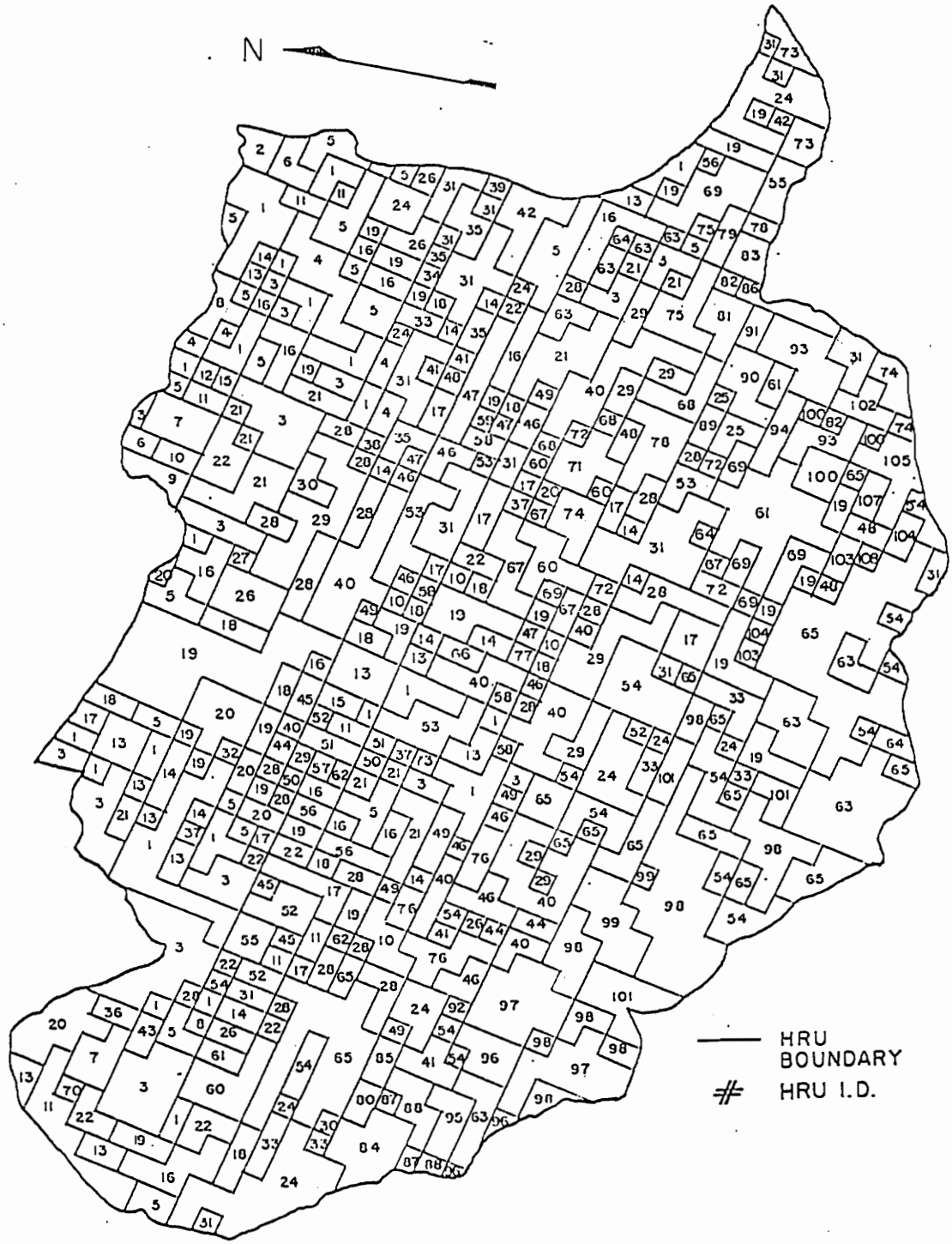

Figure 7. Distribution of Hydrologic Response Units for Brush Creek watershed "detailed" data base.

5.3.2.3 *"Lumped" Data Base*

This data base represents the normal situation where detailed soils, land use, and topography data do not exist. None of the detailed surveys described in the previous section were utilized for this data base. All geographic data was obtained from the USGS 7.5 minute Pilot (topographic) quadrangle maps and a general soils map of Virginia. The data layers were created following procedures previously outlined in Chapter 4.

Due to the scale (1:24000) and detail of the USGS topographic map, all data was digitized at 1 hectare (2.471 acres), which required creating an overlay of square grids measuring approximately 4.1 mm (0.164 in.) on a side. This procedure resulted in digital data layers of 20 by 30 cells or a total of 600 cells.

Soils: Because no soil survey report existed for Floyd County, a general soils map of Virginia was used to identify soil types. The dominant soil series is a Chester-Hayesville loam complex. Although one soil series was assumed to encompass the entire watershed, the solum was assumed to vary as a function of slope. Soils on steep slopes generally are more shallow than soils on flat or gently sloping terrain. Using the USGS topographic map, the watershed was partitioned into areas with high, medium, and low slopes. Using this procedure three soil types were defined with all soil physical parameters assumed constant except for the depth of the soil solum. A soils digital data layer was then constructed using procedures outlined previously.

Estimates for each of the parameters in the soil attribute list were determined from approximate soil characteristics. The FAW and FGW values were estimated from soil texture (Table 3). The hydrologic soil group was used to estimate F_c (Table 4), and the control depth was assumed to vary with slope. An approximate range of depths was determined from soil descriptions accompanying the general soils map of Virginia and neighboring county soil survey reports. The top, middle, and low values of this range were assigned to the areas with low, medium, and high slopes, respectively. The soil attribute list (Table 9) was then manually entered into a computer file.

Table 9. Brush Creek "lumped" soil parameter list.

Index No.	FAW (in./in.)	FGW (in./in.)	F_c (in./hr)	Depth (in.)
1	0.139	0.089	0.335	16.0
2	0.139	0.089	0.335	13.0
3	0.139	0.089	0.335	10.0

Land use: The land use information was obtained from the USGS topographic map. These maps distinguish between open and wooded land. It was assumed, for this study, that the areas indicated by these land uses did not change significantly from year to year. Based on visual observation of the drainage basin, all areas defined as open were assumed to be pasture. A grid overlay was overlaid on the topographic map and the land use information was digitized as described previously and manually entered into a computer map file, or digital data layer. The same land use attribute list created for the "detailed" data base was used for this data base.

Topography: The USGS topographic map was used to create a finite element grid (Figure 8) using procedures described in Chapter 3. The grid structure contains 7 subsheds and 26 elements. A grid overlay was created and overlaid on the finite element map and each grid was assigned an element number using procedures described previously.

Overland and channel flow geometry (group 6 in Table 5) was estimated from the topographic map and the channel roughness coefficient was estimated based on visual inspection and work by Chow (1959). These overland and channel attributes were then manually entered directly into the FESHM input file.

HRUs: The distribution of HRUs throughout the watershed is shown in Figure 9. The HRUs were determined with computer program HRU.FOR and the soil and land use digital files as described in Chapter 4. Output included a digital HRU data layer and the HRU attribute section of the FESHM input file, or group 4 (Table 5).

Elements: Computer program ELEMENT.FOR, the HRU digital data layer and the finite element grid digital data layer were then used to create the element/HRU cross-reference section of the input file, or data group 3 (Table 5), and a list of elements and their areas to assist in creating the element attribute section of the input file, or data group 6 (Table 5). An example input file for the "lumped" Brush Creek data base is shown in Appendix E.

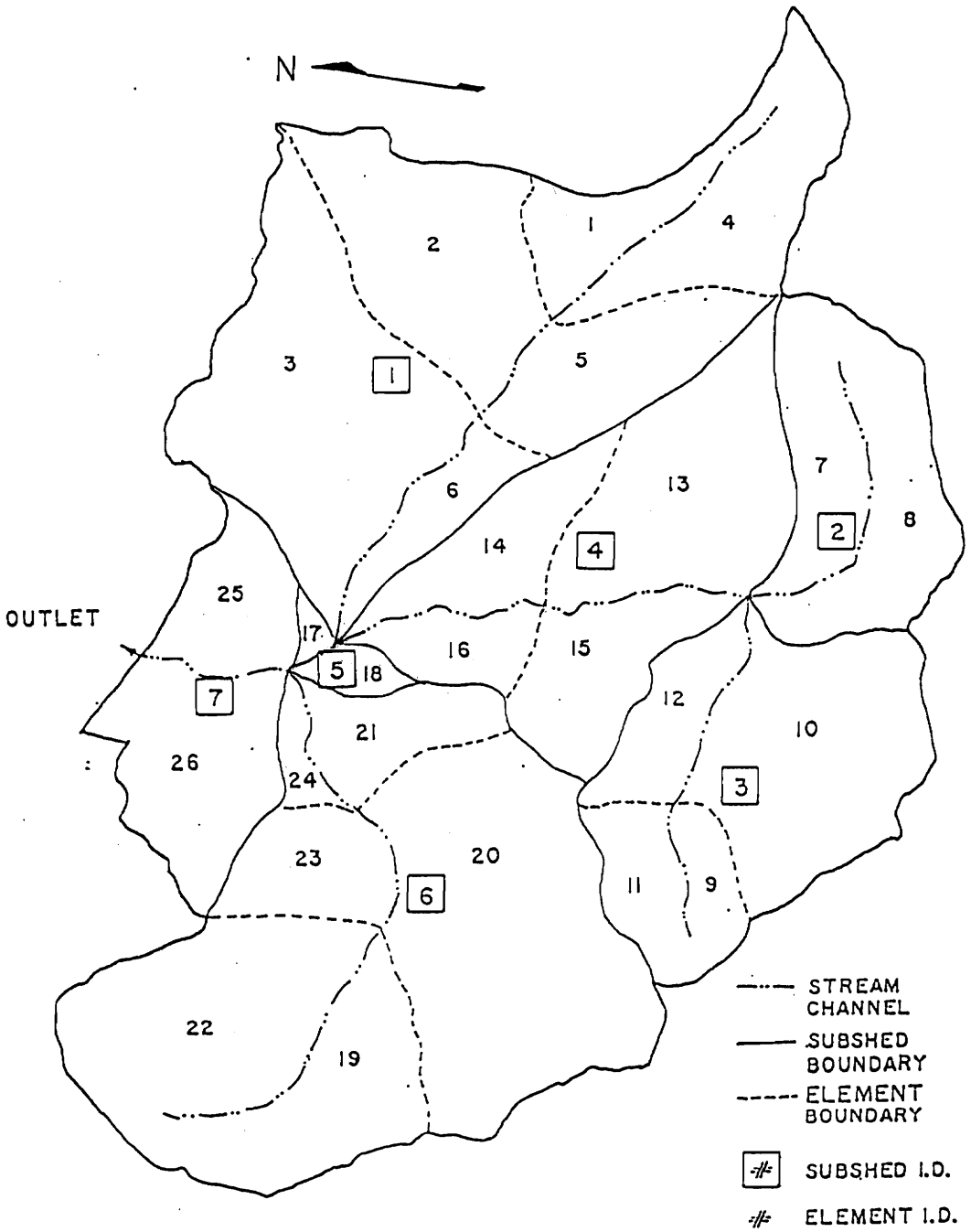

Figure 8. Finite element grid structure for Brush Creek watershed "lumped" data base.

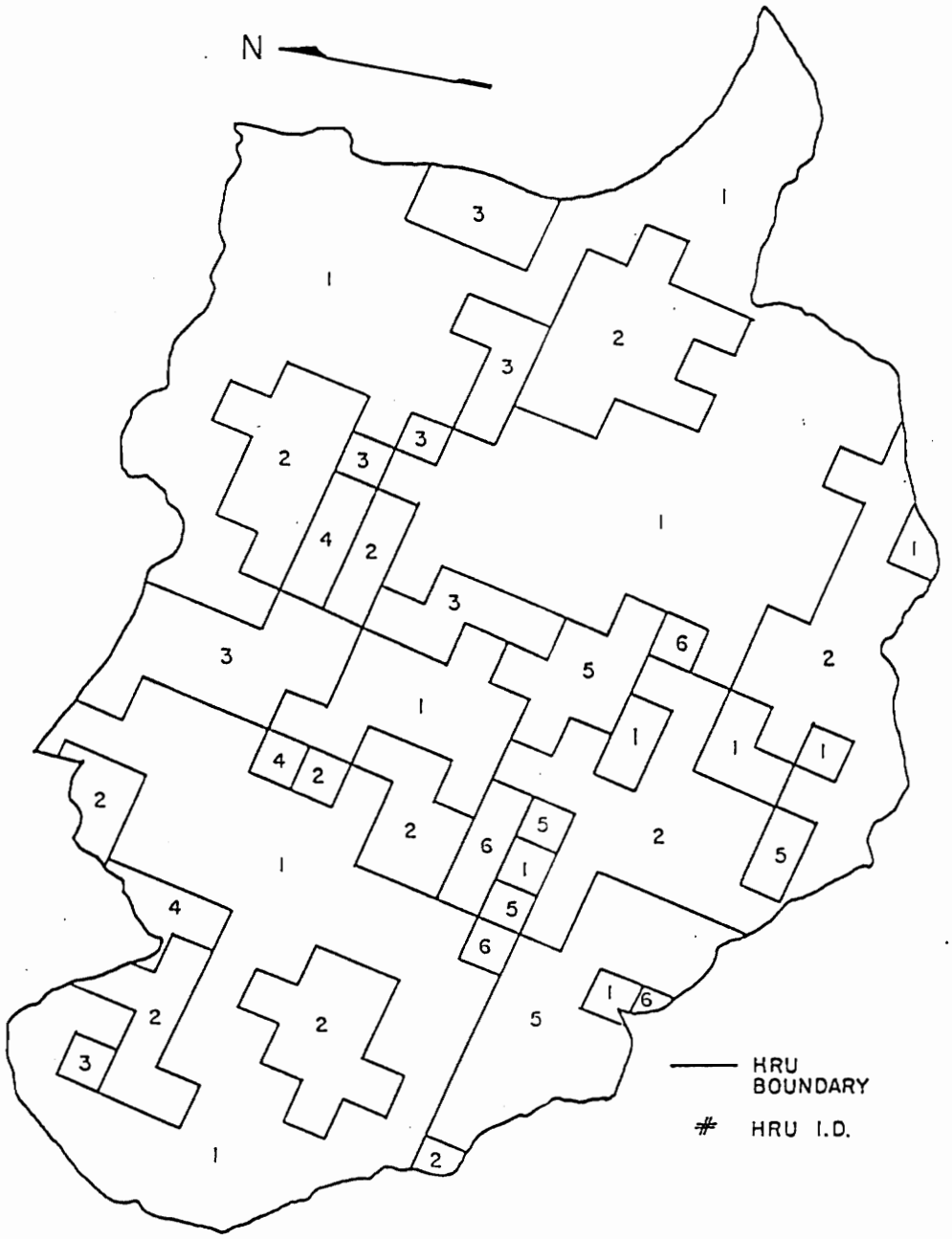

Figure 9. Distribution of Hydrologic Response Units for Brush Creek watershed "lumped" data base.

5.4 MILLSTONE BRANCH WATERSHED

5.4.1 Description of Watershed

The Millstone Branch watershed is located in Russell County, Virginia. Russell County is in the heart of the coal mining regions of southwest Virginia. The watershed drains approximately 40 hectares (101 acres). The entire watershed is forest with no land disturbances. Total watershed relief is nearly 152.4 meters (500 feet).

The USDA Forest Service, Northeastern Forest Experiment Station, Research Work Unit 4302, Berea, Kentucky monitored rainfall, runoff, and water quality for this watershed from 1982 to 1985 (Dyer, 1982). Flow was recorded with a strip chart recorder and rainfall data was collected with a continuous recording raingage.

5.4.2 Data Base

The geographic data base for the Millstone Branch watershed was developed from the USGS 7.5 minute Carbo (topographic) quadrangle map and the Russell County soil survey report (Obenshaw et al., 1945). The data layers were created following the GIS procedures outlined in Chapter 4. All data were digitized at a resolution of 1 hectare (2.47 acres), which resulted in digital data layers of 8 by 13 cells or a total of 104 cells in size.

Soils: A modern Soil Conservation Service (SCS) soil survey was not available for Russell County. The existing soil survey was completed in 1945 and does not contain the detailed information on soil characteristics available in modern soil surveys. The soil survey map was at a scale of 1:48000, which was considered adequate to define the spatial variability of the soil types throughout the watershed. The resulting grid overlay consisted of square grids measuring approximately 2.05 mm

(0.082 in.) on a side. The soils were digitized and a digital data layer was created using procedures outlined previously.

Written descriptions were available for each of the five soil types found within the watershed. When possible, the soil related input data required by FESHM were extracted from these descriptions. However, some values were estimated from the literature based on texture and hydrologic soil group. For example, the values for FAW and FGW were obtained from Table 3 based on soil texture. Also, the hydrologic soil groupings were determined from discussions with local SCS personnel and used to determine F_c from Table 4. The most difficult parameter to estimate was the depth to control zone. The range of the control depth was estimated for each soil type from the descriptions of root penetration and color given in the soil survey as outlined by Smolen (1984). The average of each range was used as the estimate of control depth. The soil attribute list is summarized in Table 10.

Land use: The land use information was obtained from the USGS topographic map. This map distinguishes between open and wooded land. It was assumed that the areas indicated as open land were pasture. A grid overlay was overlaid on the topographic map and the land use information was digitized as described previously and manually entered into a computer map file, or digital data layer. The attributes for pasture and wooded land were obtained from Table 2.

Topography: The USGS topographic map was used to create a finite element grid (Figure 10) using procedures described in Chapter 3. The grid structure contains 5 subsheds and 12 elements. A grid overlay was created and overlaid on the finite element map and each grid was assigned an element number.

Overland and channel flow geometry (group 6 in Table 5) was estimated from the topographic map. These attributes were then manually entered into the FESHM computer input file.

HRUs: The resulting distribution of HRUs throughout the watershed is shown in Figure 11. Seven distinct HRUs were defined using computer program HRU.FOR and the soil and land use digital files as described in Chapter 4. Output included a

Table 10. Millstone Branch soil parameter list.

Soil Type	FAW (in./in.)	FGW (in./in.)	F_c (in./hr)	Depth (in.)
Montevallo shaly silt loam	.199	.114	.200	15.0
Muskingum loam	.156	.144	.150	26.0
Muskingum fine sand loam	.117	.210	.150	21.0
rough stoney land fine sandy loam	.136	.177	.075	13.5
Jefferson fine sandy loam	.131	.235	.200	24.0

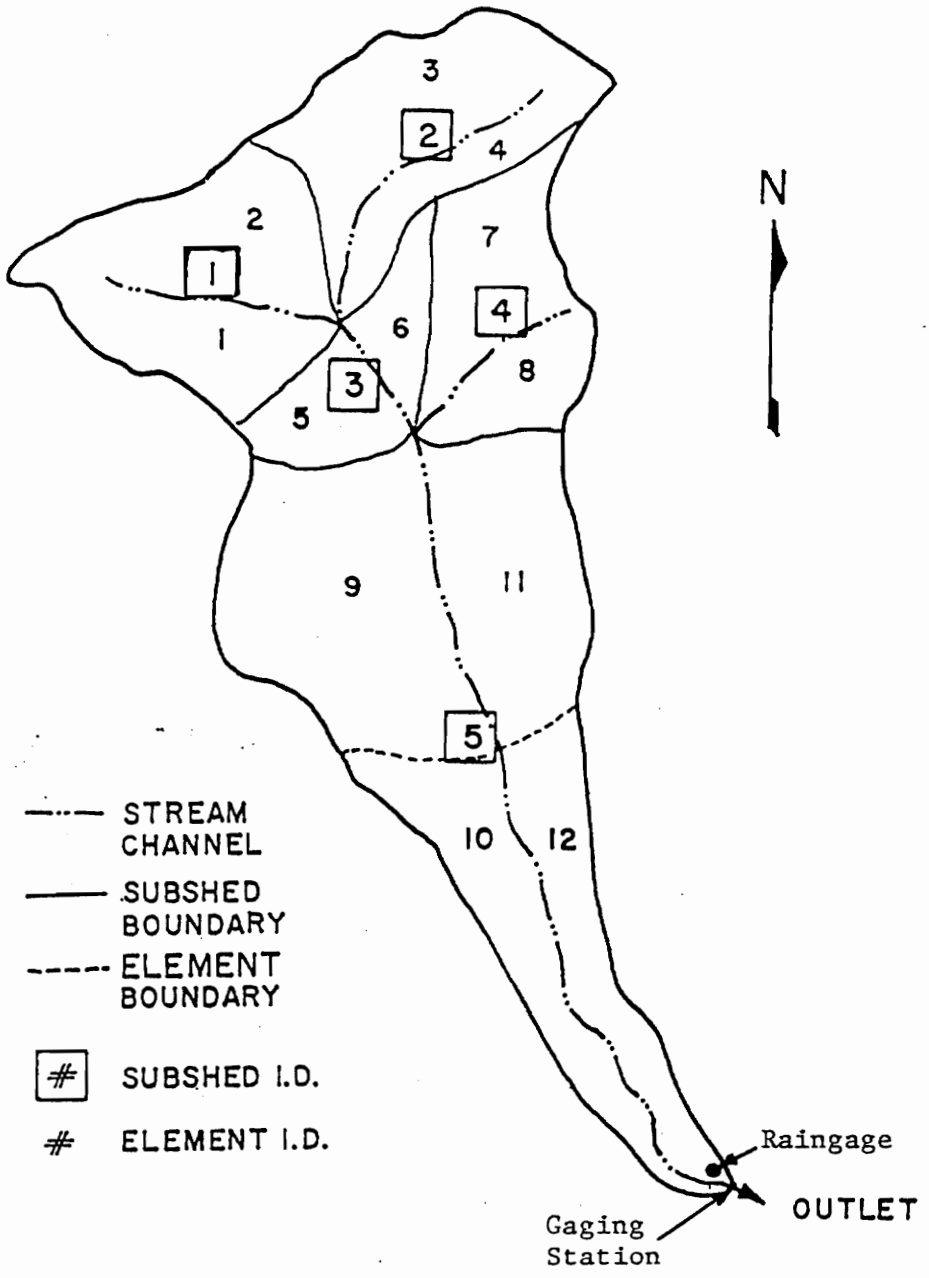

Figure 10. Finite element grid structure for Millstone Branch watershed.

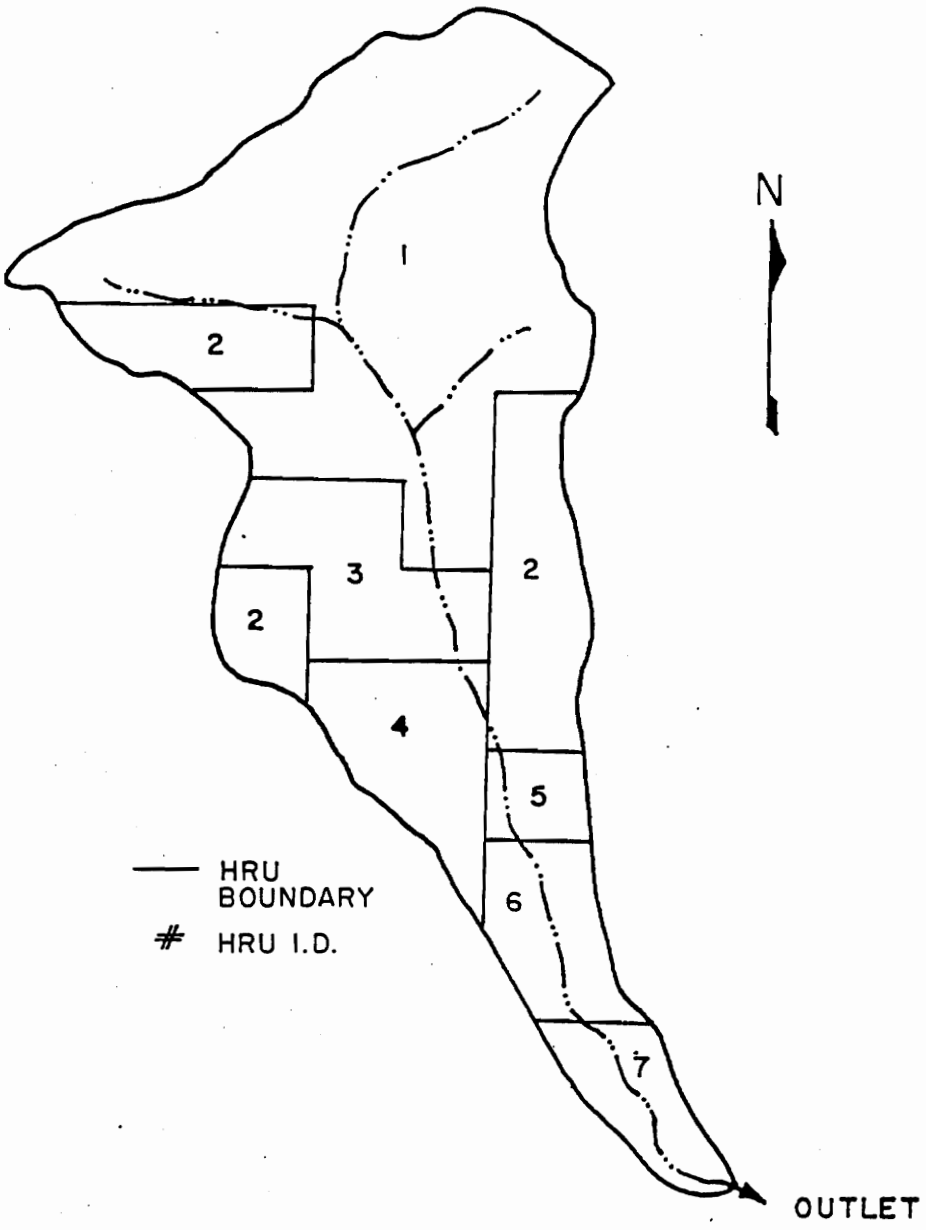

Figure 11. Distribution of Hydrologic Response Units for Millstone Branch watershed.

digital HRU data layer and the HRU attribute section of the FESHM input file, or data group 4 (Table 5).

Elements: Computer program ELEMENT.FOR, the HRU digital data layer and the finite element grid digital data layer were then used to create the element/HRU cross-reference section of the input file, or data group 3 (Table 5), and a list of elements and their areas to assist in creating the element attribute section of the input file, or data group 6 (Table 5). An example input file for the Millstone Branch watershed is shown in Appendix E.

5.5 RIGHT FORK SANDLICK CREEK WATERSHED

5.5.1 Description of Watershed

The Right Fork Sandlick Creek watershed is located in McDowell County, West Virginia. The watershed is located in the mining regions of eastern West Virginia. The watershed has a drainage area of approximately 313 hectares (774 acres), which is undisturbed forest except for a 1 to 2 hectare residential area at the outlet. The total watershed relief is nearly 256 meters (840 feet) with an average land slope of 46%.

The U.S. Geologic Survey (USGS), West Virginia District, monitored rainfall, runoff, and sediment for this watershed in 1981 and 1982 (Scott, 1984; Doyle et al., 1983; Scott, 1980; Hirsch, 1982). The data from this watershed along with several others was used to calibrate the USGS Precipitation-Runoff Modeling System (PMRS) for various simulation studies.

5.5.2 Data Base

The data base for the Right Fork Sandlick Creek watershed was developed solely from the USGS 7.5 minute Gary (topographic) quadrangle map and a general soils map of West Virginia. All geographic data were placed in a cellular GIS as described in Chapter 4. The data were digitized at a resolution of 1 hectare (2.47 acres) and the resulting computerized data layers were 23 by 26 cells in size.

Soils: Because no soil survey report existed for McDowell County, a general soils map of West Virginia (Doyle et al., 1983) was used to estimate soil parameters. The watershed is located in a region characterized by the Clymer-Dekalb-Jefferson soil association. Descriptions of the three soils in the association were found in the soil survey report for the nearby counties of Mercer and Summers. Most of the soil parameters also were readily available from the Mercer and Summers soil survey report. When a range of values was given, the arithmetic average was assumed as the estimate of the parameter. The procedure was as follows: the parameters were first estimated for each of the soil types in the association and then the arithmetic average of the parameters for the three soil types was used as the final parameter estimation for the soil association.

FAW was obtained from the soil survey report, however, FGW was estimated based on the ratio of FGW to FAW obtained from Table 3 for the appropriate soil texture. The F_c values were estimated from Table 4 based on hydrologic soil group as defined in the soil survey report. The depth of control zone was estimated from soil profile descriptions. Control depth was not varied as a function of slope because little variation in slope existed throughout the drainage basin. The parameter estimates for each soil type and the final averaged parameters for the soil association are given in Table 11.

Land use: The land use information was obtained from the USGS topographic map. The entire watershed was defined as being forest because open land was negligible. The land use attributes were then obtained from Table 2.

Table 11. Right Fork Sandlick Creek soil parameter list.

Soil Type	FAW (in./in.)	FGW (in./in.)	F_c (in./hr)	Depth (in.)
Clymer channery loam	.120	.110	.250	21.0
Dekalb sandy loam	.090	.136	.100	28.0
Jefferson sandy loam	.123	.186	.250	28.0
Average	.111	.144	.200	25.7

Topography: The USGS topographic map was used to create a finite element grid (Figure 12) using the procedures described in Chapter 3. The grid structure contains 7 subsheds and 20 elements. A grid overlay was created and overlaid on the finite element map and each grid assigned an element number.

Overland and channel flow geometry (group 6 in Table 5) was estimated from the topographic map. These overland and channel attributes then were manually entered into the FESHM computer input file.

HRUs: The HRU.FOR program was not executed for this watershed because only one soil-land use combination was defined. This data base represents the extreme "lumped" situation, with only one HRU defined as being uniformly distributed throughout the watershed.

Elements: Computer program ELEMENT.FOR was run merely to obtain the areas for the 20 elements to assist in creating the element attribute section of the input file, or data group 6 (Table 5). Since there was no variation of HRUs within the elements, no element/HRU cross-reference table (group 3 in Table 5) was needed. An example input file for the Right Fork Sandlick creek watershed is shown in Appendix E.

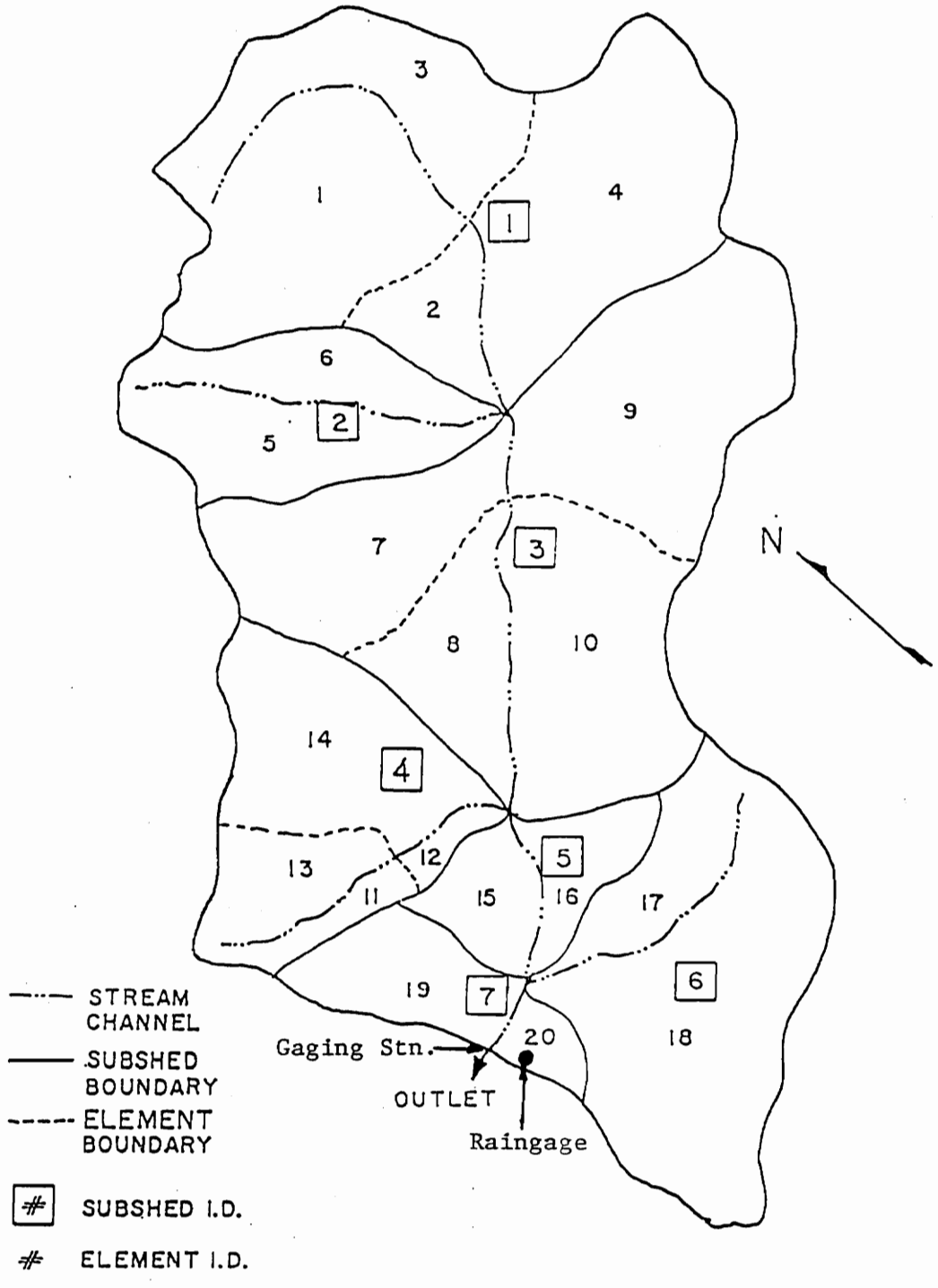

Figure 12. Finite element grid structure for Right Fork Sandlick watershed.

6.0 SENSITIVITY ANALYSIS

6.1 PROCEDURES

Sensitivity analysis is a technique for assessing the relative change in model response resulting from a change in model parameters (Lane and Ferreira, 1980). For this study, the sensitivity of FESHM to ten model parameters was evaluated using the 25-year, 6-hour design storm (Table 7) as rainfall input and the data bases for the three watersheds described in Chapter 5. For the Brush Creek watershed only the "lumped" data base was utilized in order to gain insight into using data at a resolution typical in mining regions.

The procedure involved executing the model using recommended parameter values to establish the reference or base hydrograph. Then each parameter was varied while holding all others constant at their reference value. Although this procedure provides important information on relative variability, it gives little insight when complex parameter interactions exist.

6.2 RESULTS AND DISCUSSION

Sensitivity results are shown in Tables 12, 13, and 14 and graphical displays are presented in Appendix F. The tables for each watershed include parameter estimates and variations, simulated runoff volumes and peak flows, and the percentage change in model response. The graphs in Appendix F illustrate how variations in parameter values influence hydrograph shape. The results are discussed in detail for each of the ten parameters in the following sections.

Table 12. Summary of Brush Creek sensitivity analysis for ten model input parameters.

Model Parameter (1)	Parameter Estimate (2)	Variation (3)	Runoff Volume (mm) (4)	% Change (5)	Runoff Peak (CMS) (6)	% Change (7)
RAIN[1]	114.3 mm	-10%	57.32	-16.2	34.05	-16.8
			68.42		40.93	
		+10%	80.18	+17.2	48.12	+17.6
SMC[1]		-66.7%	59.03	-13.7	36.11	-11.8
		-33.3%	64.32	- 5.9	38.43	- 6.1
	100%		68.42		40.93	
GINDEX[1]	.3		68.42		40.93	
		+100%	64.53	- 5.7	38.74	- 5.4
		+200%	62.34	- 8.9	37.51	- 8.4
AFLU[1]	0.6,1.0	-20%	69.72	+ 1.9	41.58	+ 1.6
			68.42		40.93	
		+20%	67.11	- 1.9	40.33	- 1.5
RCLU[2]	0.25-0.40	-.05	69.61	+ 1.7	44.11	+ 7.8
			68.42		40.93	
		+.05	66.98	- 2.1	37.99	- 7.2
CHANNEL ROUGHNESS[1]	0.07-0.12	-50%	68.45	+ 0.04	45.54	+11.3
			68.42		40.93	
		+100%	68.06	- 0.5	35.26	-13.8
FAW[1]	.139	-20%	67.60	- 1.2	40.56	- 0.9
			68.42		40.93	
		+20%	69.19	+ 1.1	41.35	+ 1.0
FGW[1]	.089	-20%	68.92	+ 0.7	41.93	+ 2.4
			68.42		40.93	
		+20%	67.79	- 0.9	40.17	- 1.8
F_c[2]	.335	-.1	79.90	+16.8	43.60	+ 6.5
			68.42		40.93	
		+.1	58.49	-14.5	38.75	- 5.3
DEPTH[2]	10-16	-3.0	71.52	+ 4.5	42.99	+ 5.0
			68.42		40.93	
		+3.0	65.35	- 4.5	39.43	- 3.7

[1] Variation indicates the percentage by which the base parameter estimate was modified for analysis.

[2] Variation indicates the constant by which the base parameter estimate was modified for analysis.

Table 13. Summary of Millstone Branch sensitivity analysis for ten model input parameters.

Model Parameter (1)	Parameter Estimate (2)	Variation (3)	Runoff Volume (mm) (4)	% Change (5)	Runoff Peak (CMS) (6)	% Change (7)
RAIN[1]	92.4 mm	-10%	18.24	-25.6	2.30	-21.8
			24.50		2.94	
		+10%	31.96	+30.4	3.72	+26.5
SMC[1]		-66.7%	11.29	-53.9	1.78	-39.4
		-33.3%	15.79	-35.6	2.22	-24.5
	100%		24.50		2.94	
GINDEX[1]	.3		24.50		2.94	
		+100%	12.68	-48.2	1.78	-39.4
		+200%	7.54	-69.2	1.07	-63.6
AFLU[1]	0.6-1.0	-20%	29.47	+20.3	3.43	+16.7
			24.50		2.94	
		+20%	20.92	-14.6	2.62	-10.9
RCLU[2]	0.28-0.40	-.05	24.52	+ 0.08	3.03	+ 3.1
			24.50		2.94	
		+.05	24.06	- 1.8	2.80	- 4.8
CHANNEL ROUGHNESS[1]	0.09-0.12	-50%	24.50	0.0	3.20	+ 8.8
			24.50		2.94	
		+100%	24.47	- 0.1	2.28	-22.4
FAW[1]	0.117-0.182	-20%	20.81	-15.1	2.56	-12.9
			24.50		2.94	
		+20%	27.88	+13.8	3.37	+14.6
FGW[1]	0.144-0.210	-20%	35.66	+45.6	3.87	+31.6
			24.50		2.94	
		+20%	15.76	-35.7	2.11	-28.2
F_c[2]	0.150-0.200	-.1	28.11	+14.7	3.20	+ 8.8
			24.50		2.94	
		+.1	21.12	-13.8	2.65	- 9.9
DEPTH[2]	17-26	-3.0	30.44	+24.2	3.36	+14.3
			24.50		2.94	
		+3.0	20.12	-17.9	2.62	-10.9

[1] Variation indicates the percentage by which the base parameter estimate was modified for analysis.

[2] Variation indicates the constant by which the base parameter estimate was modified for analysis.

Table 14. Summary of Right Fork Sandlick Creek sensitivity analysis for ten model input parameters.

Model Parameter (1)	Parameter Estimate (2)	Variation (3)	Runoff Volume (mm) (4)	% Change (5)	Runoff Peak (CMS) (6)	% Change (7)
RAIN[1]	92.9 mm	-10%	50.60	-16.2	23.47	-16.8
			60.39		28.20	
		+10%	70.80	+17.2	34.12	+20.9
SMC[1]		-66.7%	43.01	-28.8	22.20	-21.3
		-33.3%	50.67	-16.1	25.44	- 9.8
	100%		60.39		28.20	
GINDEX[1]	.3		60.39		28.20	
		+100%	54.78	- 9.3	24.10	-14.5
		+200%	51.78	-14.2	21.15	-25.0
AFLU[1]	1.00	-20%	63.37	+ 4.9	29.78	+ 5.6
			60.39		28.20	
		+20%	59.02	- 2.3	27.12	- 3.8
RCLU[2]	0.40	-.05	61.50	+ 1.8	30.28	+ 7.4
			60.39		28.20	
		+.05	60.10	- 0.4	27.23	- 3.4
CHANNEL ROUGHNESS[1]	0.07-0.12	-50%	60.45	+ 0.09	31.23	+10.7
			60.39		28.20	
		+100%	60.17	- 0.4	23.89	-15.3
FAW[1]	0.111	-20%	60.10	- 0.5	28.05	- 0.5
			60.39		28.20	
		+20%	61.59	+ 1.9	28.45	+ 0.9
FGW[1]	0.144	-20%	66.04	+ 9.4	31.18	+10.6
			60.39		28.20	
		+20%	54.32	-10.0	25.67	- 8.9
F_c[2]	0.100	-.1	66.52	+10.2	30.71	+ 8.9
			60.39		28.20	
		+.1	53.73	-11.0	26.61	- 5.6
DEPTH[2]	12	-3.0	68.67	+13.7	31.97	+13.4
			60.39		28.20	
		+3.0	51.10	-15.4	25.50	- 9.5

[1] Variation indicates the percentage by which the base parameter estimate was modified for analysis.

[2] Variation indicates the constant by which the base parameter estimate was modified for analysis.

6.2.1 Rainfall

The major driver for most hydrologic models is rainfall, which results in models being relatively sensitive to this input parameter. In this study, the volume of rainfall was varied by ±10% to demonstrate expected variability. Characteristics of storm events which also are important include: intensity rate, intensity distribution, and spatial distribution of rainfall.

A ±10% variation in rainfall amount resulted in a 17% to 30% change in the simulated runoff volumes and peak flow rates of the three watersheds. On a watershed scale, measurement of rainfall is difficult to achieve within a ±10% accuracy, particularly the spatial distribution. Errors in measuring point rainfall can occur because of mechanical or electronic malfunction of sensors and/or during data reduction and analysis. When attempting to simulate recorded hydrographs with physically based models and then comparing the results to recorded hydrographs, accurate rainfall data is absolutely essential.

6.2.2 Antecedent Soil Moisture Content (SMC)

The soil moisture condition prior to a rainfall event is important because it determines the amount of available water storage capacity in the soil, which affects the amount of rainfall available for runoff. A decrease in SMC results in decreased runoff amounts.

The reference SMC value was set at 100% of field capacity. It is important to note that SMC is used to index only the plant available portion of the soil storage (see Figure 4). Therefore, a SMC of 100% does not represent complete saturation because only the plant available storage capacity is full, not the gravitational portion. Variations were set at 2/3 and 1/3 field capacity. These variations affected the simulation for each watershed differently. With SMC set at 1/3 field capacity, the Brush Creek watershed volumes were reduced 13.7%, the Millstone Branch volumes

53.9% and the Right Fork Sandlick Creek volumes 28.8%.

6.2.3 Growth Index (GI)

The growth index parameter adjusts the infiltration rate based on seasonal fluctuations of plant cover. Currently the model uses GI to index the first term in the Holtan infiltration equation. GI is assumed to be constant by month, ranging from 0 to 1. A reference value of 0.3 was chosen and it was varied to 0.6 and 0.9 for analysis. As GI increases infiltration increases and runoff decreases.

As with SMC, the sensitivity to this parameter varied from watershed to watershed. The Brush Creek simulations changed very little, the Millstone Branch simulations changed up to 69% and Right Fork Sandlick Creek simulations changed moderately. GI is used to index the storage volume component in Holtan's infiltration equation. Therefore, the relative change in infiltration due to variations in GI is a function of volume and the greater the actual volume change the greater the sensitivity. The Millstone Branch watershed depth estimates, and therefore the storage volumes, are significantly higher than those of the other watersheds. Therefore, variations in GI resulted in greater actual volume change and, thus, greater sensitivity for the Millstone Branch watershed.

6.2.4 Holtan's Vegetative Index (AFLU)

The *"a"* factor from Holtan's original infiltration equation (Holtan, 1961) is used to index the effect of vegetative and general soil cover on runoff. This parameter ranges from 0 for impervious areas to 1 for highly pervious areas. The reference values were set at 0.6 for pasture and 1.0 for woods and they were varied by ±20%. An increase in AFLU is expected to increase infiltration, which decreases the amount of runoff.

The variations in AFLU resulted in changes of approximately ±2% for Brush

Creek simulations, ±15% for Millstone Branch simulations, and ±4% for Right Fork Sandlick Creek simulations. Holtan's *"a"* factor also is used to index the storage volume in Holtan's infiltration equation. Therefore, Millstone Branch watershed simulations are expected to be more sensitive to variations in this parameter for the same reasons as those given previously for GI.

6.2.5 Overland Flow Roughness Coefficient (RCLU)

Manning's roughness coefficient is used to index the effect of surface roughness on overland flow. The reference values were selected for each land use from Table 2 and were varied by ±.05.

The volume simulations showed little or no sensitivity to these variations, while peak flows changed slightly. Variations in RCLU affected the timing and shape of the runoff hydrographs as shown in Figures F-5, F-15 and F-25 in Appendix F. Higher values of RCLU tend to dampen flow and delay peaks. This effect can influence volumes by slowing flow velocities and allowing greater transmission losses from overland flow (Shanholtz et al., 1981).

6.2.6 Channel Roughness Coefficient (RCOEF)

Manning's roughness coefficient also is used to index the effect of channel roughness on flow routing. The reference values ranged from .07 to .12 and were varied by dividing or multiplying by a factor of 2.

Volume simulations were not sensitive to changes in RCOEF. The peak flows were more sensitive with the largest change being -22% with a RCOEF variation of 100%. As with RCLU, the channel roughness influences hydrograph shape as shown in Figures F-6, F-16 and F-26 in Appendix F.

6.2.7 Plant Available and Gravitational Water (FAW and FGW)

FAW and FGW are used in Holtan's infiltration equation to index change in infiltration as a function of soil type. The reference values were selected for each soil type based on textural class (Table 3) and were varied by ±20%.

The simulated runoff volumes and peak flows of the Brush Creek and Right Fork Sandlick Creek watersheds did not appear to be sensitive to variations in these parameters. However, the Millstone Branch simulations were sensitive to both parameters, especially to variations in FGW.

The interaction between FAW and FGW is very important. The ratio of gravitational to plant available water is used to index the available storage of the control zone. Normally these two parameters are selected together based on soil type, but for this study each was varied separately while the other remained at reference value. The lack of sensitivity to FAW may, in part, be due to the fact that SMC is set at 100%. As stated previously, when SMC is at this level the plant available portion of the storage volume is zero at the beginning of the storm and remains constant regardless of the magnitude of FAW. Sensitivity to change, therefore, will be limited to the value of FGW and it's interactions with DEPTH. Infiltration recovery occurs only by free drainage, which is limited to the gravitational water zone.

6.2.8 Final Infiltration Rate (F_c)

The final infiltration rate represents the steady state infiltration of the soil and is usually estimated based on the hydrologic soil group. The reference values were estimated for each soil type from Table 4 and were varied by ±2.54 mm/h (0.1 in./h).

The percent change due to F_c variations ranged from 10% to 17% for volumes and 5% to 10% for peak flows. These results indicate the importance of the F_c

parameter. F_c influences infiltration prior to saturation because all surface water enters the storage zone at a rate of F_c and gravitational water is allowed to move from the FGW zone to the FAW zone, or percolate when SMC is 100%, at a rate of F_c. Therefore, F_c is the primary mode for infiltration recovery and storms with intensity rates less than F_c will produce no runoff.

Once saturation is reached the storage capacity becomes zero, infiltration rate equals F_c, and all rainfall falling at a rate greater than F_c becomes runoff. If F_c is much smaller than the rate of rainfall, it will exert little influence on the resulting runoff. The design storm used for this evaluation had a peak intensity of approximately 65 mm/hr, which is from 8 to 26 times the F_c values selected for the three watersheds. The sensitivity of simulations to variations in F_c are significant and should increase as intensity levels decrease.

6.2.9 Depth of Soil Profile (DEPTH)

Infiltration is described by the Holtan equation as being a direct function of the volume of unfilled pore space in a given soil depth. The reference values of DEPTH were obtained for each soil type from soil profile descriptions and ranged from 254 to 660.4 mm (10 to 26 in.). The depths were varied by ±76.2 mm (3 in.) for analysis. Increasing the depth of the control zone increases the available storage capacity, while decreasing runoff amounts.

The changes resulting from these variations ranged from 3.7% to 24.2%. The sensitivities to this parameter is tempered by important interactions with other variables. For example, the interaction between DEPTH and SMC is very important. With SMC set at 100% the plant available portion of storage is assumed to be full at the beginning of the storm, which means that changes in the depth are only reflected in the gravitational portion of the control depth.

6.2.10 Summary

The simulations for all of the watersheds were very sensitive to changes in rainfall input. The effects of changes in the remaining variables varied greatly from watershed to watershed. In general, variations in antecedent soil moisture content, final infiltration rate, and the depth of control zone caused significant changes in simulation results. Although the overland and channel roughness coefficients did not affect the magnitudes of volumes or peak flows, they affected the timing and shape of the simulated hydrographs.

The importance of the remaining parameters such as FAW and FGW were tempered by important interactions with each other, with DEPTH, and with SMC. The sensitivity of model simulations to changes in the parameter values involved in infiltration computations are related to the magnitude of the rainfall intensity. Very large rainfall intensities tend to minimize the effects of the variables, while small intensities tend to magnify their importance.

As a result of this sensitivity analysis, it is recommended that rainfall, SMC, F_c, and DEPTH be estimated with extreme care and field checked when possible. Also, due to varying results from watershed to watershed, a sensitivity analysis should be performed for each watershed undergoing pre-mining modeling analysis.

The purpose of this sensitivity analysis was not to establish base parameter estimates nor to adjust values previously estimated in an ungaged, non-calibrated context. However, this analysis was conducted in order to gain insight into the importance of various input parameters and how they affect simulation results.

7.0 WATERSHED SIMULATIONS

7.1 BRUSH CREEK WATERSHED

A major focus of this phase of the study was to evaluate FESHM for simulating runoff peaks and volumes in an ungaged context. That is, model input was determined from the best available sources and simulations conducted with no further attempts to achieve better correspondence with measured flow sequences.

Model evaluation involved the comparison of simulation results using the "detailed" and "lumped" data bases described in Chapter 5. Then the significant runoff events during a six month monitoring period, as defined for surface mining permits, were simulated for each year of 17 years of the historical record using the "lumped" data base.

7.1.1 "Detailed" and "Lumped" Simulation Results

7.1.1.1 *Procedures*

In hydrologic modeling, there is a potential for errors emanating from ignoring spatial variability. In general, the error in prediction is expected to increase as the level of resolution decreases, that is, as the geographic detail included in the data base moves from detailed to lumped. The transition, however, is not well understood.

Simulations were conducted with the Brush Creek watershed to evaluate the impact of data at a resolution expected to be available in mining regions. In mining regions, seldom will data at the resolution of the Brush Creek "detailed" data base be available. Typically the best available information will be USGS topographic maps and general soils information at the soil series level. This study was intended to

indicate the extent that data constraints limit the applicability of FESHM for pre-mining analysis.

Rainfall-runoff events during the six month period from May through October in 1968 were selected for inclusion in this simulation study. The year 1968 was chosen randomly from the available record. Because FESHM was designed for simulating flood flow events, runoff event selection was based on the gage height measured at the outlet of the watershed. Through observation of historical data and past experience it was decided that an event causing a gage height greater than 15.24 cm (6 in.) for the Brush Creek watershed could be described as a significant runoff event. Using this definition nine events were selected. Additionally, the two largest recorded events from the historical record and the two design storms described in Chapter 5 were used.

7.1.1.2 *Results and Discussion*

Using FESHM and the two data bases described in Chapter 5, runoff hydrographs were generated for the eleven recorded storm events and the two design storms. The results are summarized in Tables 15 and 16 and in Figures 13 through 23.

Table 15 lists the simulation results for the eleven recorded events including the peak flows and volumes from the recorded data, the "lumped" data base simulations, and the "detailed" data base simulations. Also given in Table 15 are the storm volumes and peak intensity rates. The recorded, "lumped", and "detailed" runoff hydrographs are compared graphically for nine of these events in Figures 13 through 21. The remaining two events produced no simulated runoff.

Simulations of events 1 and 6 resulted in no runoff using either of the data base levels. The peak rainfall intensity for both of these storms was very low. The intensity rates of these storms never exceeded the final infiltration rate (F_c) for the "lumped" data base and the range of storm intensities for event 1 never exceeded the F_c values for the "detailed" data base, therefore no runoff was possible as discussed in

Table 15. Comparison of recorded and simulated peak and volume of runoff with "lumped" and "detailed" data bases.

Event No.	Rainfall Volume (mm)	Rainfall I^1 (mm/hr)	Recorded Peak Flow (m^3/s)	Recorded Volume (mm)	Simulated Lumped Data Peak Flow (m^3/s)	Simulated Lumped Data Volume (mm)	Simulated Detailed Data Peak Flow (m^3/s)	Simulated Detailed Data Volume (mm)
(events from 1968)								
1	8.9	1.6	.270	1.47	.000	.00	.000	.00
2	12.9	18.9	.256	.56	.130	.28	.420	.68
3	15.5	54.9	.192	.41	.218	.36	.114	.23
4	19.3	44.7	.202	.71	.126	.22	.058	.09
5	16.5	65.0	.285	.56	.816	1.07	.793	1.02
6	4.7	5.0	.223	.58	.000	.00	.000	.00
7	16.8	43.7	.172	.36	.220	.36	.130	.19
8	17.6	45.7	.348	.69	.307	.46	.238	.41
9	83.3	24.2	1.846	10.67	2.354	5.36	7.950	21.79
(largest recorded events)								
10	65.5	177.8	21.670	10.92	29.978	23.39	32.780	22.20
11	41.7	68.8	9.190	11.43	10.654	10.44	9.690	8.66

[1] Peak intensity rate of storm event.

Table 16. Comparison of relative errors between recorded and simulated runoff peaks and volumes for the "lumped" and "detailed" Brush Creek data bases.

Event Number	Relative Errors (%)			
	"Lumped" Data		"Detailed" Data	
	Peak Flow	Volume	Peak Flow	Volume
(events from 1968)				
1[1]	-- no simulated runoff --			
2	- 49	- 50	+ 64	+ 21
3	+ 14	- 12	- 41	- 44
4	- 38	- 69	- 71	- 86
5	+186	+ 91	+178	+ 82
6[1]	-- no simulated runoff --			
7	+ 22	0	- 24	- 47
8	- 12	- 33	- 32	- 40
9	+ 28	- 50	+331	+104
(largest recorded events)				
10	+ 38	+114	+ 51	+103
11	+ 16	- 9	+ 5	- 24
MARE[2]	55	57	91	68
LMARE[3]	30.3	26.5	50.5	52.7

[1] Not included in calculations since no runoff was simulated.
[2] Mean absolute relative error.
[3] Logarithmic mean absolute relative error.

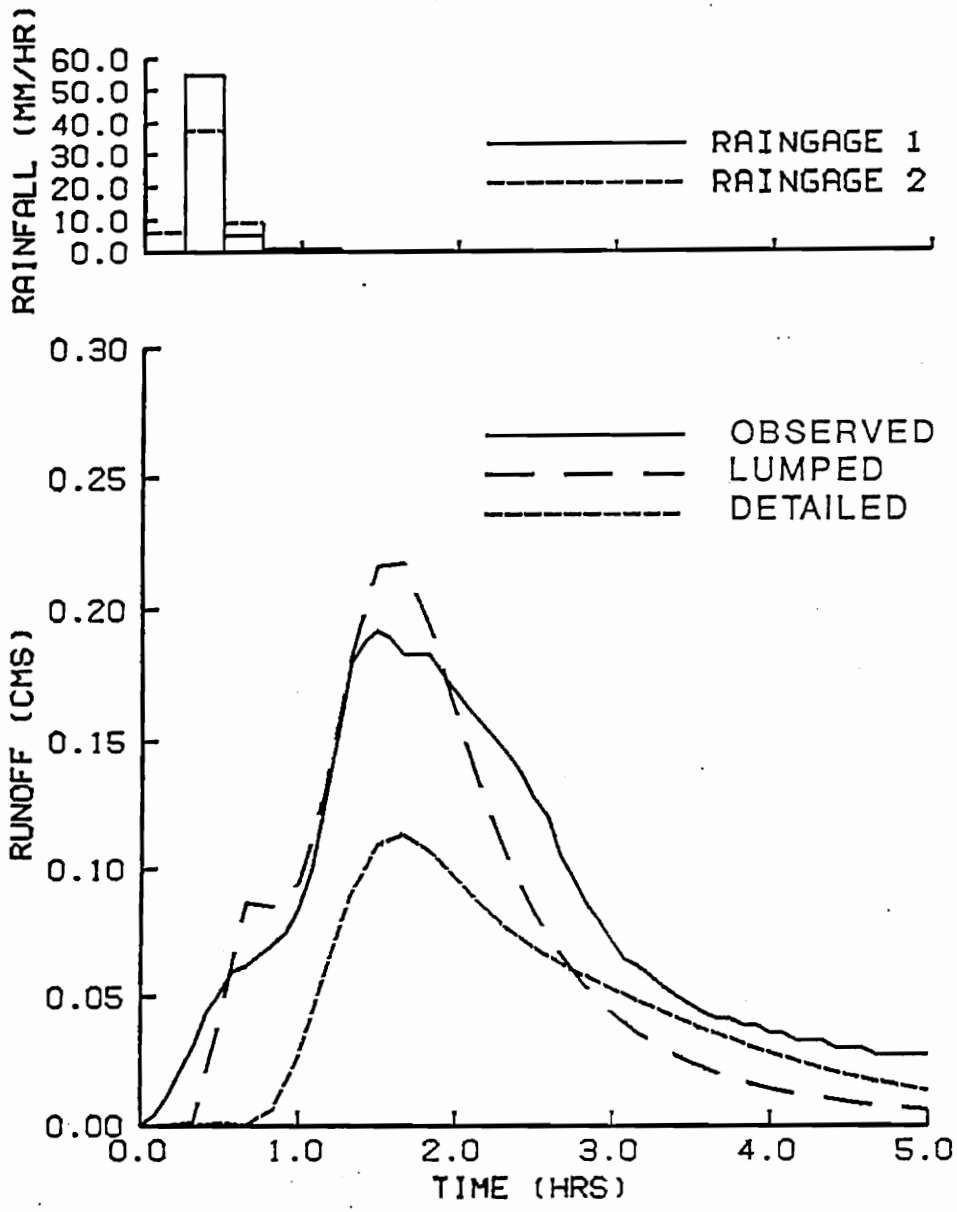

Figure 13. Comparison of simulated hydrographs for Event #2 using Brush Creek "detailed" and "lumped" data bases.

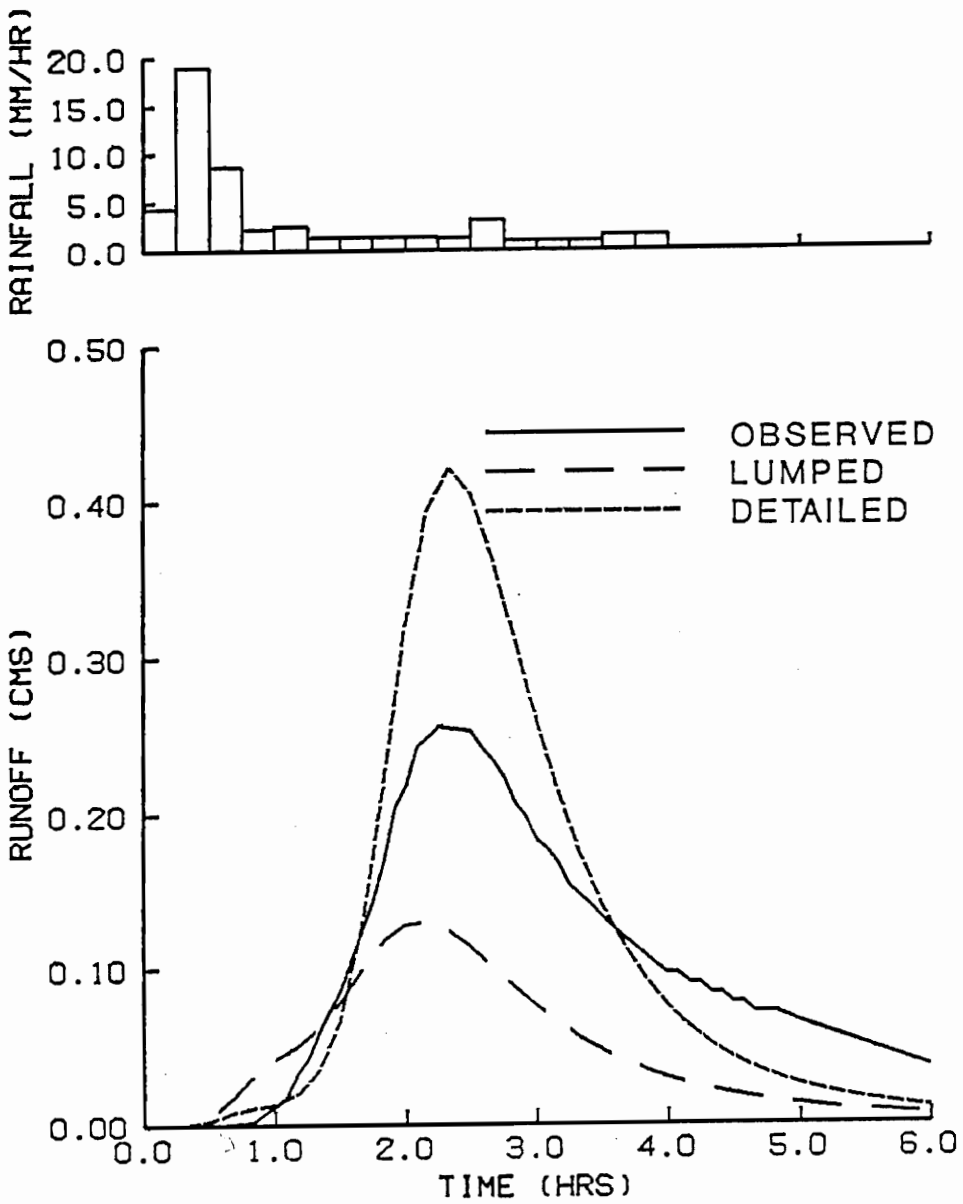

Figure 14. Comparison of simulated hydrographs for Event #3 using Brush Creek "detailed" and "lumped" data bases.

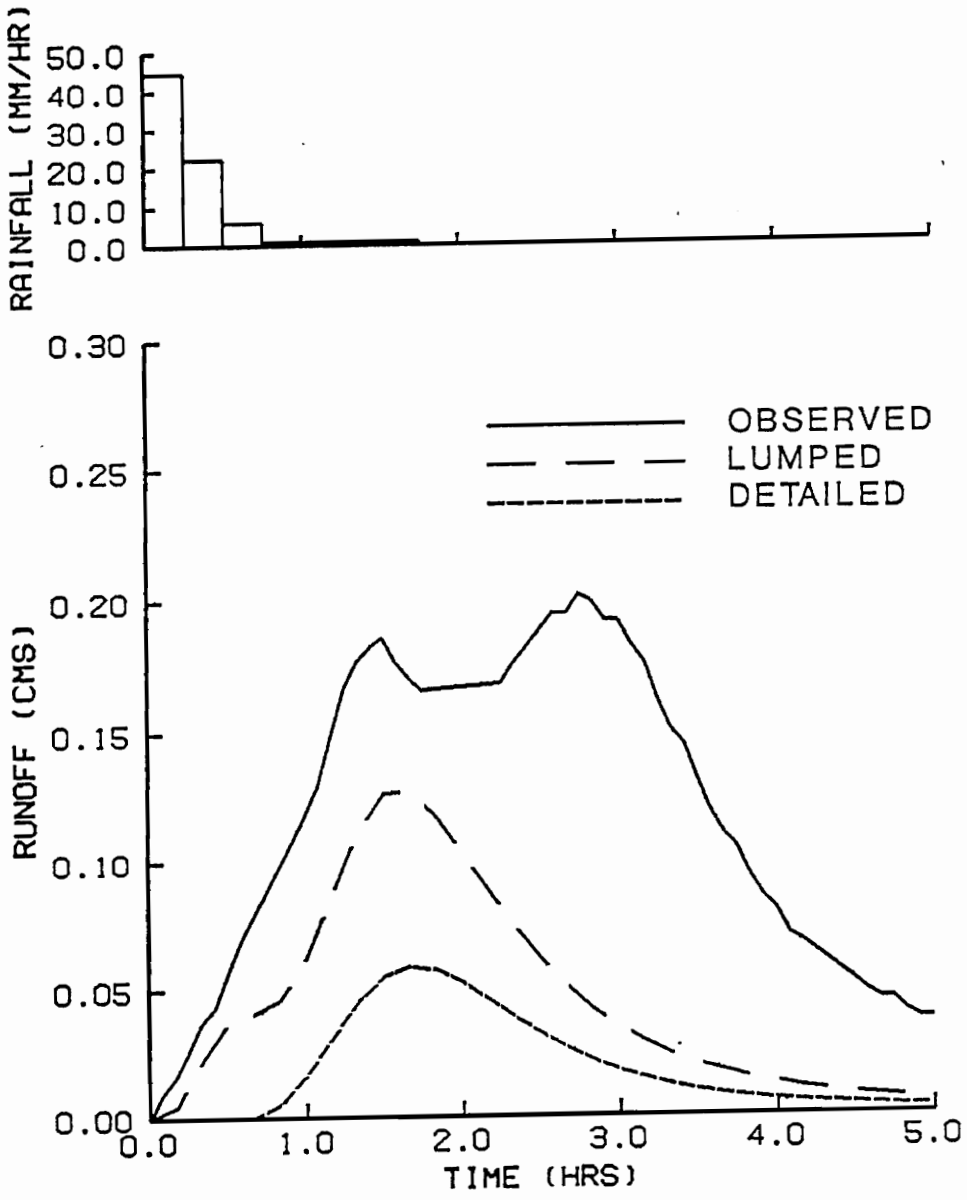

Figure 15. Comparison of simulated hydrographs for Event #4 using Brush Creek "detailed" and "lumped" data bases.

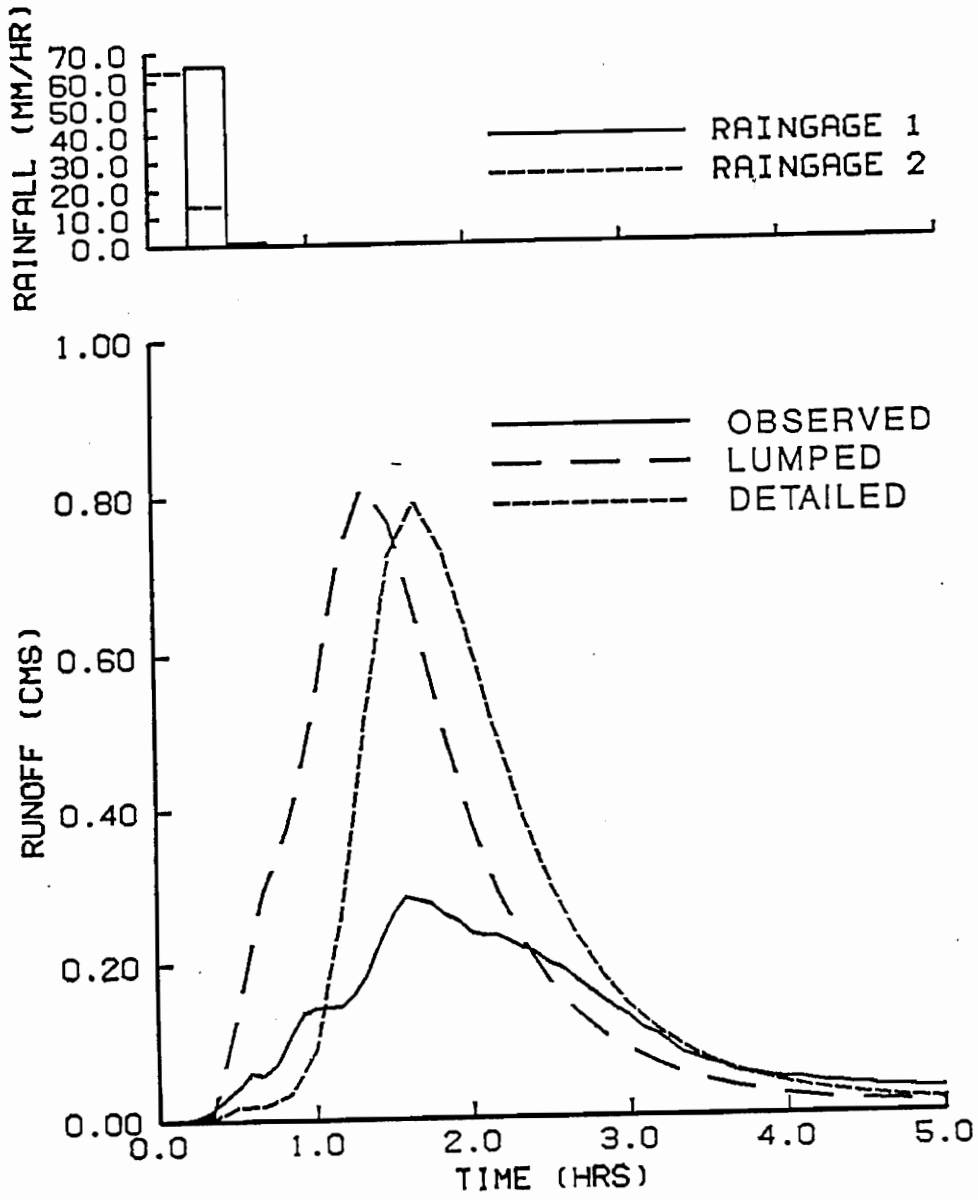

Figure 16. Comparison of simulated hydrographs for Event #5 using Brush Creek "detailed" and "lumped" data bases.

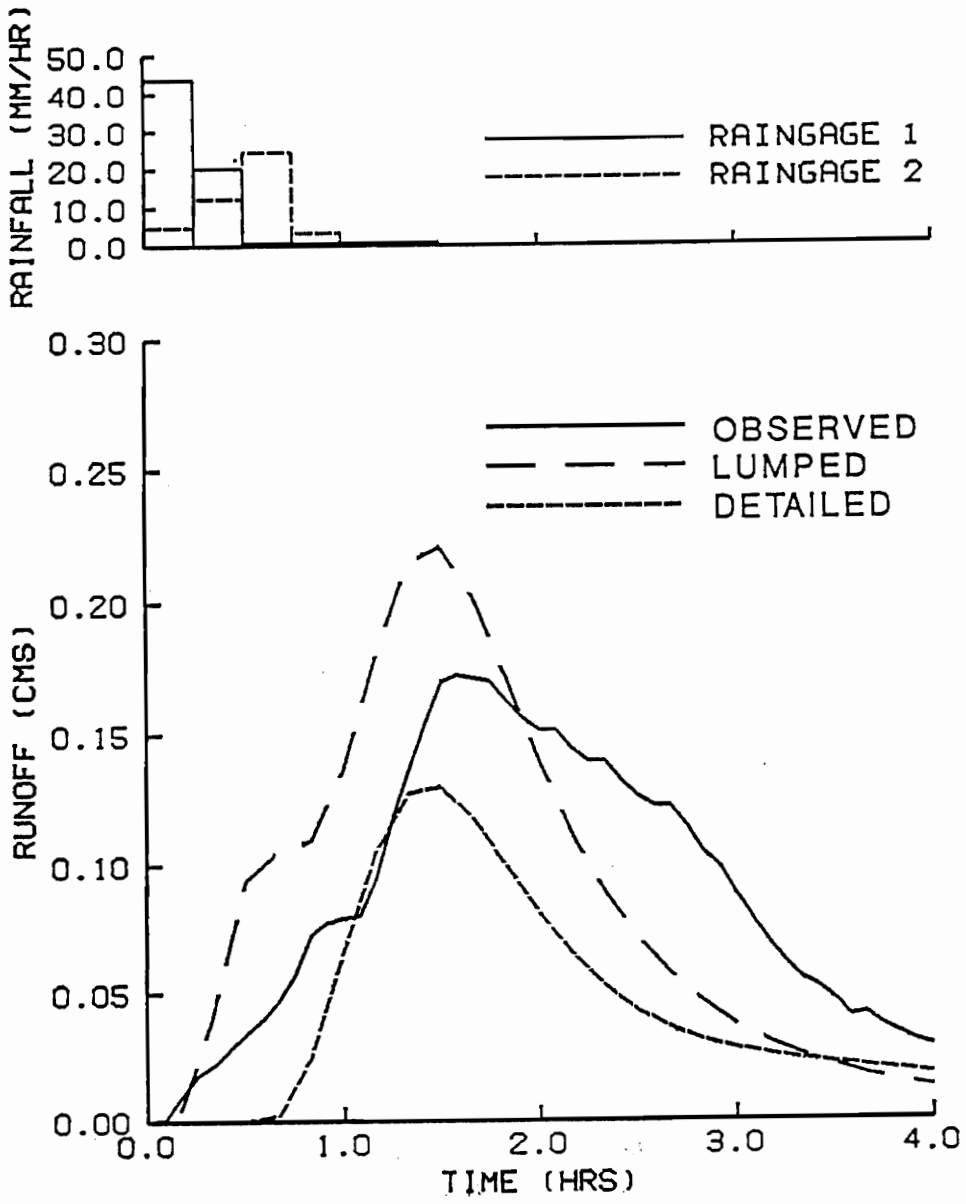

Figure 17. Comparison of simulated hydrographs for Event #7 using Brush Creek "detailed" and "lumped" data bases.

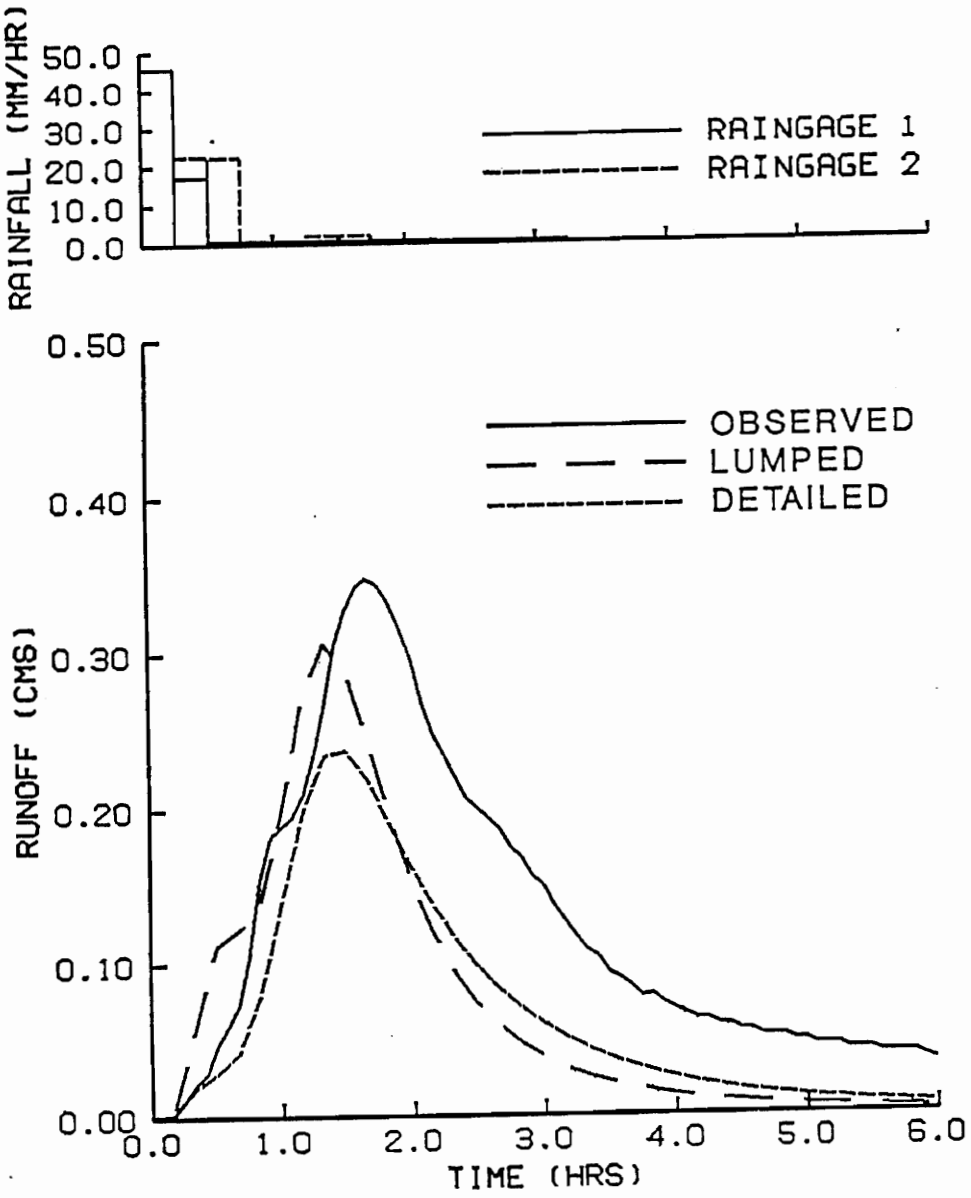

Figure 18. Comparison of simulated hydrographs for Event #8 using Brush Creek "detailed" and "lumped" data bases.

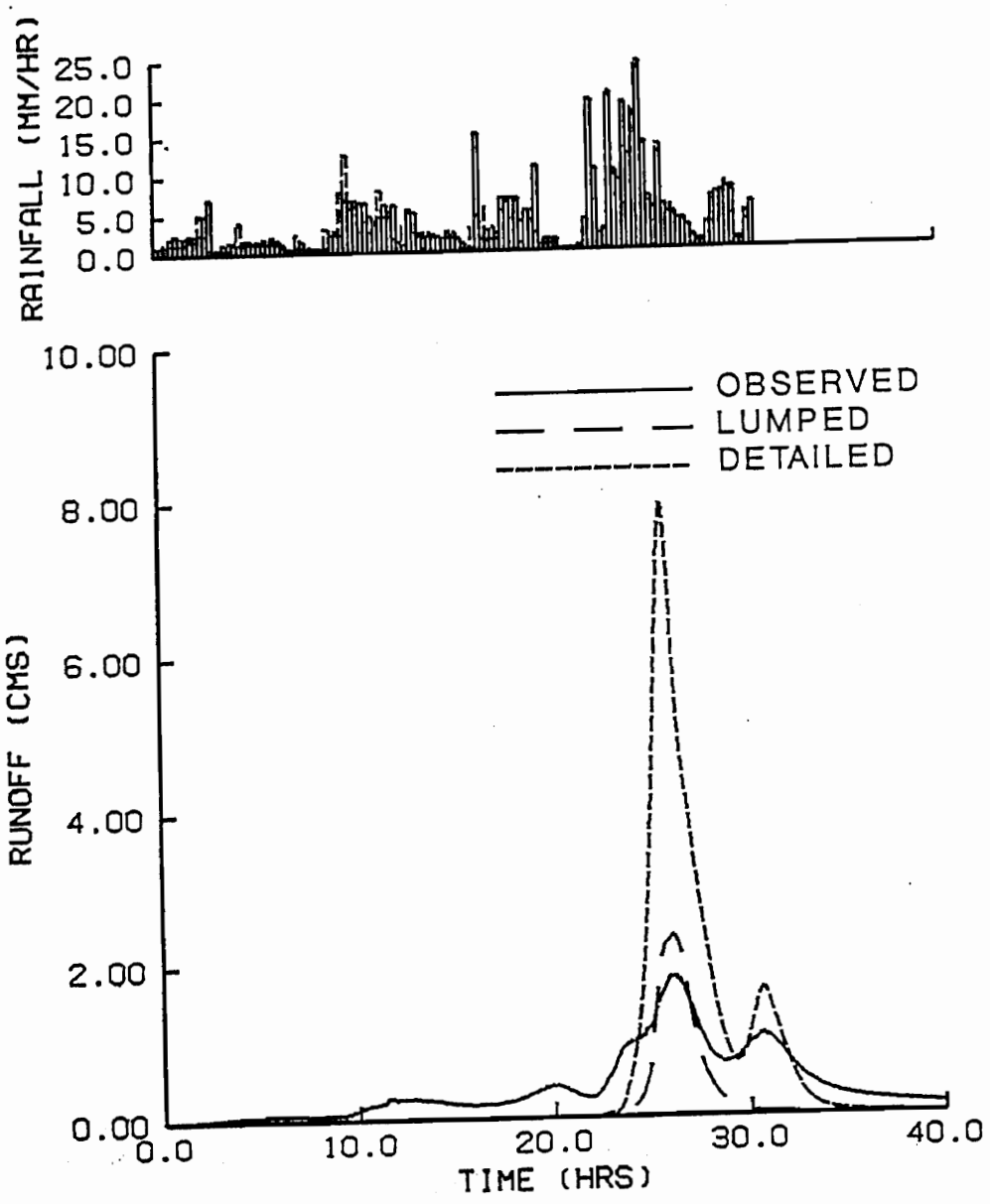

Figure 19. Comparison of simulated hydrographs for Event #9 using Brush Creek "detailed" and "lumped" data bases.

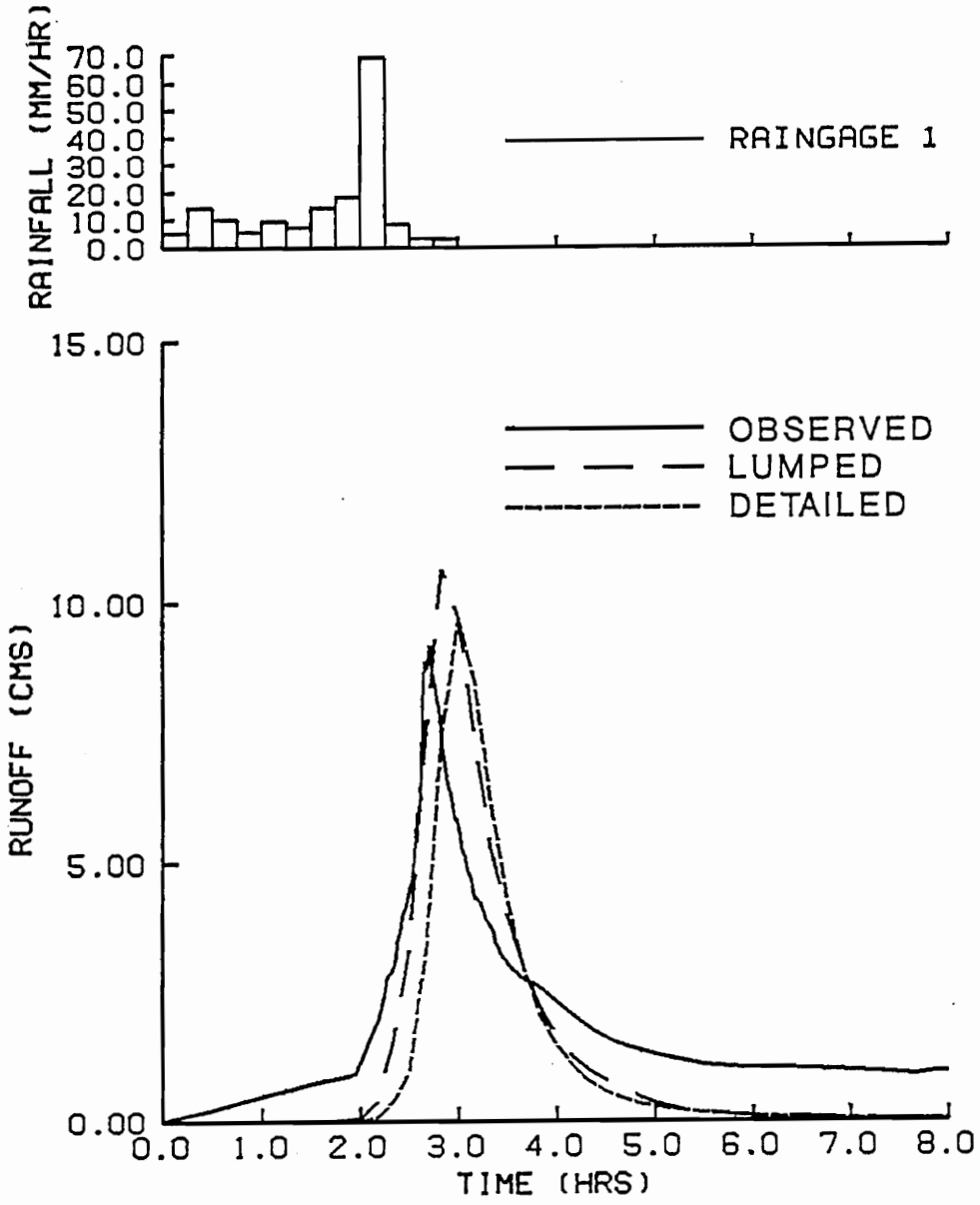

Figure 20. Comparison of simulated hydrographs for Event #10 using Brush Creek "detailed" and "lumped" data bases.

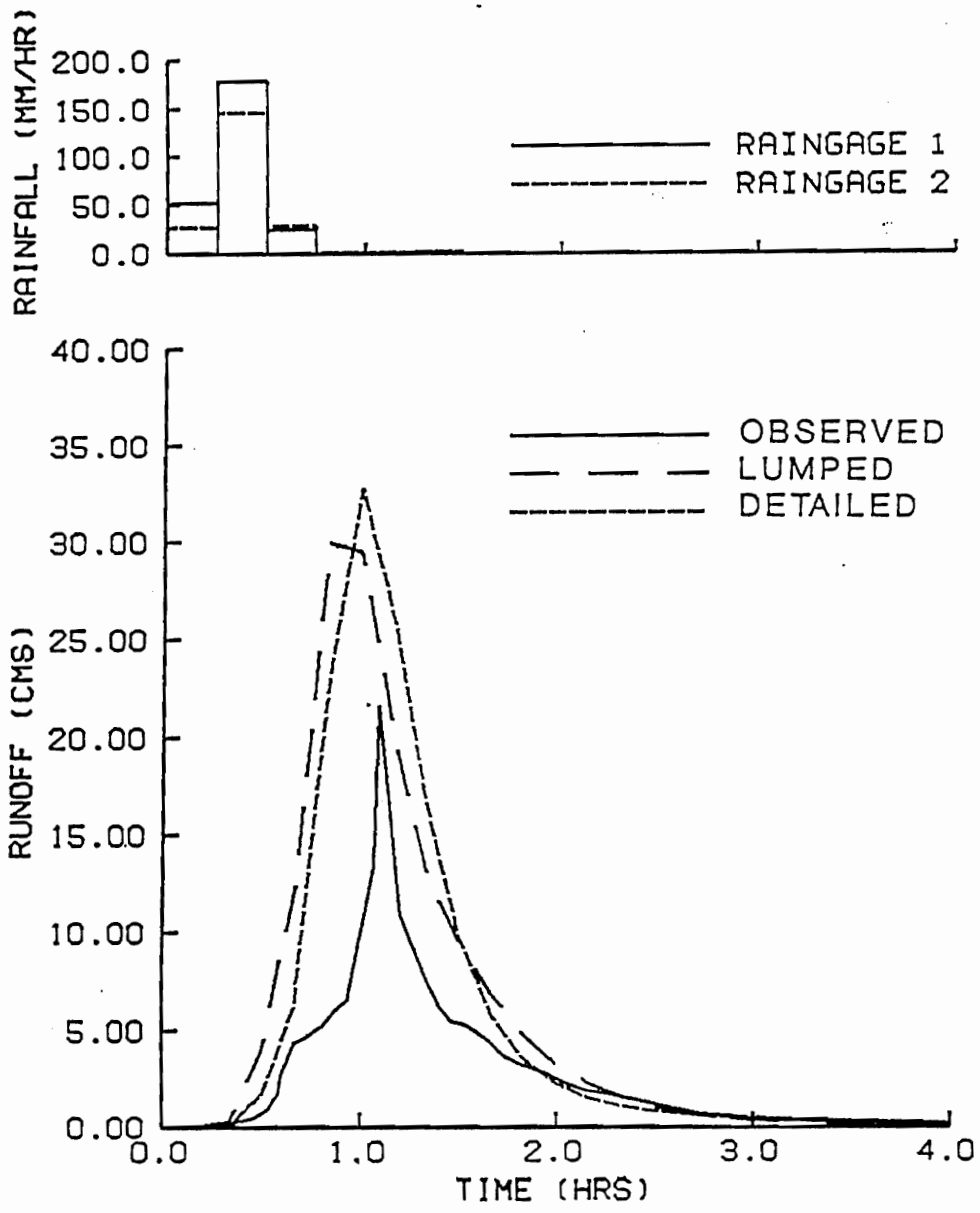

Figure 21. Comparison of simulated hydrographs for Event #11 using Brush Creek "detailed" and "lumped" data bases.

Chapter 6. However, the intensity level of event 6 did exceed the F_c of the "detailed" data base momentarily, at which time there was sufficient available storage in the control zone to prevent the occurrence of runoff.

Figures 13, 14, 15, 17 and 19 show that the simulation results varied greatly depending on the data base used. This indicates that there are definitely important differences between the two data bases and their representation of the watershed. The discretization differences are illustrated in Figures 6, 7, 8 and 9. However, the simulations of events 5, 8, 10 and 11 (Figures 16, 18, 20 and 21) are very similar for the two data bases. In most cases the "lumped" data base produced better simulation results.

As shown in Figure 22 and Figure 23, the simulated hydrographs resulting from the two design storms are similar, although the "detailed" data base predicted slightly higher peak flows and runoff volumes. These results can be misleading because the design storms are extremely rare and intense events and the variation between lumped and non-lumped simulations can be expected to increase with lower rainfall intensities (Shanholtz et al., 1981).

In an attempt to quantify the abilities of the different levels of information to simulate recorded runoff, the relative errors in simulation were computed from:

$$Relative\ Error = \frac{Simulated - Observed}{Observed} * 100\% \qquad [4]$$

The relative errors are given in Table 16 for the peak flows and runoff volumes of both the "lumped" and "detailed" data base simulations. The results from events 1 and 6 were not used in this analysis since no runoff was simulated using either data base. Since the model can not simulate negative runoff (zero runoff is a boundary condition), the relative errors from Equation 4 would be -100%, which may not accurately represent the actual error of simulation.

In order to make a comparison of overall performance, two mean values also were computed. The arithmetic and logarithmic means of the relative errors were

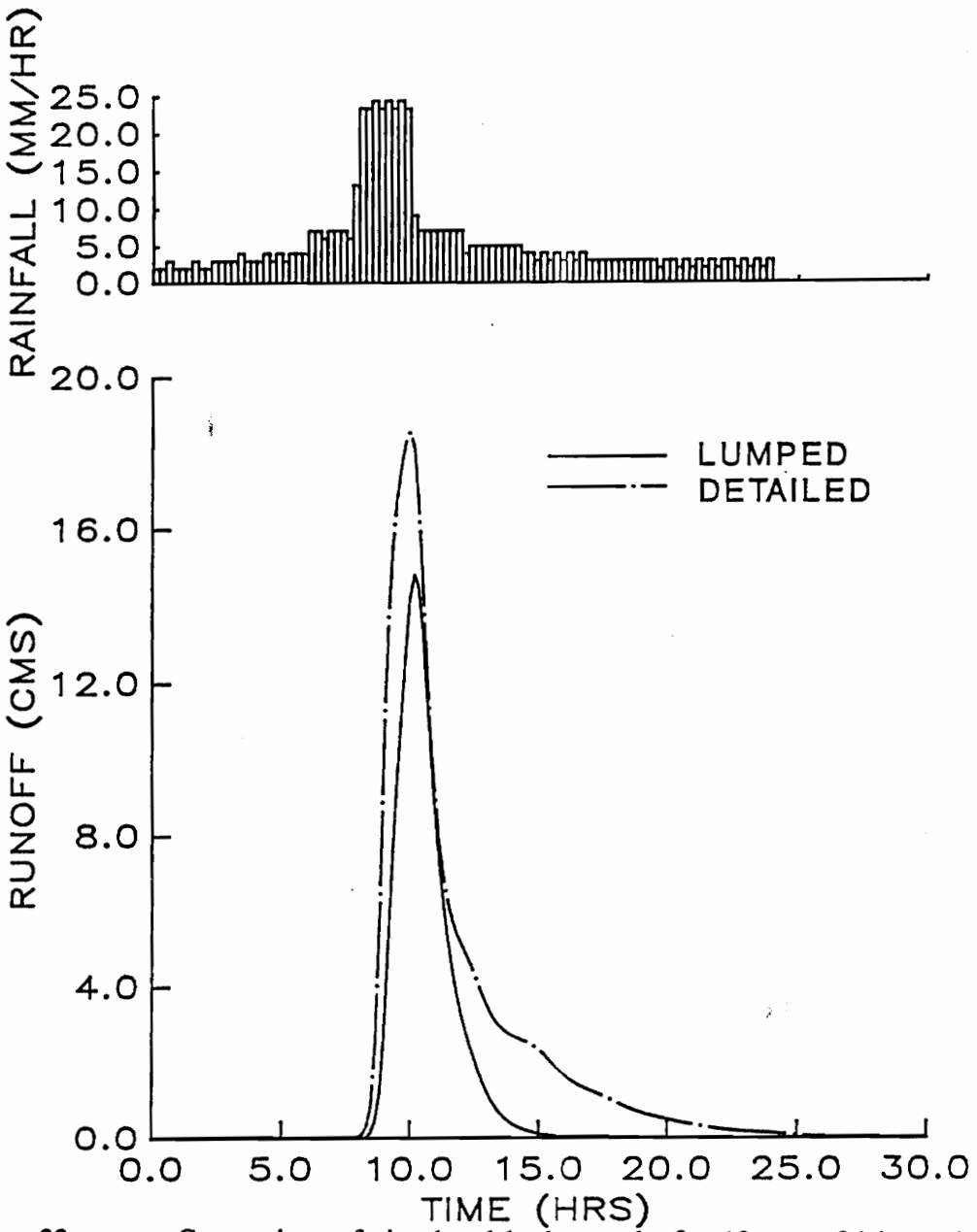

Figure 22. Comparison of simulated hydrographs for 10 year, 24 hour design storm using Brush Creek "detailed" and "lumped" data bases.

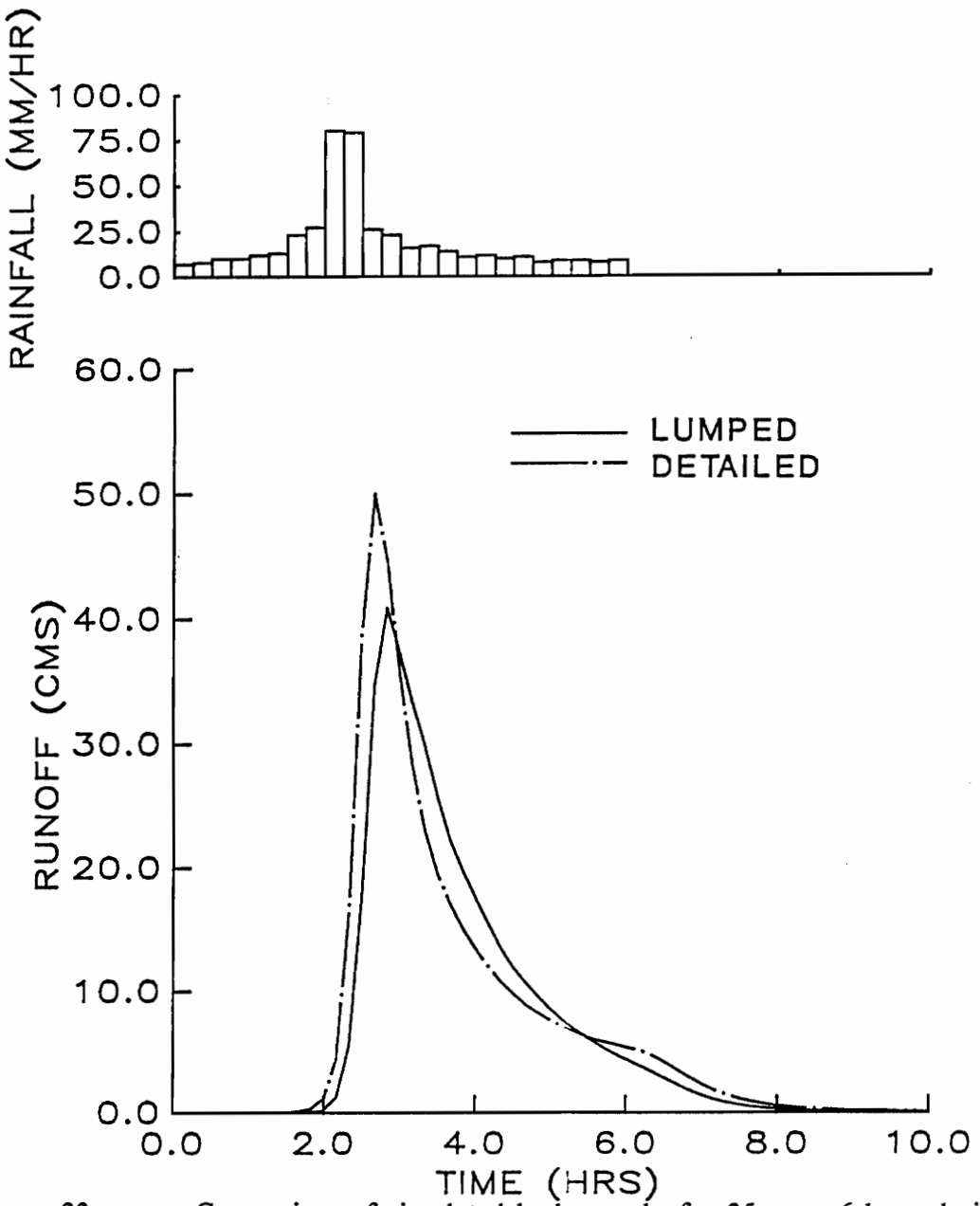

Figure 23. Comparison of simulated hydrographs for 25 year, 6 hour design storm using Brush Creek "detailed" and "lumped" data bases.

computed for the peak flows and runoff volumes of each of the data bases' results. The arithmetic mean relative errors were computed from:

$$MARE = \frac{\Sigma \mid Relative\ Error\ \% \mid}{n} \qquad [5]$$

where *MARE* is the mean absolute relative error and *n* is the number of relative errors which have been summed. Also shown at the bottom of Table 16 are the logarithmic mean absolute relative errors. A logarithmic mean tends to put less emphasis on one or two bad fits. These values were computed from the following:

$$LMARE = \frac{\Sigma\ LOG(\mid Relative\ Error\ \% \mid)}{n} \qquad [6]$$

where *LMARE* is the logarithmic mean absolute relative error and *n* is the number of observations.

Comparison of both of these means for the two data bases again shows that the "lumped" data base did a better job of simulating the observed runoff. These results show that there is no significant advantage to using the more detailed data base for the storms used in this analysis. Although the more detailed data base is expected to provide better simulations, system complexity makes it difficult to determine the level of data resolution necessary for a given level of simulation accuracy.

In an attempt to explain the differences in the simulation results of the two data bases, the mean values of 7 important input parameters are given in Table 17. All of the parameters are shown to be similar for the two data bases except F_c and DEPTH. In addition, the mean ratios of FGW to FAW, which are more significant than the individual values in affecting infiltration and runoff, are 0.6 and 0.8 for the "lumped" and "detailed" data bases, respectively.

The differences between the F_c, DEPTH, and ratio of FGW to FAW values may help to explain why the simulation results of the two data bases were different.

Table 17. Comparison of parameter estimates for the Brush Creek watershed's "lumped" and "detailed" data bases.

Model Parameter	Mean Parameter Estimate	
	Lumped Data Base	Detailed Data Base
AFLU	0.864	0.798
RCLU	0.298	0.306
CHANNEL ROUGHNESS	0.105	0.105
FAW	0.139	0.143
FGW	0.089	0.115
F_c	0.335	0.112
DEPTH	13.2	16.5

The simulated runoff using the "lumped" data base would be expected to be less than those using the "detailed" data base considering the mean F_c values. However, the mean values of DEPTH and ratio of FGW to FAW suggest that the "detailed" data base runoff simulations would be lower. Based on this analysis and others conducted previously, no definite conclusion can be made regarding the effect of data availability on model simulation results. Further studies are needed to determine the effect of parameter estimation, spatial variation, variable interactions and data availability on model simulations.

7.1.2 Evaluating Goodness of Fit

The predictive capability of FESHM in an ungaged context was evaluated using the Brush Creek "lumped" data base and 17-years of the historical record. Storms from the six month time period May through October were selected for the analysis. All rainfall events causing at least an increase of 15.24 cm (6 in.) in stream level were selected from the recorded history covering the period 1958-1974. Based on these criterion, a total of 111 events were selected.

7.1.2.1 *Procedures*

Using FESHM, surface flow hydrographs were systematically simulated for each storm event with no parameter fitting to improve correspondence with recorded flows. The peak flows and volumes were extracted for analysis from the simulated runoff hydrographs. In an effort to quantitatively evaluate the results, the following tests or methods of analysis were used:

1) Relative Error Analysis
2) Frequency Distribution Analysis
3) Linear Regression Analysis
4) Multiple Regression Methodology

FESHM is intended for use in simulating flood flows. Within the initial set of 111 events there were many small events which, from a design perspective, were not considered important. Therefore, event significance was further defined with the help of the Soil Conservation Service's (SCS) curve number method (SCS, 1972). A 25-year, 6-hour design storm was used along with a conservative curve number for the Brush Creek watershed. The estimated peak flow and runoff volume were 1.2 m^3/s and 3.56 mm, respectively. Thus, only events with observed peak flows or runoff volumes equal to or greater than these values were considered significant. Thirty one of the original 111 events were selected for extended evaluation as indicated with an asterisk in Table G-1.

The complete set of 111 events and the 31 event data set were evaluated separately using both relative error analysis and frequency distribution analysis, but only the 31 event data set was analyzed using linear regression analysis and multiple regression methodology.

7.1.2.2 *Results and Discussion*

Relative Error Analysis: The peak flows and volumes, observed and simulated, and computed relative errors for the 111 events are given in Appendix G, Table G-1. Relative error was calculated from Equation 4.

The relative error ranged from -100% to +405% for the peak flows and -100% to +223% for the runoff volumes. A negative relative error indicates that the model underpredicted the recorded value and a positive value indicates overprediction.

The model simulated no runoff for 32 of the 111 events, approximately 29% of the events, as indicated by relative errors of -100%. Four of these events were retained in the 31 event data set. These four storms had the four lowest 30-minute intensity levels (less than 7mm) amongst the 31 storms and three of these storms had durations greater than 14 hours.

Among the 31 significant events 32% of the peak flow simulations and 9% of the volume simulations were within ±20% relative error. The 30-minute intensity

levels for these events tended to be in the middle ranges (12-31mm) with durations ranging from 3 to 8 hours.

Six of the set of 31 peak flows were overpredicted by more than 100%. These events accounted for six of the eight highest 30-minute intensity levels (greater than 27mm) and all had durations less than 5 hours. Two of the 31 volume simulations had a relative error greater than +100%. These storms had the highest 30-minute intensity levels (greater than 50mm) and durations of only 2 hours. These results suggest that either spatial variability has not been well defined or parameters such as SMC, F_c, and DEPTH were not adequately estimated.

Frequency Distribution Analysis: Williams et al. (1985) suggest that it is important that the frequency distributions produced by the simulation model be similar to those of the measured data. Two distribution sets were generated for both the peak flows and runoff volumes. The first included all 111 simulated results and the second distribution set was derived using the 31 event data set.

Before constructing distributions for the peak flows and volumes, the data sets were analyzed for the absence of correlation between events, a necessary condition for meaningful comparison between distributions (Haan, 1977). The existence of correlation between events that occurred close together was expected. The lag-1 serial correlation test described by Haan (1977) was performed on all pairs of events occurring within seven days of each other. When no correlation exists, the distributions can be constructed using the complete duration series, that is, all observed and simulated values can be used. When correlation exists, however, only an extreme value series, or the maximum values from each year, can be used.

The lag-1 serial correlation test revealed no correlation at a significance level of 0.05. Based on this result, all runoff events were used to create simulated and corresponding recorded frequency distributions.

Frequency distributions of peak flows and volumes of the set of 111 events are shown in Figure 24 and 25, respectively. The simulated frequency distribution is in the foreground and the corresponding observed distribution is in the background

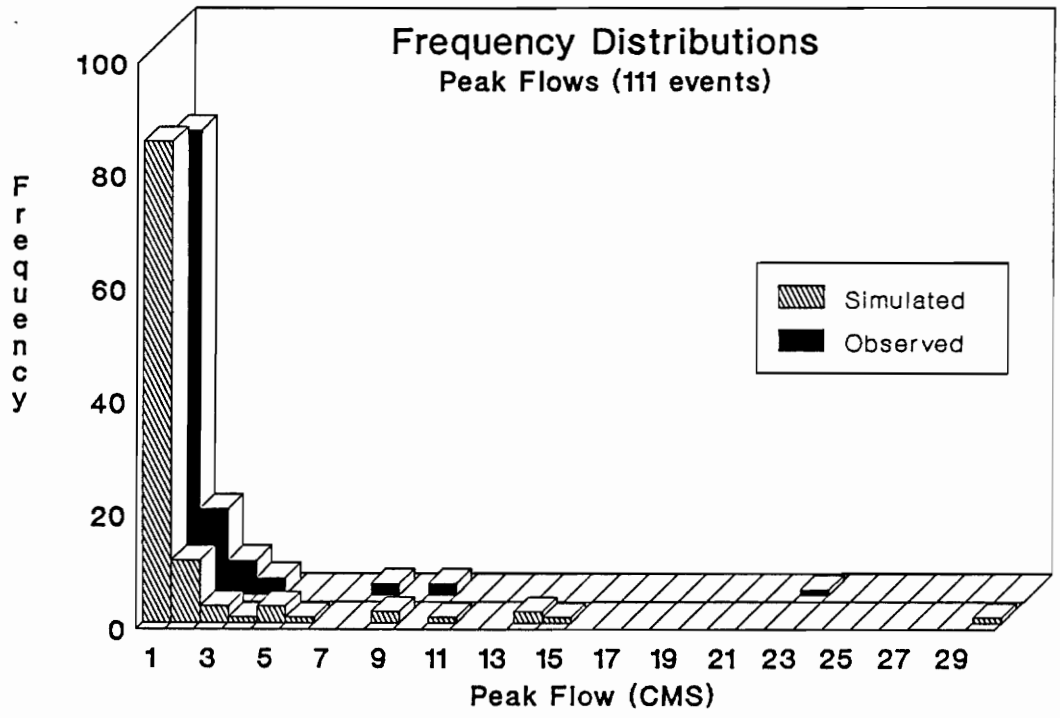

Figure 24. Comparison of peak flow frequency distributions, 111 events.

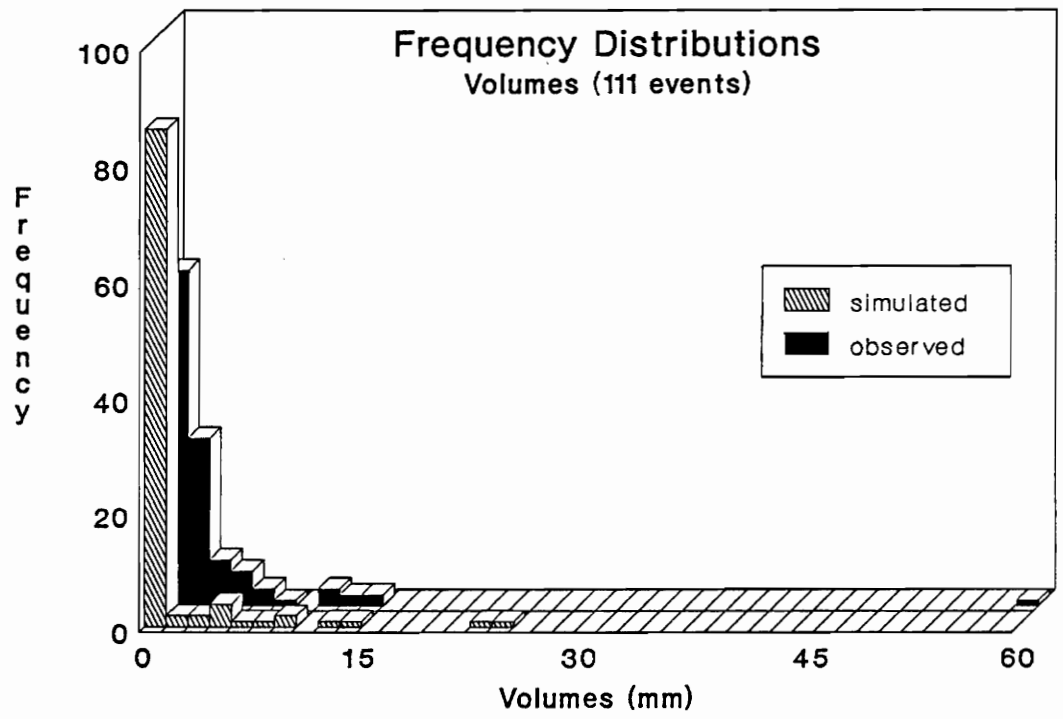

Figure 25. Comparison of volume frequency distributions, 111 events.

of each figure. From visual inspection, the peak flow distributions do not appear different. The volume distributions also appear similar, except for a higher occurrence in the lowest interval for the simulated volumes. However, these graphical displays may be deceiving because the 29% of the events that had no predicted runoff were included in the first interval along with all values ranging from 0 to 1 m^3/s for peak flows and 0 to 1.5 mm for runoff volumes.

The distributions were compared for statistical significance using a paired t-test as described by Ostle (1963). In this statistical test, two sample means are compared to test the hypothesis that the distributions are not significantly different. Using a significance level of 0.05, the peak flow frequency distributions were not significantly different, but the distributions of the runoff volumes were.

The distributions for the 31 event data set are shown in Figure 26 and Figure 27. Upon visual observation, the peak flow distributions look similar with differences most pronounced in the lower intervals. The volume distributions appear more similar than with the larger set of 111 events analyzed previously. A paired t-test showed a reversal in the results obtained for the larger data set. A significant difference was indicated for the peak flow distributions at the 5 percent probability level, but not for the runoff volume distributions.

It appears that by eliminating the smaller insignificant events, some good peak flow simulations and some bad volume simulations were eliminated. This indicates that for the data sets used the volumes for small runoff events were not simulated well while peak flows were simulated fairly well.

Linear Regression Analysis: Simple linear regression analyses were performed on the simulation results from the 31 event data set in an attempt to evaluate the predictive performance of FESHM. Ideally, the relationship between the observed

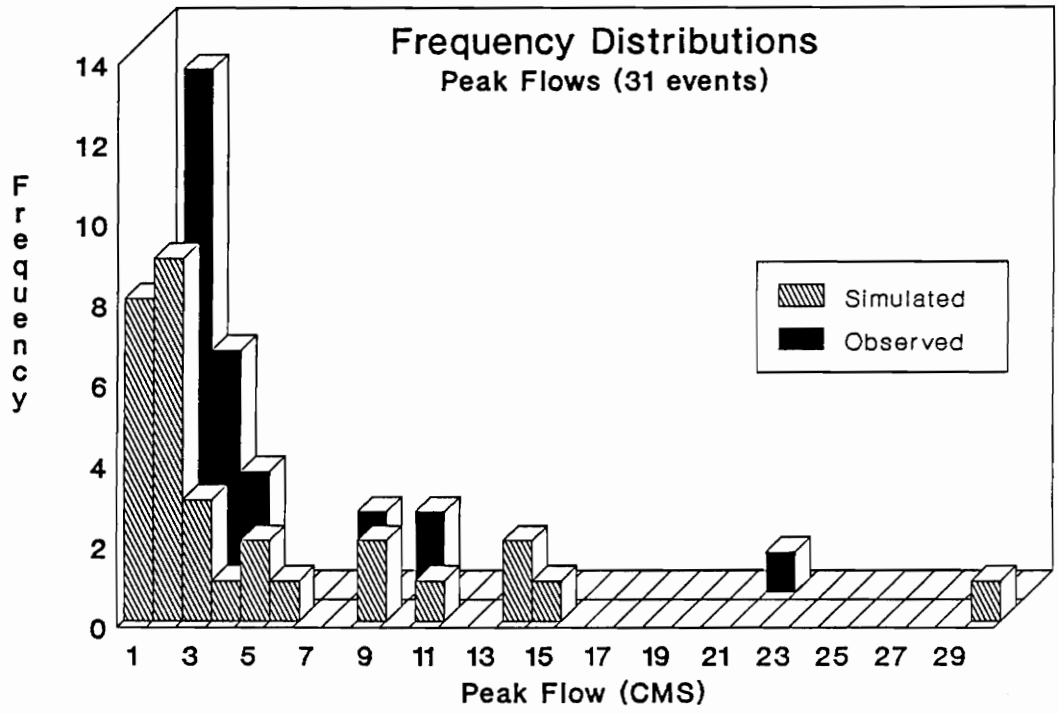

Figure 26. Comparison of peak flow frequency distributions, 31 events.

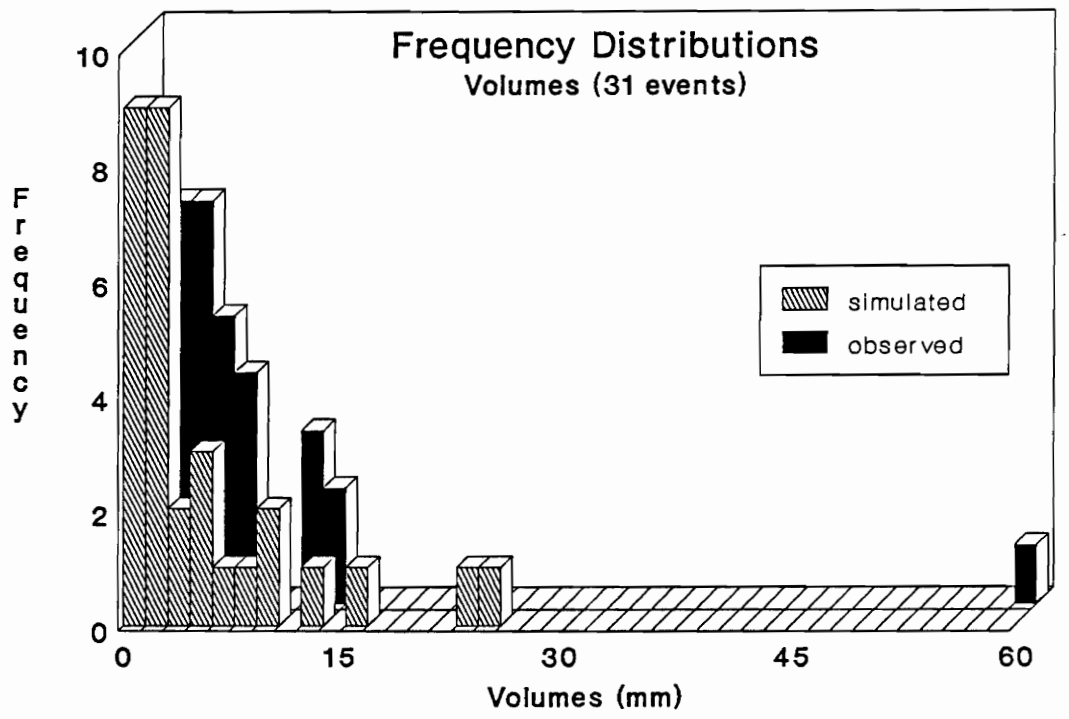

Figure 27. Comparison of volume frequency distributions, 31 events.

and simulated peak flows and runoff volumes would be:

$$Y = X \qquad [7]$$

where Y is the simulated value of peak flow or runoff volume and X is the observed value of peak flow or runoff volume. The linear regression procedure helps to define the degree of association between the observed and simulated values.

The regressions were performed, using the Statistical Analysis System (SAS) (SAS Institute Inc., 1982), on the peak flows and runoff volumes of the 31 event data set. The scatterplot of simulated peak flows versus observed peak flows, the resulting simple linear regression line and the line of equal value (the ideal relationship) are shown in Figure 28. The resulting regression describing the relationship of simulated to observed is:

$$P_S = -.04 + 1.37*P_O \qquad [8]$$

where P_S is simulated peak flow in m^3/s and P_O represents observed peak flow in m^3/s. The coefficient of determination or R^2 value is .82 for this regression.

The scatterplot of simulated runoff volumes versus observed runoff volumes, the resulting simple linear regression line and the line of equal value are shown in Figure 29. The resulting regression describing the relationship of simulated to observed runoff volumes is:

$$V_S = 2.03 + .44*V_O \qquad [9]$$

where V_S represents simulated volume in mm and V_O represents observed volume in mm. The coefficient of determination or R^2 value is .48 for this regression.

The R^2 of .82 for the peak flow regression indicates that the model accounted for more than 80% of the variance in observed peak flows and that the resulting

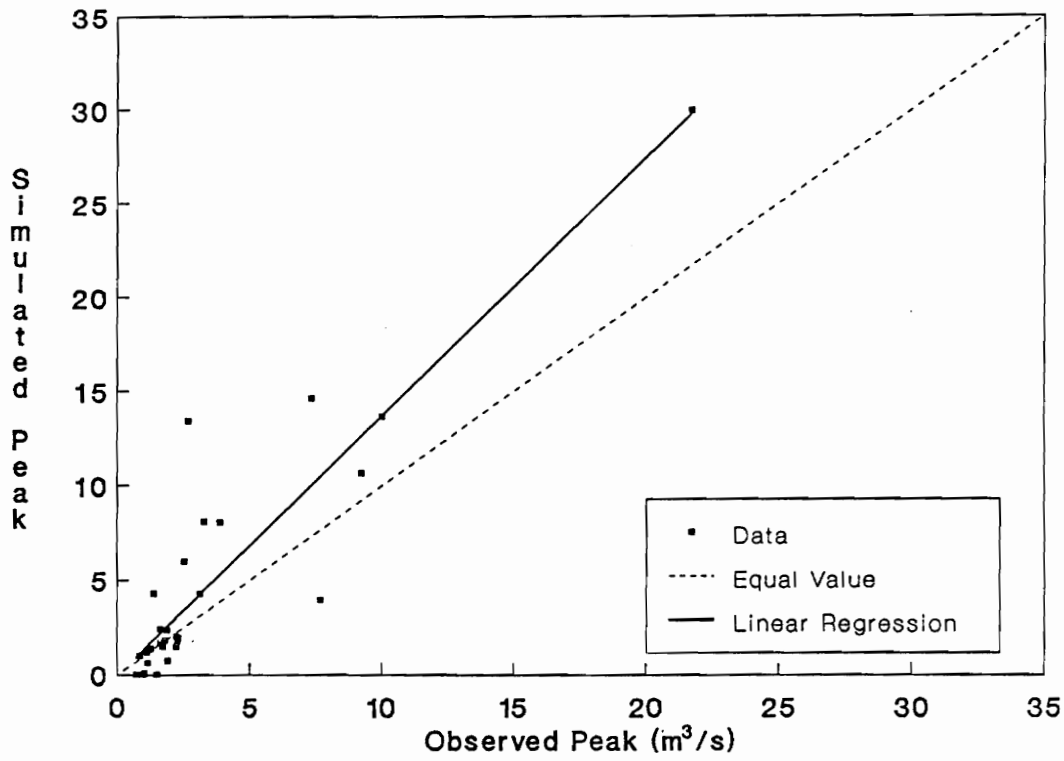

Figure 28. Comparison of simulated and observed peak flows and linear regression results (31 events).

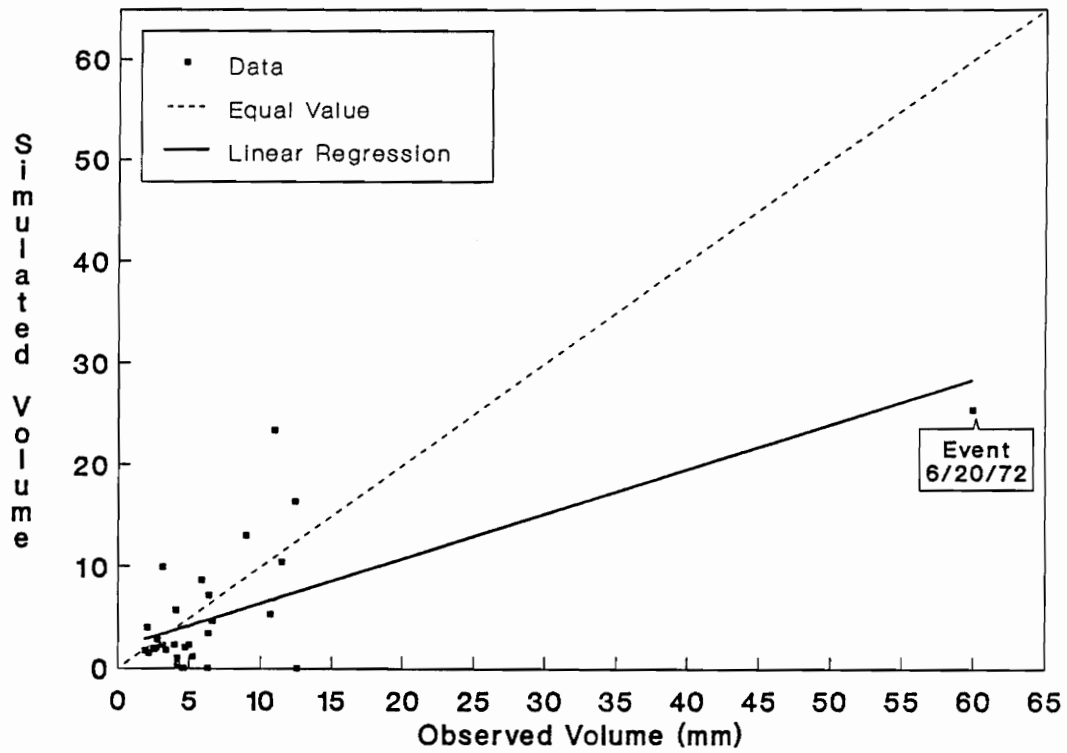

Figure 29. Comparison of simulated and observed volumes and linear regression results (31 events).

regression line does a good job in representing the scattered points. Events with very low observed peak flows were underpredicted, while events with peak flows greater than 1 m^3/s were overpredicted. For the larger events, peak flows were overpredicted by approximately 40%.

The R^2 of .48 for the volume regression indicates that the regression line does not do a good job of representing the data. The regression equation indicates that the model underpredicted peak flows by approximately 50%. Through visual observation of the scatterplot it appears that one bad data point influences the regression significantly. This bad point represents simulation results of the event which occurred on 6/20/72. Some difficulty was encountered when simulating this event due to its duration of 36 hours. Computer storage overrun errors occurred due to the immense amount of data involved in modeling such a long event. Thus, the first half of the storm, which was characterized by low intensity intermittent rainfall, was replaced in the input file by a high antecedent soil moisture content and the storm was reduced to an 18 hour event to avoid storage overrun errors. The recorded runoff event also was very complex, consisting of multiple peaks.

Due to the unusual circumstances surrounding the simulation of this event it was eliminated from the data set and a new simple linear regression was performed on the remaining runoff volume data points. The resulting regression line is shown in Figure 30 and the corresponding regression equation is:

$$V_S = -.83 + .98*V_O \qquad [10]$$

where V_S represents simulated volume in mm and V_O represents observed volume in mm. The coefficient of determination or R^2 value is .39 for this regression. The regression line is very close to the desired equal value line, but the low R^2 value suggests that scatter or variance is great, no relationship is evident, and the model results do not appear acceptable. Perhaps the relationship could be better described with an exponential function, but no strong trends were apparent. The event on

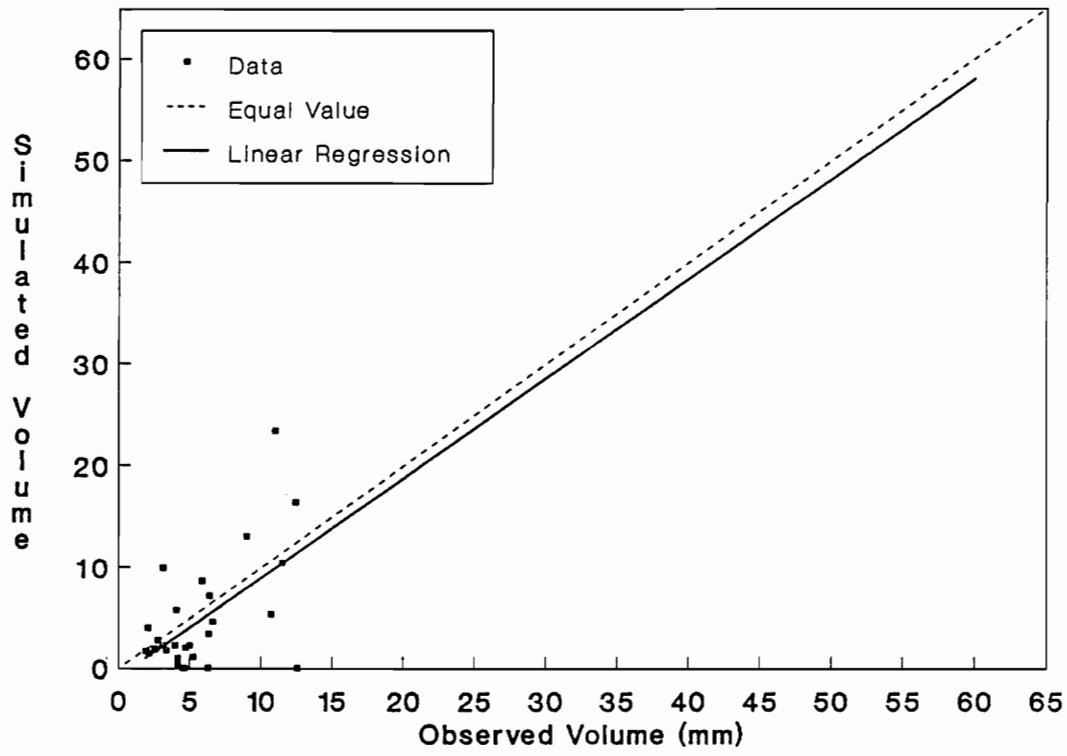

Figure 30. Comparison of simulated and observed volumes and linear regression results (30 events, without 6/20/72).

6/20/72 was eliminated from the peak flow data and linear regression again was performed with little or no change in the previous results.

Regression Methodology: Regression methodology, as described by Reynolds and Chung (1986), was used to model the error or bias as a function of FESHM input variables. This procedure was used to detect and explain trends in prediction error. The methodology employs the use of multiple linear regression procedures with the prediction error as the dependent variable and selected input variables as the independent variables.

The independent variables were selected to correspond to the most important observable input variables in the real system which vary from event to event. The variables chosen were:

1) TRN - total rainfall amount (mm)
2) RN15 - maximum 15-minute rainfall intensity (mm)
3) RN30 - maximum 30-minute rainfall intensity (mm)
4) GI - monthly growth index value
5) SMC - antecedent soil moisture content (%)
6) TIME - length of storm (hrs.)

Both the 15-minute and 30-minute rainfall intensities were included because the rainfall was input into the model at 15-minute intervals and studies indicate that an important characteristic of rainfall in determining runoff is the maximum 30-minute intensity level (Shanholtz and Dickerson, 1964). Any correlation between these variables was taken into account during the regression analysis.

This regression procedure was performed on both the peak flows and runoff volumes from the 31 event data set. The prediction error used in this analysis is given by:

$$D = \text{Observed} - \text{Simulated} \quad \text{(peak flows or runoff volumes)} \qquad [11]$$

where D is the peak flow or runoff volume prediction error, or difference. The prediction error and six input variables for the 31 events are given in Table 18.

A multiple regression was performed with the prediction error as the dependent variable and the six input variables as independent variables. The initial regression model for both the peak flow and runoff volume differences can be represented as:

$$D = B_0 + B_1*TRN + B_2*RN15 + B_3*RN30 + B_4*GINDEX + B_5*SMC + B_6*TIME + \epsilon \quad [12]$$

where D is the difference calculated by Equation 11, the B*is* are coefficients and ϵ is the random error term.

The regression was done separately for the peak flow and runoff volume prediction errors. Four methods of stepwise regression were employed using the Statistical Analysis System (SAS) (SAS Institute Inc., 1982). The regression procedures conducted were: the forward selection procedure, the backward elimination procedure, the stepwise regression procedure, and the maximum R-square improvement procedure. These regression methods are useful in determining which variables should be included in the regression model when there are many independent variables.

The regression model obtained for the prediction error of the peak flows without eliminating any of the independent variables was:

$$D = .44 + .02*TRN - .08*RN15 - .21*RN30 + 3.44*GINDEX + .01*SMC - .10*TIME \quad [13]$$

with an R^2 value of .83.

Not all of the independent variables in Equation 13 were found to be significant. After examining the R^2 values and the significance levels of the various input parameters selected with the stepwise regression procedures, the following model was chosen as the best in describing prediction error or bias of the peak flow

Table 18. List of peak flow and runoff volume prediction errors and six input parameters for each of the 31 events.

Event No.	Prediction Error[1]		Input Parameters					
	Peak (m^3/s)	Volume (mm)	TRN (mm)	RN15 (mm)	RN30 (mm)	GI	SMC (%)	TIME (hrs.)
1	-7.31	-4.06	42.16	20.57	34.54	0.60	80	2
2	0.21	2.69	20.57	8.89	15.24	0.80	100	4
3	-8.27	-12.47	65.53	44.45	57.40	0.90	150	2
4	0.20	0.86	30.48	12.95	19.81	0.75	80	3
5	-3.65	-3.96	47.50	18.29	29.97	0.40	98	2
6	-4.18	-2.74	41.40	23.88	38.10	0.90	70	2
7	-2.89	-1.96	35.31	14.73	27.69	0.90	33	5
8	0.50	3.20	33.53	10.16	15.75	0.75	65	6
9	0.71	4.55	34.04	1.27	2.29	0.60	70	15
10	-4.80	-0.79	58.67	22.10	31.24	0.90	53	3
11	0.00	0.58	26.16	17.78	23.11	0.90	67	2
12	-0.13	2.67	56.64	12.95	17.78	0.90	96	8
13	0.95	3.84	112.01	4.06	7.11	0.75	100	23
14	-0.05	0.71	23.37	15.75	21.59	0.90	31	5
15	-3.43	-1.68	34.04	16.76	27.94	0.90	95	5
16	-0.12	0.79	28.45	9.14	12.95	0.90	150	6
17	0.99	6.22	82.80	3.56	6.10	0.40	30	18
18	-0.51	5.31	83.31	5.84	10.41	0.40	100	22
19	-0.03	0.69	21.34	11.43	21.08	0.80	100	6
20	0.71	1.57	45.72	14.48	18.03	0.90	95	4
21	-1.16	1.93	35.56	9.91	19.56	0.60	76	3
22	0.37	1.68	32.26	8.89	16.51	0.80	66	3
23	-10.72	-6.86	50.04	34.29	49.53	0.90	17	2
24	1.18	4.09	29.21	6.35	9.40	0.40	100	7
25	3.72	34.57	152.40	8.89	15.24	0.80	150	18
26	1.49	12.52	40.64	5.33	7.11	0.90	43	14
27	-1.46	0.99	41.66	17.27	21.84	0.60	143	3
28	-0.77	-0.08	27.94	12.95	16.00	0.60	80	8
29	-0.12	0.25	32.00	11.68	21.08	0.90	41	4
30	0.86	4.50	50.55	2.54	4.06	0.75	80	4
31	0.51	2.90	50.80	12.70	24.13	0.75	78	5

[1] Computed using Equation 11.

simulations:

$$D = 3.37 - .22*RN30 \qquad [14]$$

The R^2 value of .77 and the significance level of the variable RN30 suggests that a bias in peak flow simulations can be related to RN30. A plot of the residuals against the independent variable showed no apparent pattern and this was taken as the final peak flow error regression model. The estimated peak flow bias as a function of the 30-minute intensity level (RN30) is shown in Figure 31 and shows that the peak flow simulation results are sensitive to the storm intensity levels.

The regression model for the prediction error of runoff volumes using all of the independent variables was:

$$D = -3.24 + .19*TRN - .46*RN15 - .13*RN30 + 8.48*GINDEX + .01*SMC - .31*TIME \qquad [15]$$

with an R^2 of .71. Further investigation led to the selection of the following model for explaining bias in runoff volume simulation:

$$D = 1.25 + .15*TRN - .45*RN15 \qquad [16]$$

From this relationship, the bias in volume prediction may be explained with TRN and RN15. A plot of the residuals against each of the independent variables showed no apparent pattern. The estimated bias as a function of TRN is shown in Figure 32 and as a function of RN15 in Figure 33.

Visual inspection of Figure 32 indicates that, as with the simple linear regression analysis described previously, this regression is overly weighted toward event number 25 (Table 18) which occurred on 6/20/72. The regression as a function of RN15 (Figure 33) does not appear to be sensitive to this data point.

The entire regression analysis was again performed on runoff volume bias

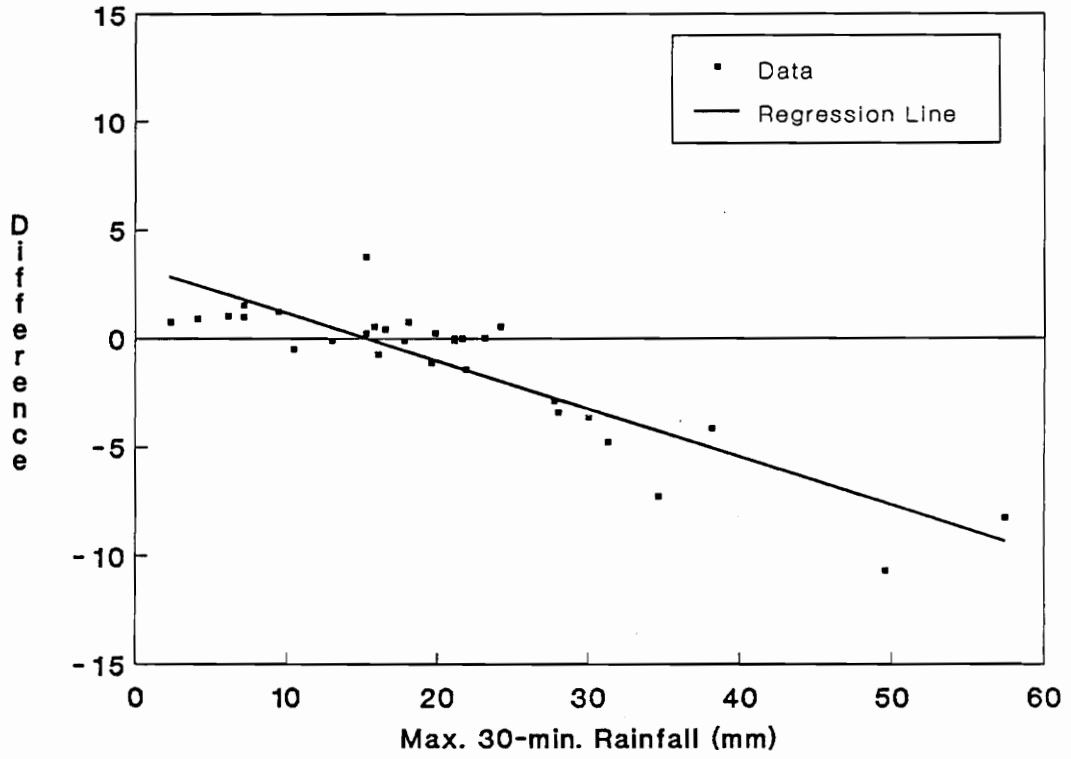

Figure 31. Estimated peak flow bias as a function of the 30-minute rainfall intensity level (31 events).

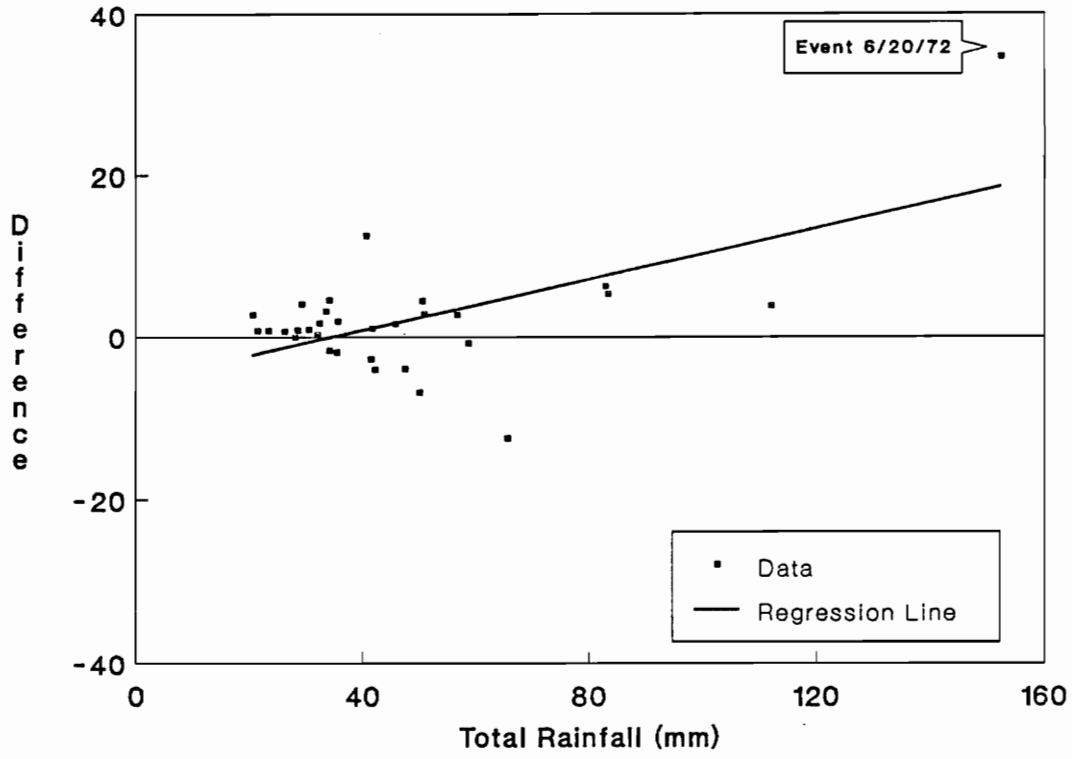

Figure 32. Estimated volume bias as a function of the total rainfall amount (31 events).

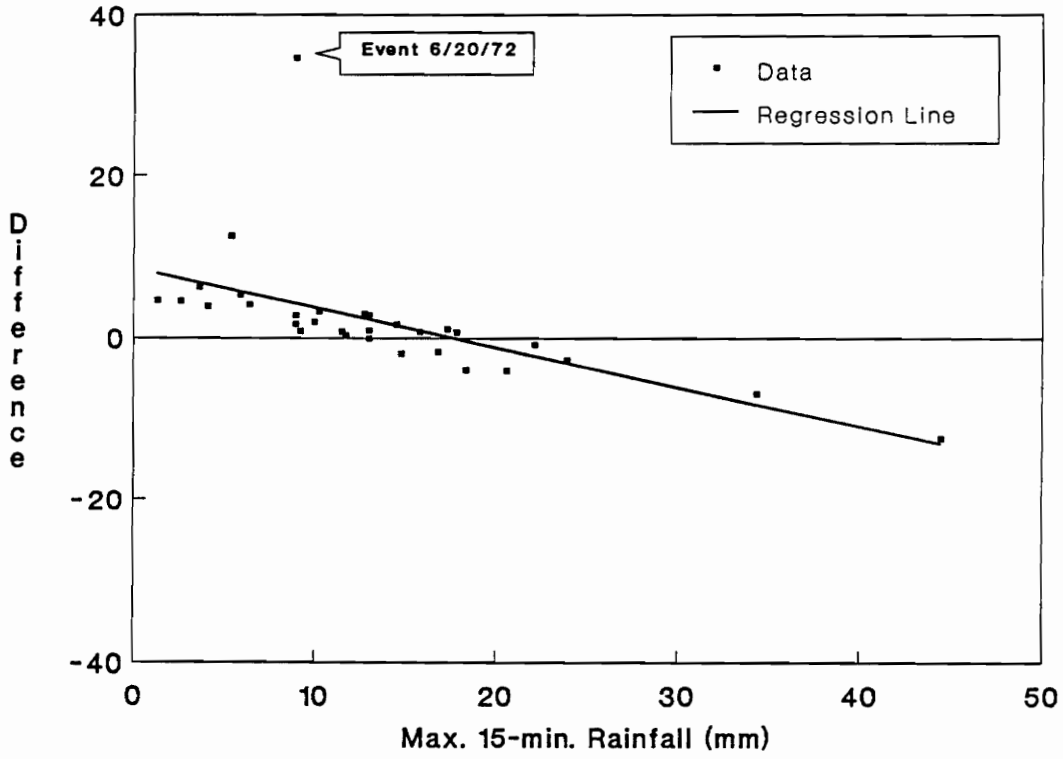

Figure 33. Estimated volume bias as a function of the 15-minute rainfall intensity level (31 events).

after extracting event number 25. The resulting plot of the bias as a function of TRN is shown in Figure 34 and suggests that total rainfall amount (TRN) does not help explain the bias in the simulation of runoff volumes. The regression line has a slope approaching zero and lays very close to the line indicating zero bias. Therefore, the following model was chosen as the most appropriate in explaining the bias in runoff volume simulations:

$$D = 6.79 - .43*RN15 \qquad [17]$$

The coefficient of determination or R^2 of this regression is .79. This result suggests that the volume simulation bias can be related to the 15-minute intensity level (RN15) of the input storm. The estimated volume bias as a function of RN15 is shown in Figure 35.

Inspection of Figure 31 and Figure 35 shows that both the peak flow and runoff volume simulation errors can be related to the intensity level of the storm event. The maximum 30-minute rainfall amount affects peak flow bias, while the maximum 15-minute rainfall amount affects volume bias.

With the above regression analysis, the bias has been linked to a particular input variable and at least a starting point for investigating the problem has been identified. The bias in model simulations may be due to problems in the data base, parameter estimations, or with algorithms within FESHM. A resolution of these biases was not attempted in this study.

This analysis indicated that simulation bias is associated to the level of the input rainfall intensity levels. Therefore, the algorithm affected by intensity level, Holtan's infiltration equation, may need review for possible improvement or replacement. Most likely, an improved method of parameter estimation and more accurate definition of spatial variability of important parameters such as SMC, F_c, DEPTH, FAW, and FGW are needed. In addition, the results indicate that FESHM is not applicable in an ungaged context and that some calibration may be necessary.

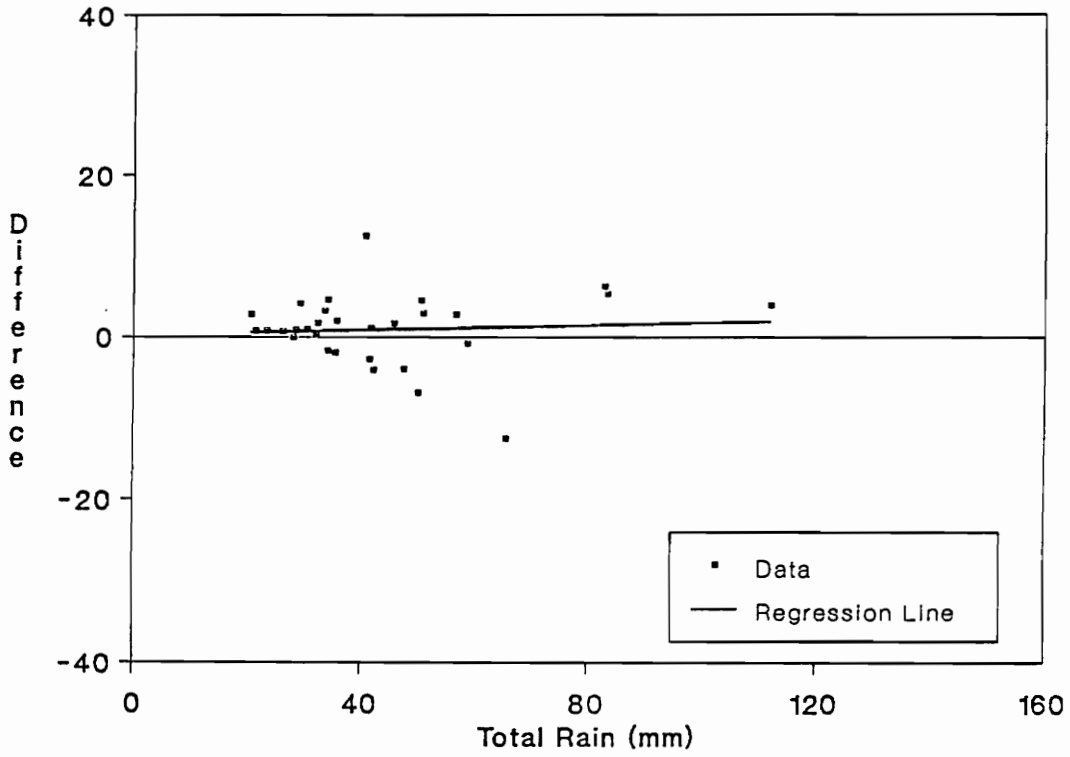

Figure 34. Estimated volume bias as a function of the total rainfall amount (30 events, without 6/20/72).

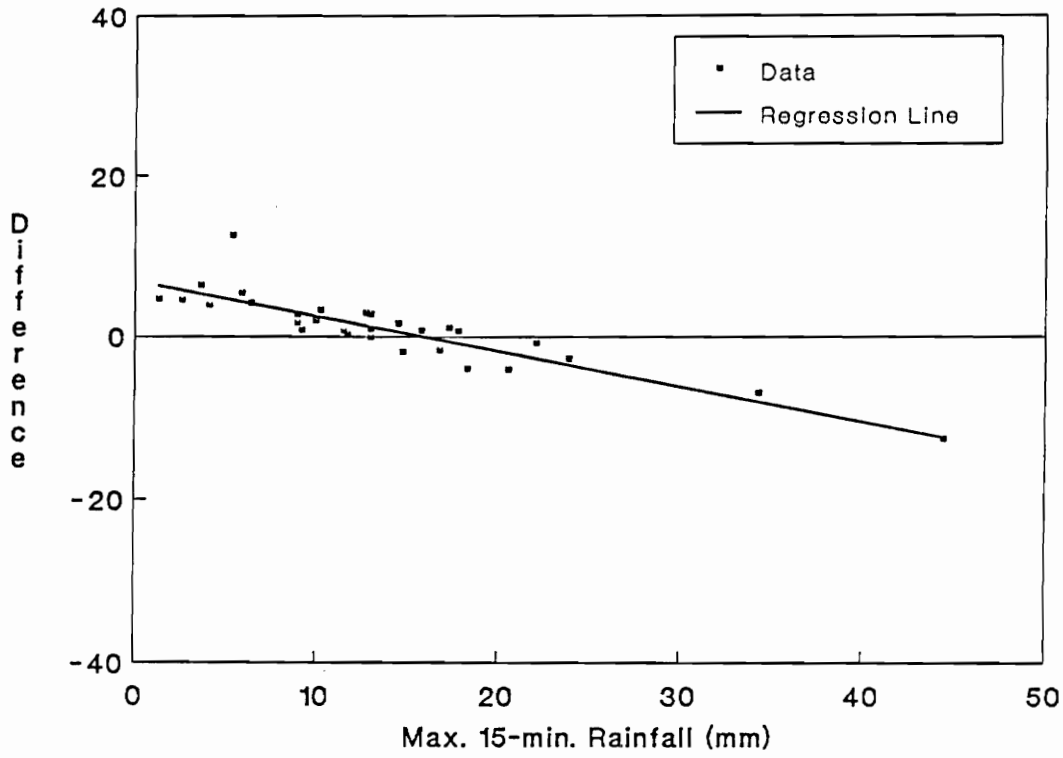

Figure 35. Estimated volume bias as a function of the 15-minute rainfall intensity level (30 events, without 6/20/72).

7.2 MILLSTONE BRANCH WATERSHED

7.2.1 Procedures

The Millstone Branch watershed is considered representative of the type of drainage basin typically encountered in Virginia's surface mining region. The procedure for selecting events, as described in the Brush Creek simulations, was used. Only four runoff events were found in the four year period of record that met the selection criteria. These events were simulated using the data base described previously with no parameter calibration.

7.2.2 Results and Discussion

A comparison of peak flows and volumes is given in Table 19 and Figures 36 through 39. The relative error was determined from Equation 4.

Table 19 shows that the simulated peak flows compared favorably with observed peak flows, however, volume simulations were poor. Inspection of Figures 36 through 39 indicates that, following the peak flows, the simulated hydrographs recede rapidly, while the observed hydrographs have very shallow recession curves.

The events depicted in Figures 37 and 38 were complex rainfall events. The resolution of the data and the precision with which they were estimated make the response to these types of storms difficult to simulate. The intensities of these events are very low. Some parameters which may not have been adequately estimated or defined spatially are FAW, FGW, F_c, and DEPTH. It was determined in the Brush Creek studies that FESHM has a bias which can be explained by rainfall intensity levels, and that FESHM also tends to underpredict runoff from rainfall events with predominantly low intensities. The remaining events were relatively simple storms with high intensity levels.

Table 19. Millstone Branch simulation results.

Event Date	Peak Flow (m^3/s)			Volume (mm)		
	Observed	Simulated	Relative Error (%)	Observed	Simulated	Relative Error (%)
1982						
6/ 8	0.33	0.32	- 3.0	8.16	2.42	- 70.3
9/14	0.22	0.16	- 27.3	9.70	1.32	- 86.4
1984						
5/ 6	0.83	0.52	- 37.3	35.60	6.54	- 81.6
1985						
6/11[1]	0.11	0.09	- 18.2	13.54	1.25	- 90.8
	0.15	0.07	- 53.3			

[1] The runoff hydrograph for this event had two separate peaks.

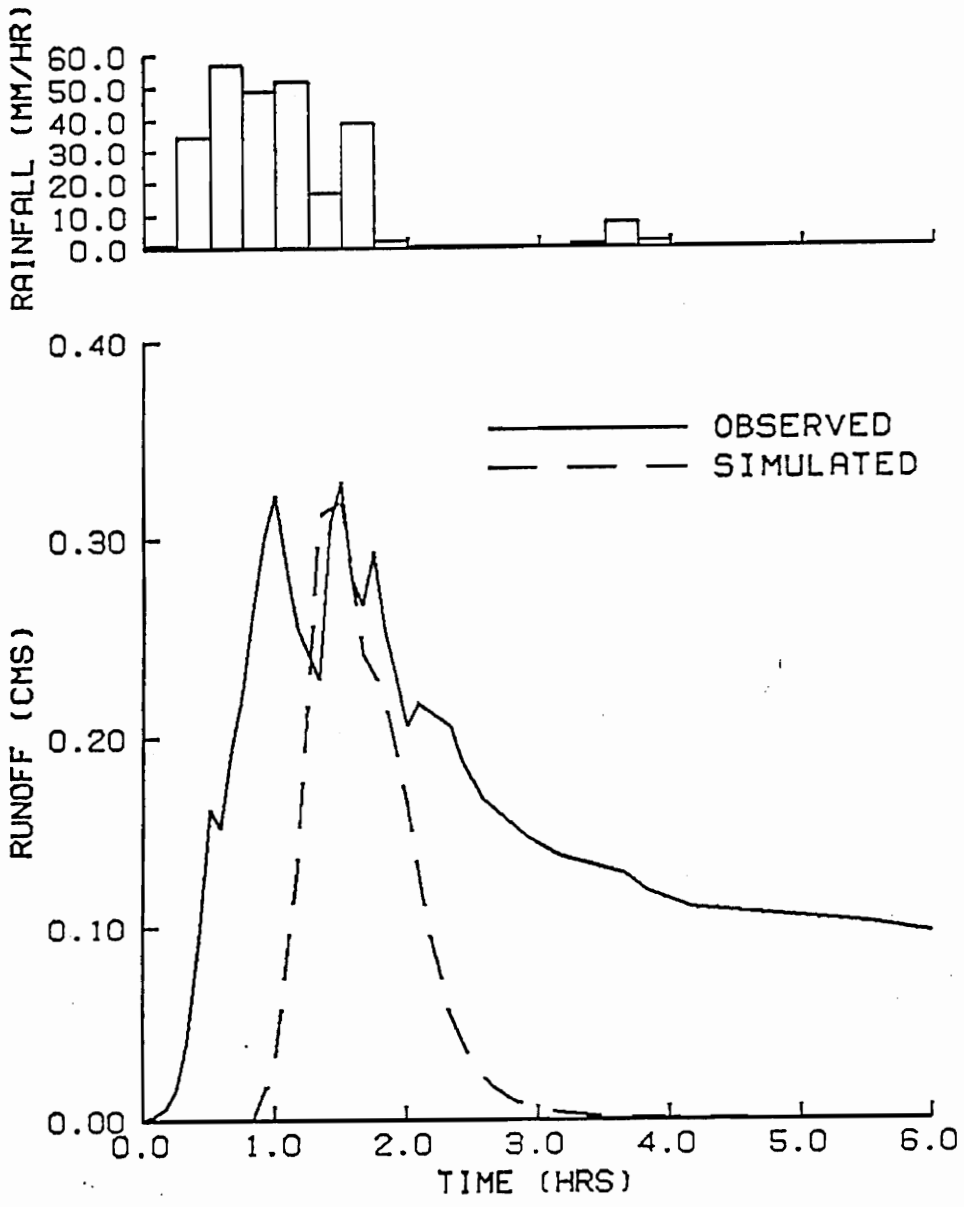

Figure 36. Comparison of simulated and observed runoff hydrographs for Millstone Branch watershed, event 6/8/82.

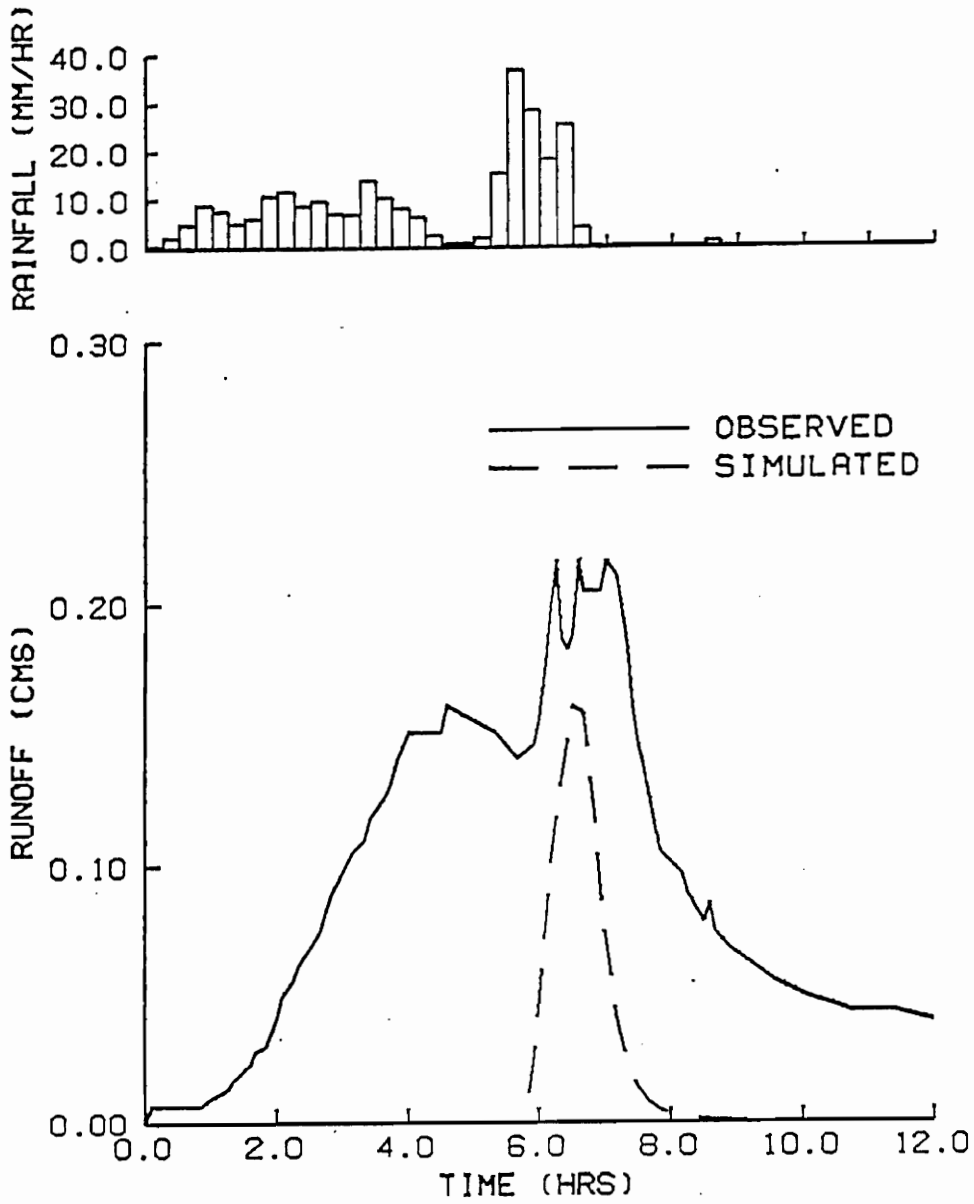

Figure 37. Comparison of simulated and observed runoff hydrographs for Millstone Branch watershed, event 9/14/82.

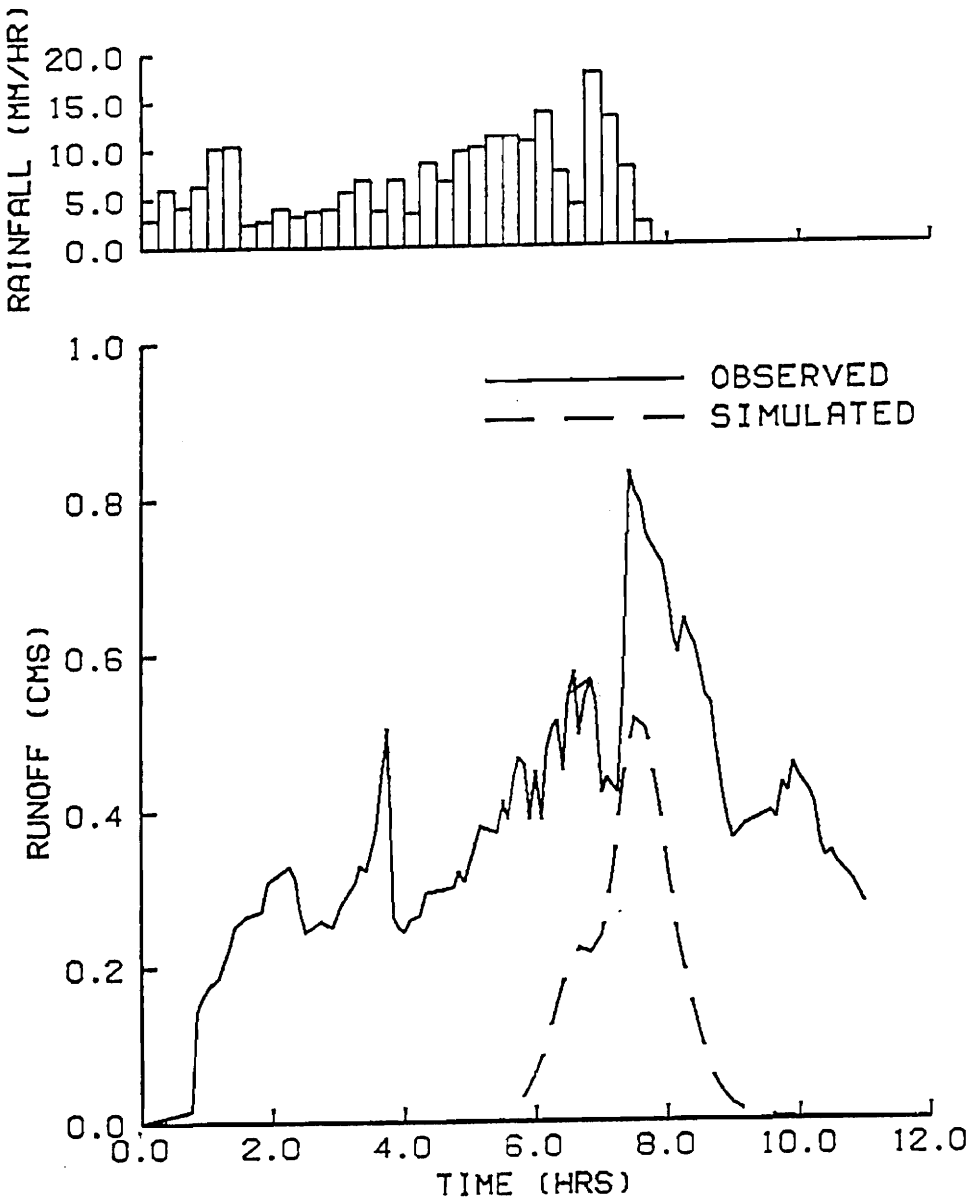

Figure 38. Comparison of simulated and observed runoff hydrographs for Millstone Branch watershed, event 5/6/84.

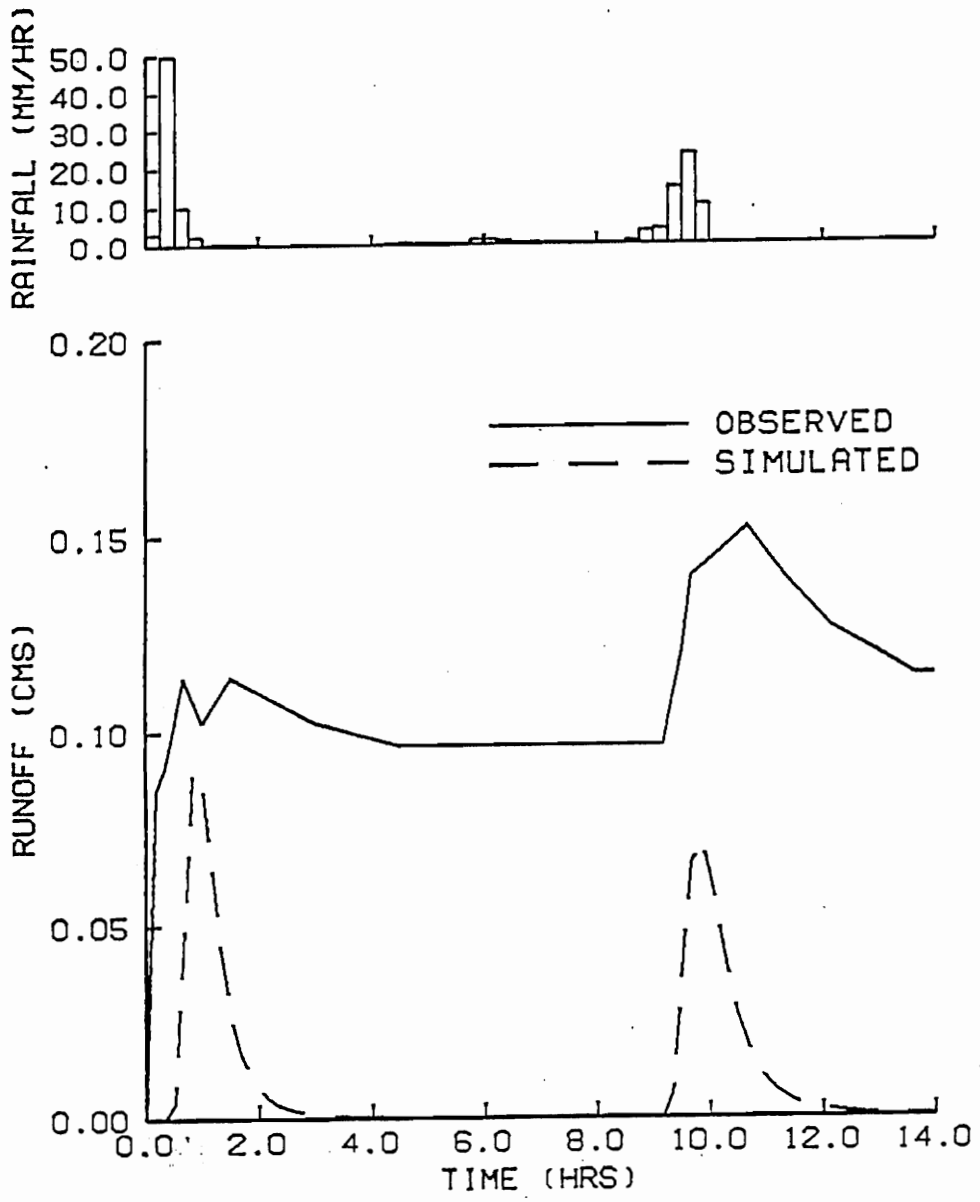

Figure 39. Comparison of simulated and observed runoff hydrographs for Millstone Branch watershed, event 6/11/85.

The problem with these simulations likely is because much of the watershed was forested. FESHM was developed for use on agricultural watersheds which are characterized by different flow processes. FESHM was not structured to simulate the physical processes involved in forest hydrology. Lee (1980) states that in forest hydrology overland flow is negligible. Interflow and sub-surface flow contributions usually control runoff (Thomas and Beasley, 1986) and these processes are not modeled by FESHM. Inspection of the observed hydrographs in Figures 36 through 39 suggests that sub-surface flow contributions are probably a significant portion of the observed flow. To better characterize hydrograph shape and improve water yield estimates, algorithms must be added to FESHM to better define the physical processes if it is to be used in forest watersheds without calibration. An alternative is to use a model designed specifically for forested watersheds, such as the modification of the ANSWERS model by Thomas and Beasley (1986). The validity of this model, however, was not evaluated with the data bases used in this study.

7.3 RIGHT FORK SANDLICK CREEK WATERSHED

7.3.1 Procedure

The Right Fork Sandlick Creek watershed, although it is in West Virginia, is also considered to be representative of the type of drainage basin typically encountered in southwestern Virginia's surface mining region. The procedure for selecting runoff events, as described in the Brush Creek simulations, also was used, but no runoff events met the selection criteria. Therefore, the largest runoff event from each year was chosen for simulation. These two events were simulated with FESHM using the data base described previously and with no parameter calibration.

7.3.2 Results and Discussion

A comparison of the observed and simulated peak flows and runoff volumes are given in Table 20 and Figures 40 and 41. The relative error was determined from Equation 4.

The results were consistent with Millstone Branch simulation results, where peak flows were simulated well and volumes poorly. Inspection of the hydrograph plots (Figures 40 and 41) indicates that, as with the Millstone Branch simulations, the simulated hydrographs tend to recede much more rapidly than the observed hydrographs. The rainfall hyetograph in Figure 40 does not support the shape of the observed hydrograph, therefore, data may not have been adequate, which would certainly affect the simulation results.

Part of the problem was probably with the resolution of the data. Both the land use and soil characteristics were completely lumped throughout the watershed. Shanholtz et al. (1981) state that gross errors were noted when an area was sub-divided into one HRU, as was the case with this study. Under these circumstances spatial variability is neglected.

The fact that the watershed was entirely forested was also a major problem. As was discussed with the Millstone Branch simulation results, FESHM does not account for interflow and sub-surface flow contributions which are the dominating processes in forested areas.

In order to improve the simulations of this watershed's runoff events, a more thorough investigation of the watershed's characteristics must be made. A soil survey of the watershed and more careful selection of the parameters would be advisable. The problems involving the physical processes of forest hydrology may not be solvable without major revision of FESHM.

Table 20. Right Fork Sandlick Creek simulation results.

Event Date	Peak Flow (CMS)			Volume (mm)		
	Observed	Simulated	Relative Error (%)	Observed	Simulated	Relative Error (%)
1981						
6/ 6	0.59	0.72	22.0	6.84	1.26	- 81.6
1982						
7/13	0.18	0.12	- 33.3	0.64	0.23	- 64.1

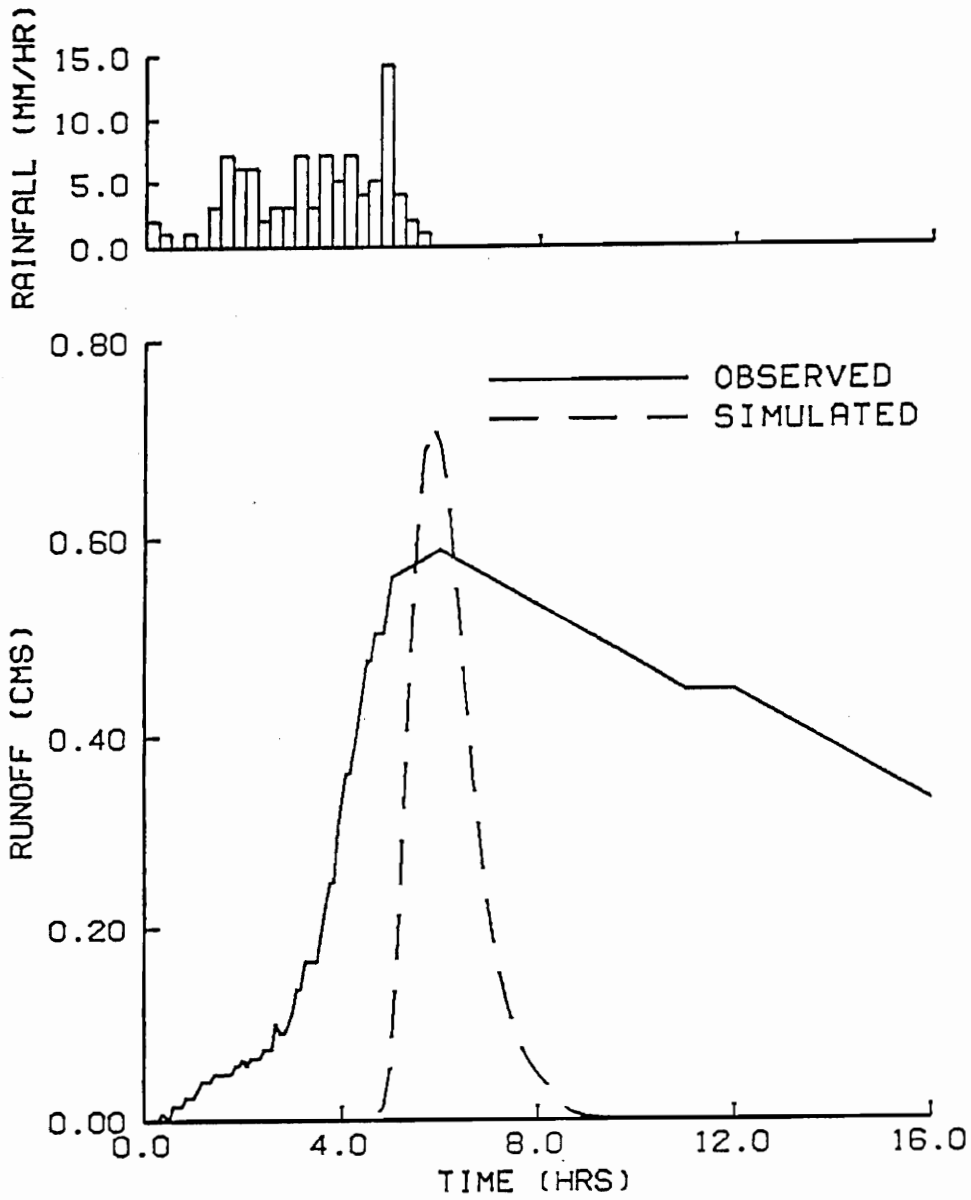

Figure 40. Comparison of simulated and observed runoff hydrographs for Right Fork Sandlick watershed, event 6/6/81.

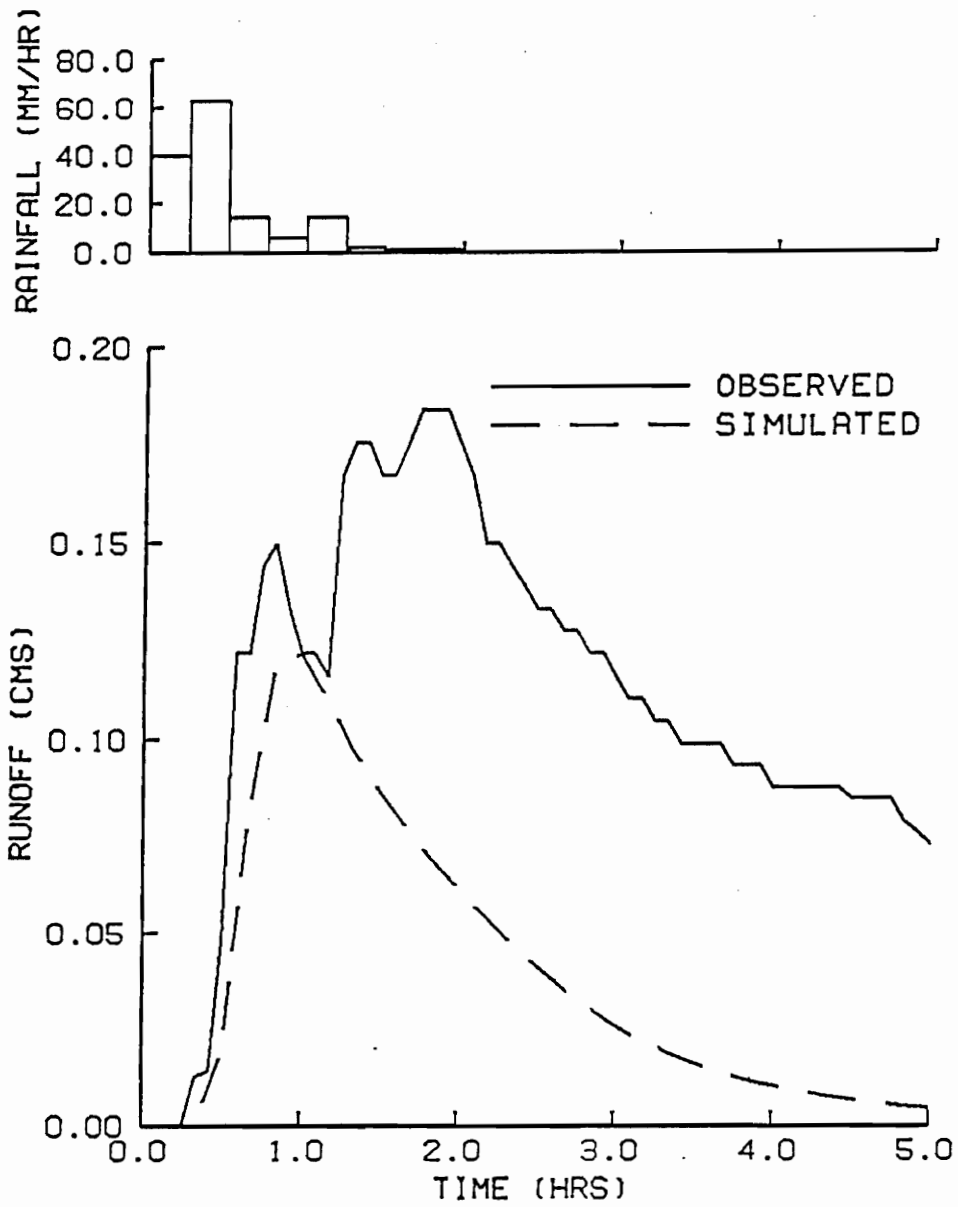

Figure 41. Comparison of simulated and observed runoff hydrographs for Right Fork Sandlick watershed, event 7/13/82.

8.0 SUMMARY AND CONCLUSIONS

The Finite Element Storm Hydrograph Model's (FESHM) computational processes and input requirements were thoroughly reviewed. The model's code was upgraded from Fortran 66 to Fortran 77 and WATFIV for improved run time error analysis and diagnostics. A subroutine also was added to simplify modeling of large drainage basins with complex geographic data.

The use of GIS technology was explored as a possible tool for improving data management and modeling efficiency. Geographic data layers were digitized, stored, and manipulated using a grid-cell GIS. Appropriate software was developed to interface the GIS with FESHM.

The application of GIS technology did not provide for the entire range of management and manipulation of data desired for creating FESHM input files. The system did, however, simplify data management and reduce the difficulty and time involved in modeling complex watersheds. Less complex applications were best left to manual techniques. The methodology and software developed lend themselves to use with GISs such as the Virginia GIS (Shanholtz et al., 1987).

Data from three experimental watersheds were used to evaluate FESHM's predictive ability in an ungaged context. The sensitivity of FESHM to ten model parameters was evaluated using the data bases for each of the watersheds. Simulations were performed using 25-year, 6-hour design storms and initial parameter estimates to establish reference hydrographs. Then each parameter was varied while holding all others constant at their reference value.

The simulations for all three watersheds were very sensitive to changes in rainfall input. The effects of changes in the remaining variables varied greatly from watershed to watershed. In general, variations in antecedent soil moisture content, final infiltration rate and the depth of control zone caused significant changes in simulation results. The sensitivity to other parameters may have been tempered by

important variable interactions.

The Brush Creek watershed was used to evaluate the effects of data availability and spatial representation on FESHM's prediction capabilities. FESHM then was used to simulate the significant runoff events from 17 years of the historical record. The results from these simulations were evaluated using relative error, statistical distribution comparisons and linear regression techniques. Regression methodology then was used to assess expected error and model bias to various rainfall input variables.

The Brush Creek "lumped" data base produced better simulation results than the "detailed" data base for the events used in this analysis. In most applications the more detailed scenario is expected to produce more accurate simulations. Inspection of the two data bases showed that, in addition to their representation of spatial variability, several important input parameter estimates varied significantly. These differences may help to explain the results, however, due to system complexity and the brevity of this analysis, no definite conclusions regarding the effect of data availability on model simulations can be made. More thorough and detailed research is needed to determine the level of data resolution necessary for a given level of simulation accuracy.

Simulations of selected events over 17 years of the historical record, using the Brush Creek "lumped" data base, showed that the model simulated peak flows more closely than runoff volumes. However, the evaluation of goodness of fit showed that the predictive capability of FESHM in an ungaged context was not adequate. Regression methodology showed that simulation bias was related to the input rainfall intensity levels. The results suggest that either spatial variability or parameter values were not adequately defined and that some form of calibration is needed.

The two remaining drainage basins were considered representative of Virginia's surface mining region. Simulations were conducted in order to evaluate FESHM's appropriateness under actual pre-mining conditions. The Millstone Branch and Right Fork Sandlick Creek peak flows were simulated fairly well, while volume

simulations were poor. The inability to simulate runoff volumes can, at least in part, be attributed to the fact that the watersheds were mostly forested. FESHM was not structured to simulate the physical processes involved in forest hydrology, such as interflow and sub-surface flow.

It is important to remember that these simulations were conducted in an ungaged context with no calibration or parameter fitting. Under these circumstances the model did fairly well and could possibly be used for analyses and designs where peak flow rates are of primary interest.

The results of this study suggest that more work in needed in order to use FESHM with confidence for pre-mining analysis. The use of the model for pre-mining analysis will require thorough and careful selection of input parameter values and calibration with nearby watershed or otherwise applicable records.

9.0 RECOMMENDATIONS

The following recommendations are presented to guide future development of FESHM and its use in simulating pre-mining hydrologic conditions:

1. Research is needed to determine the applicability of FESHM for pre-mining modeling analysis when calibration techniques are used. Additional research is needed to better quantify the issues when conducting hydrologic modeling with or without calibration.
2. Extensive evaluation of FESHM's predictive ability in an ungaged context, similar to the evaluation with the Brush Creek data, should be conducted on several watersheds. Similar graphical and statistical techniques should be employed to determine if the results from the Brush Creek evaluation are applicable to all FESHM simulation studies. Additional research on the effects of limited data availability on simulation results is needed using several different drainage basins.
3. Future hydrologic modeling studies should be conducted to include the simulation of all the required hydrologic, sediment, and chemical characteristics in order to eliminate the tedious and costly monitoring requirements.
4. An evaluation of FESHM's sediment yield routines on natural drainage basins is needed. This would require obtaining accurate and thorough rainfall, runoff, and sediment data for several watersheds.
5. The simulation of chemical processes should also be developed and added to FESHM. A routine for simulating pesticide losses has been developed (Kenimer, 1987). The addition of routines to simulate nitrogen and phosphorous yield would make FESHM more appropriate when water quality issues are the major concern.

6. More physically based infiltration equations should be evaluated for simulating the spatial variability of infiltration and subsequent incorporation into FESHM.

7. Comparison of GIS techniques and manual methods for creating input files should be made to better assess costs and benefits. The evaluation should include a comparison of the simulation results obtained from these two methods and an evaluation of the effect of cell size (lumping of spatial variability) on simulation results.

8. The development of additional software to complete the data management and manipulation methodology for creating FESHM input files with GIS technology is recommended. This software could utilize digital elevation and channel index maps to create the overland and channel attribute portion of FESHM input files. This could make the creation of the basic input files from existing data bases such as the VirGIS (Shanholtz et al., 1987) a relatively routine task.

9. Another area which requires additional research is developing the methodology for better simulation of the physical processes involved in forest hydrology. Specifically, the simulation of interflow and sub-surface flow would have to be included in FESHM to adequately simulate hydrology in forested watersheds.

10. Additional models, which specialize in simulating forest hydrology, should be investigated for use in simulating pre-mining hydrologic conditions.

11. Future uses of FESHM are limited due to the large amounts of computer memory required to execute the model. The model should be restructured and modified to make more efficient use of computer space. This may be accomplished, in part, by eliminating the practice of storing each computation at each time step. Once the size requirements of FESHM have been significantly reduced, emphasis

should be put on making it available on personal computers and making it more "user friendly."

12. FESHM should be modified to allow the user to enter input and obtain output in either English or SI units.
13. A routine should be added to FESHM which computes the volume of the simulated runoff. For this study a separate program was written for estimating the volumes from the simulation output files.
14. The use of simulated intensity patterns developed from historical data (e.g. Storm, 1986), which is characteristic of each watershed, should be investigated as an optional method of obtaining design storms for simulation studies.

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11.0 APPENDICES

11.1 APPENDIX A: SAMPLE FESHM OUTPUT FILE

TITLE:

BRUSH CREEK LIMITED DATA BASE: INTERNAL SMC

STORM EVENT-- 8/ 2/68
STARTING TIME--15:00
INITIAL MOISTURE CONDITION FOR THE WATERSHED-- DETERMINED INTERNALLY FOR EACH HRU

2	0.553
3	0.552
6	0.550
14	0.554
16	0.552
17	0.557
18	0.555
19	0.550
20	0.544
21	0.550
22	0.551
23	0.551
24	0.554
25	0.555
26	0.552
1	0.608
4	0.600
5	0.612
7	0.600
8	0.600
9	0.573
10	0.593
11	0.543
12	0.600
13	0.600
15	0.551

SUMMARY OF HYDROLOGIC RESPONSE UNITS

HRU NO	LANDUSE NO	SLOPE CLASS	MANNINGS N	DEPRESSION STORAGE	HOLTANS A	FRACTION OF AVAIL WATER	FRACTION OF GRAVITY WATER	EXPONENT C	FINAL INFIL-TRATION RATE	DEPTH OF THE A HORIZON	MAXIMUM STORAGE
1	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	13.33	3.04
2	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	13.82	3.15
3	1	A	0.301	0.000	0.868	0.139	0.089	0.640	0.335	13.47	3.07

4	1	A	0.277	0.000	0.836	0.139	0.089	0.640	0.335	13.00	2.96
5	1	A	0.342	0.000	0.922	0.139	0.089	0.640	0.335	13.50	3.08
6	1	A	0.306	0.000	0.875	0.139	0.089	0.640	0.335	13.00	2.96
7	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	13.00	2.96
8	1	A	0.333	0.000	0.911	0.139	0.089	0.640	0.335	13.00	2.96
9	1	A	0.400	0.000	1.000	0.139	0.089	0.640	0.335	12.00	2.74
10	1	A	0.375	0.000	0.967	0.139	0.089	0.640	0.335	12.75	2.91
11	1	A	0.367	0.000	0.956	0.139	0.089	0.640	0.335	11.00	2.51
12	1	A	0.355	0.000	0.940	0.139	0.089	0.640	0.335	13.00	2.96
13	1	A	0.256	0.000	0.808	0.139	0.089	0.640	0.335	13.00	2.96
14	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	14.09	3.21
15	1	A	0.375	0.000	0.967	0.139	0.089	0.640	0.335	11.25	2.56
16	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	13.50	3.08
17	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	16.00	3.65
18	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	14.50	3.31
19	1	A	0.303	0.000	0.871	0.139	0.089	0.640	0.335	13.00	2.96
20	1	A	0.327	0.000	0.903	0.139	0.089	0.640	0.335	11.69	2.67
21	1	A	0.300	0.000	0.867	0.139	0.089	0.640	0.335	13.00	2.96
22	1	A	0.309	0.000	0.878	0.139	0.089	0.640	0.335	13.26	3.02
23	1	A	0.267	0.000	0.822	0.139	0.089	0.640	0.335	13.33	3.04
24	1	A	0.280	0.000	0.840	0.139	0.089	0.640	0.335	14.20	3.24
25	1	A	0.250	0.000	0.800	0.139	0.089	0.640	0.335	14.50	3.31
26	1	A	0.280	0.000	0.840	0.139	0.089	0.640	0.335	13.60	3.10

ROUTING TIME INCREMENT FOR OVERLAND FLOW-- 150 SECONDS
ROUTING TIME INCREMENT FOR CHANNEL FLOW-- 50 SECONDS

PRECIPITATION FOR RAINGAGE NUMBER 1
FOR EACH 15-MINUTE INCREMENT OF THE STORM

PRECIPITATION INCREMENTS FROM THE BEGINNING OF THE STORM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PRECIPITATION																							
0.43	0.20	0.01	0.01	0.01	0.01	0.00	0.00																

PRECIPITATION FOR RAINGAGE NUMBER 2
FOR EACH 15-MINUTE INCREMENT OF THE STORM

PRECIPITATION INCREMENTS FROM THE BEGINNING OF THE STORM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

PRECIPITATION

0.05 0.12 0.24 0.03 0.00 0.00 0.00 0.00

CHANNEL FLOW INFORMATION FOR SUB-SHED NUMBER 7

ELEMENT NUMBER	ELEMENT LENGTH	ELEMENT RELIEF	ELEMENT SLOPE	ELEMENT MANNING N	NODE NUMBER	NODE TOP WIDTH AT 2 FT DEPTH
1	1100.0	20.0	0.018	0.070	2	230.0

FLOW CHARACTERISTICS AT THE LAST NODE OF THE STRIP

TIME	DISCHARGE	AREA	RATE	DEPTH	SEDIMENT LOAD (LBS)	SEDIMENT LOAD (GRAMS)	ACCUMULATED SEDIMENT (GRAMS)	SEDIMENT CONCENTRATION (MG/L)
0.1667	0.1483	0.4253	0.3486	0.0860	0.00000000	0.00000000	0.00000000	0.00000000
0.3333	1.4607	2.3602	0.6189	0.2026	0.00000000	0.00000000	0.00000000	0.00000000
0.5000	3.3150	4.3606	0.7602	0.2754	0.00000000	0.00000000	0.00000000	0.00000000
0.6667	3.7117	4.7460	0.7821	0.2873	0.00000000	0.00000000	0.00000000	0.00000000
0.8333	3.8711	4.8978	0.7904	0.2919	0.00000000	0.00000000	0.00000000	0.00000000
1.0000	4.8278	5.7789	0.8354	0.3170	0.00000000	0.00000000	0.00000000	0.00000000
1.1667	6.3855	7.1255	0.8961	0.3520	0.00000000	0.00000000	0.00000000	0.00000000
1.3333	7.5998	8.1180	0.9362	0.3757	0.00000000	0.00000000	0.00000000	0.00000000
1.5000	7.8044	8.2812	0.9424	0.3795	0.00000000	0.00000000	0.00000000	0.00000000
1.6667	7.1269	7.7366	0.9212	0.3668	0.00000000	0.00000000	0.00000000	0.00000000
1.8333	6.0431	6.8374	0.8838	0.3448	0.00000000	0.00000000	0.00000000	0.00000000
2.0000	4.9301	5.8704	0.8398	0.3195	0.00000000	0.00000000	0.00000000	0.00000000
2.1667	3.9528	4.9750	0.7945	0.2941	0.00000000	0.00000000	0.00000000	0.00000000
2.3333	3.1510	4.1980	0.7506	0.2702	0.00000000	0.00000000	0.00000000	0.00000000
2.5000	2.5161	3.5469	0.7094	0.2484	0.00000000	0.00000000	0.00000000	0.00000000
2.6667	2.0205	3.0094	0.6714	0.2288	0.00000000	0.00000000	0.00000000	0.00000000
2.8333	1.6334	2.5662	0.6365	0.2113	0.00000000	0.00000000	0.00000000	0.00000000
3.0000	1.3294	2.1994	0.6044	0.1956	0.00000000	0.00000000	0.00000000	0.00000000
3.1667	1.0892	1.8945	0.5750	0.1815	0.00000000	0.00000000	0.00000000	0.00000000
3.3333	0.8988	1.6404	0.5479	0.1689	0.00000000	0.00000000	0.00000000	0.00000000
3.5000	0.7470	1.4281	0.5230	0.1576	0.00000000	0.00000000	0.00000000	0.00000000
3.6667	0.6253	1.2500	0.5002	0.1474	0.00000000	0.00000000	0.00000000	0.00000000
3.8333	0.5270	1.0998	0.4792	0.1383	0.00000000	0.00000000	0.00000000	0.00000000
4.0000	0.4471	0.9723	0.4598	0.1300	0.00000000	0.00000000	0.00000000	0.00000000

11.2 APPENDIX B: PROGRAM VARIABLE LIST

Key:

VARIABLE= An asigned storage location name.

MODE= Type of Variable. (I)- INTEGER, (R)- REAL

DIMENSION= The size requirements for an array.
(i & j represent dimensions one and two)

UNITS= The variable representation, (Acres, Feet, etc.).

(I) = Identifies input variables.

Variable	Mode	Dimension	Units	Description#
A	R	(i)	-	Column matrix created from values of A1 for solution in subroutine GELB. i = square of the maximum number of nodal points within a strip or channel
A1	R	(i,j)	-	Values of assembled square matrix in the element equation. i = number of nodal points within a strip or channel j = number of nodal points within a strip or channel
AA	R	(i)	ft^2	Calculated area of flow at the the nodes of the overland flow strip or the channel. i = maximum number of nodal points within a strip or channel
AAP	R	(i,j)	ft^2	Calculated cross-sectional area of flow at interior nodes of an overland flow strip or channel, which is stored for printing output. i = the higher value of NHOURC/NOPRIN or NHOURC/NCPRIN j = (maximum number of nodes in a strip or channel) - 4
ACC	R	-	in	Difference between precipitation and amount of infiltration.
ACCDP	R	(i)	in	Calculated depth of accumulated water in depression storage in the ith element.

				i = NDHRU
ADD	R	-	-	Factor used in interpolation of Shield's diagram.
ADJLEV	R	-	-	Adjusted level of soil moisture content.
AFAC	R	(i)	-	Values for coefficient "a", Holtan's equation for each HRU. i = maximum of NDHRUS or NTELES
AFACTO	R	(8)	-	Factor in Yalin equation.
AFLU	R	(i)	-	(I) Index to reflect the effect of land-use on infiltration. i = number land use types in the watershed
AINT	R	-	-	Equal to NPCINT
AO	R	(i)	-	Initial cross-sectional area of flow at each node in given strip. i = maximum number of nodal points within a strip or channel
AOT	R	(i,2)	-	Intermediate storage of the calculated cross-sectional areas of flow at each node, the second variable indicating area calculated for the upper sub-strip AOT(I,1) and the lower sub-strip AOT(I,2) where applicable. i = maximum number of nodal points within a strip or channel
AREA	R	(i)	ac	(I) Area of each element in a given strip. i = maximum number of elements within any flow strip
AVAIL	R	-	in	Total water available for infiltration during a given time increment.
AVM	R	-	in	Plant available water for a given HRU.
CEXP	R	(i)	-	Value of exponent "n" in Holtan's equation for each HRU. i = maximum of NDHRUS or NTELES
CONMET	R	-	(mg/l)	Sediment concentration.

CRLIFT	R	(8)	-	Calculated critical lift force.
CRSHER	R	-	-	Critical shear stress from Shields' diagram.
CUSLE	R	(i)	-	Soil loss ratio of the USLE cover management factor for the ith HRU. i = maximum of NDHRUS or NTELES
DAILPC	R	(i,30)	in	(I) Rainfall for the ith raingage for the jth day preceding the event. i = number of raingages
DD	R	(i)	ft	(I) Calculated depth of flow at the nodes of the overland flow strip or channel. i = maximum number of nodal points within a strip or channel
DDP	R	(i,j)	ft	Calculated depth of flow at interior nodes of an overland flow strip or channel, which is stored for printing output. i = the higher value of NHOURC/NOPRIN or NHOURC/NCPRIN j = (maximum number of nodes in a strip or channel) - 4
DELTA	R	(8)	-	Excess or deficit lift force.
DEP	R	(i,j)	(lb/ft/sec)	Amount of ith particle type of jth soil deposited on the given element during the given time increment. i = number of particle types (8)_ j = maximum number elements in a strip
DEPSEP	R	-	in	Daily amount of deep seepage.
DEPTH	R	(i)	in	(I) Depth of the A horizon in inches for each HRU. i = maximum of NDHRUS or NTELES
DEPSTO	R	(i)	in	Depression storage for the ith HRU. i = maximum of NDHRUS or NTELES
DI	R	(i)	(lb/ft/sec)	Interrill detachment on the ith element. j = maximum number elements in a strip
DIA	R	(i,j)	mm	(I) Diameter of ith particle type of jth soil type. i = number of particle types (8) j = number of soil types
DITYP	R	(i,j)	(lb/ft/sec)	Rate of interrill detachment of ith type particle on jth element during

				the given time interval. i = number particle types (8) j = maximum number elements in a strip
DPAW	R	-	in	Potential plant available water in the soil profile.
DR	R	(i)		(lb/ft/sec) Rill detachment on ith element. i = maximum number elements in a strip
DRTYP	R	(i,j)		(lb/ft/sec) Rate of rill detachment of ith particle type on jth element during the given time increment. i = number of particle types (8) j = maximum number elements in a strip
DSLU	R	(i)	in	(I) Potential depression storage for the ith land use type. i = number land use types
DT	R	-	sec	Routing time increment equal to DTO or DTC.
DTC	R	-	sec	(I) Time increment for channel flow routing. Must be equal to, or some integer divisor, of DTO.
DTO	R	-	sec	(I) Time routing increment for overland flow routing. Must be equal to, or some integer divisor, of INTPCS.
DTOH	R	-	hr	Overland flow routing increment (DTO) in units of hours.
E1	R	(i,j)		(ft-tons/ac-in) Rainfall energy per unit of rainfall. i = number of raingages j = number of rainfall increments
ECUSLE	R	(i)	-	Soil loss ratio of the USLE cover management factor. i = maximum number elements in a strip
EFTRAN	R	(i)	-	Effective non-dimensional transport for ith particle in a mixture. i = number particle types (8)
EI	R	[100(ft-tons/acre)(in/hr)]		Wischmeier's rainfall erosivity (energy times 30-minute intensity).
EKUSLE	R	(i)		(tons/acre)(acre/100ft-tons)(hr/in) USLE soil erodibility factor for ith element. i = maximum number elements in a strip
ELEXC	R	(i)	in	Rainfall excess or flow loss per time increment for each element in a given

				strip. i = maximum number of nodes in a strip or channel
ENERGY	R	(i,j)	(ft-tons/ac)	Total rainfall energy during the given time increment. i = number of raingages j = number of rainfall increments
EVPOR	R	-	in	Evaporation.
EX	R			
EXCESS	R	-	-	Excess transport capacity (as a fraction of the total) to be distributed.
EPS1	R	-	in	Accumulated soil water removed from storage duringan iterative solution of equation (1).
EPUSLE	R	(i)	-	USLE contouring factor. i = maximum number elements in a strip
EVP	R	(12)	in	(I) Evaporation for the ith month.
F1	R	-	(in/hr)	Infiltration rate at beginning of time increment.
F2	R	-	(in/hr)	Infiltration rate at end of time increment.
FA	R	-	(in/hr)	Average infiltration rate over time increment.
FAW	R	(i)	(in/in)	(I) Potential plant-available water of each HRU expressed as a fraction of the volume of a unit of soil. i = maximum of NDHRUS or NTELES
FC	R	(i)	(in/hr)	(I) Final infiltration rate for each HRU. i = maximum of NDHRUS or NTELES
FGW	R	(i)	(in/hr)	(I) Potential gravitational water of each HRU expressed as a fraction of the volume of a unit of soil. i = maximum of NDHRUS or NTELES
FHRU	R	(i,j)	-	(I) Areal coverage of the jth HRU in the ith element as a fraction of the element area. i = NTELES j = maximum number of HRUs in any element

FINC				
FLAREA	R	(i)	ft^2	Calculated area of flow at the ith node. i = maximum number of nodes in a strip or channel
GINDEX	R	(12)	-	(I) Growth index for the ith month for Holtan's infiltration equation.
GRAMS	R	-	g	Total sediment yield from the given strip.
GRM	R	-	in	Temporary storage of gravitational soil water content.
GRWAT	R	-	in	Temporary variable used to compute storage recovery from deep seepage over a given time increment.
HOUR	R	-	hr	(I) Elapsed time from the beginning of the storm.
HYDRAD	R	(i)	ft	Computed hydraulic radius of flow at each nodal point in a given strip. i = maximum number of nodes in a strip or channel
IELE	I	-	-	Element number for which sediment calculations are being performed.
IHRU	R	(i,j)	-	(I) Index code to identify the jth HRU in the ith element. i = NTELES j = maximum number of HRUs in any element
INCLAS	I	-	-	Previous time increment in sediment calculations.
IND	I	-	-	Index code to indicate the first element of a sub-strip.
INIT	I	-	-	Index code to indicate the initial increment of the routing period.
INTER	I	-	-	Index to indicate if interrill detachment occurs during the time step = 0 no interrill detachment (no rainfall) = 1 interrill detachment
ITITLE	I	-	-	(I) Title of the data set.

INTPCM	I	-	min	Time increment of rainfall.
INTPCS	I	-	sec	(I) Time interval at which precipitation records are entered.
JINC	I	-	-	Precipitation input time interval corresponding to simulation time interval.
KDET	I	-	-	Index indicating progress in sediment detachment calculations. = 0 no detachment = 1 interrill detachment = 2 rill detachment
KIHRU	I	(i)	-	Raingage corresponding to the ith HRU. i = maximum of NDHRUS or NTELES
KN				
LANDU	I	(i)	-	(I) Index code that defines the given land-use type of each HRU. i = maximum of NDHRUS or NTELES
MHRU		-	-	Equal to NHRU for a given element.
MONTH	I	-	-	(I) Month in which storm occurred.
NCHECK	I	-	-	Counter for checking if potential sediment load = 0.
NCOMP	I	(i)	-	Indicates the continuity of flow at a node. i = maximum number of nodes in a strip or channel element =0 -flow discontinuous =1 -flow continuous =2 -flow continuous, but discontinuity of area maintained in the solution.
NCONF1	I	(i)	-	(I) The number of the first sub-shed with a channel confluence at the upstream channel node of the ith sub-shed for which NODE1(I)=1 or 2. i = maximum number elements in a strip
NCONF2	I	(i)	-	(I) The number of the second sub-shed with a channel confluence at the upstream channel node of the ith sub-shed.

				i = maximum number elements in a strip
NCPRIN	I	-	sec	(I) Time interval at which channel flow output is desired. Must be equal to, or some integer multiple of DTC.
NDAMS	I	-	-	(I) Number of dams in a given strip (same value for each element in the strip.
NDAY	I	-	-	(I) Day in which storm occurred.
NDHRUS	I	-	-	(I) Number of different HRU's in the watershed.
NDO	I	-	-	Counter for comparing transport capacity and potential sediment load.
NDTC	I	-	-	Equal to DTC.
NDTO	I	-	-	Equal to DTO.
NE	I	-	-	Number of elements in a given strip.
NELEM	I	-	-	Index counter of the number of elements in the watershed.
NEQUAL	I	-	-	Number of particle types for which TCAP = POTSED.
NESTRP	I	(i)	-	(I) Number of elements in each strip of the given sub-shed. i = number of sub-sheds in the watershed
NET	I	-	-	Number of elements in a given sub-strip.
NG	I	-	-	Raingage for given element.
NGAGES	I	-	-	(I) Number of raingages in the watershed for the given storm event.
NGREAT	I	-	-	Number of particle types for which TCAP is greater than POTSED.
NHEAD	I	-	-	Index code which determines format of table headings in output.
NHOURC	I	-	hr	(I) Duration of simulation.
NHOURR	I	-	hr	(I) Duration of storm event.
NHRU	I	(i)	-	(I) Number of HRU's within each element. i = NTELES
NLANUS	I	-	-	(I) Number of different land-use types in the watershed.

NLESS	I	-	-	Number of particle types for which TCAP is less than POTSED.
NMIN	I	-	min	Total number of minutes of rainfall.
NN	I	-	-	Number of nodes in a given strip.
NNA	I	-	-	Equal to NN-4.
NNN	I	-	-	Index counter of the number of elements in a flow strip.
NNT	I	-	-	Number of nodes in a given sub-strip.
NODE1	I	(i)	-	(I) Index code specifying the boundary condition to be applied at the upstream channel node of the ith sub-shed. i = number of subsheds + 1 NODE1(I)=0: No flow at upstream boundary. NODE1(I)=1: Flow is the sum of the discharges at the downstream channel node of sub-sheds NCONF1 and NCONF2. NODE1(I)=2: For an immaginary sub-shed when the watershed outlet is at the confluence of sub-sheds NCONF1 and NCONF2.
NOPRIN	I	-	-	(I) Time interval at which overland flow output is desired. Must be equal to, or a multiple integer of, DTO.
NOWTIM	I	-	sec	Index counter of elapsed time of simulation.
NPART	I	(i)	-	(I) Number of particle types in the ith soil. i = number of soils
NPC1	I	-	-	Equal to NCONF1 for a given sub-shed.
NPC2	I	-	-	Equal to NCONF2 for a given sub-shed.
NPCHAN	I	(i)	-	(I) Index which defines the print status for channel flow output for each subshed. See INPUT subroutine. i = number of sub-sheds in the watershed
NPCINT	I	-	-	Number of rainfall intervals for the storm.
NPER		(i)	-	i = maximum of NDHRUS or NTELES

NPERCT	I	-	-	Value of SMCWS expressed as a percentage.
NPOS	I	(i)	-	Indicates the position of each element of a sub-strip in the flow strip. i = maximum number of elements in a strip
NPOVER	I	(i)	-	(I) Index which defines the print status for output of overland flow for each sub-shed. See INPUT subroutine. i = number of sub-sheds in the watershed
NPRINC	I	-	sec	The time interval of output listings. NPRINC set to NPRIN or NCPRIN.
NPRTS	I	-	-	Total printing intervals for the simulation.
NPSTRP	I	(i,j)	-	(I) Index which defines the print status for the output of overland flow for each strip of a given sub-shed. See INPUT subroutine. i = number of sub-sheds in the watershed j = number of sub-sheds in the watershed
NRGAGE	I	(i)	-	(I) Raingage assigned to each element. i = NTELES
NS	I	-	-	Soil type number.
NSECC	I	-	sec	Duration of simulation.
NSECR	I	-	sec	Duration of rainfall.
NSED	I	-	-	(I) Index that indicates if sediment calculations are desired. = 0 calculations not executed = 1 calculations executed
NSOIL	I	(i)	-	(I) Soil type number for the ith HRU. i = maximum of NDHRUS or NTELES
NSSHED	I	-	-	Number of sub-sheds in watershed.
NST	I	-	-	(I) Number of soil types in the watershed.
NSTART	I	-	-	(I) Hour at which precipitation records begin.
NSTRPS	I	-	-	(I) The total number of strips within a given sub-shed.

NTAB	I	-	-	Number of tables of rainfall excess which must be printed to cover duration of storm event.
NTBLHS	I	-	-	(I) Print code for the table describing the HRU's. = 0 table is not printed = 1 table is printed
NTBLPE	I	-	-	(I) Print code for table listing precipitation and precipitation excess for both HRU's and elements. = 0 table is not printed = 1 table is printed
NTELES	I	-	-	(I) Total number of elements in the watershed.
NTIME	I	-	-	Index counter of elapsed time of simulation.
NTSS	I	-	-	(I) Total number of sub-sheds in the watershed.
NTSSX	I	-	-	Number of sub-sheds, including imaginary sub-shed, in the watershed.
NTYPE	I	-	-	Number of particles in particular soil type.
NUMBER	I	(24)	-	Column matrix to store numerals 1 thru 24. These data used to generate headings in specific output table listings.
NUMP	I	-	-	Counter for checking if potential sediment load = 0.
NUMTAB	I	-	-	Index code which controls heading of rainfall excess tables.
NWRITE	I	-	-	Index code which controls headings of flow information table.
NYEAR	I	-	-	(I) Last two digits of year in which storm occurred.
NZIP	I	-	-	Index code used to control branching to I/O functions.
PCINTH	R	-	-	Time interval of rainfall.

PEAK	R	-	cfs	Peak rate of runoff during the given time increment.
PERDIF	R	-	-	Variable used in interpolating table of values from Shield's diagram.
PL	R	(i)	(cfs/ft)	Potential flow losses for each element of a strip for a given time increment. i = maximum number of elements in a strip
POTSED	R	(i)	(lb/ft/sec)	Potential sediment load of ith particle type. i = number of particle types (8)
PRECIP	R	(i,j)	in	(I) Rainfall in the ith raingage for the jth time increment. i = number of raingages j = number of rainfall increments
PRECP	R	-	in	Rainfall for a given element and time increment.
PREDTO	R	(i,j)	in	Amount of precipitation during one overland flow routing time interval. i = number of raingages j = number of rainfall increments
PUSLE	R	(i)	-	USLE contouring factor for the ith HRU. i = maximum of NDHRUS or NTELES
QCONF	R	(i,j)	cfs	Discharge at the downstream node of each channel per computation time increment (routing interval). i = (NHOURC*3600)/DTC j = number of sub-sheds in the watershed
QO	R	(i)	cfs	Initial discharge at each nodal point in a strip. i = maximum number of nodes in a strip or channel
QOT	R	(i,2)	cfs	Intermediate storage of the discharge values at each node for a given time increment (see description of AOT). i = maximum number of nodes in a strip or channel
QOUT	R	(i,j)	cfs	Lateral flow to the channel from each overland flow strip in a subshed per routing interval. i = maximum number of strips in any sub-shed j = (NHOURC*3600)/DTO

QQ	R	(i)	cfs	(I) Calculated discharge at the nodes of the overland flow strip or channel. i = maximum number of nodes in a strip or channel
QSED	R	(i,j)	(lb/ft/sec)	Amount of ith particle type of jth soil leaving the given element at the end of the given time increment. i = number of particle types (8) j = maximum number of nodes in a strip or channel
QP	R	(i,j)	cfs	Calculated discharge at interior nodes of an overland flow strip or channel, which is stored for printing output. i = the higher value of NHOURC/NOPRIN or NHOURC/NCPRIN j = (maximum number of nodes in a strip or channel) - 4
QQX	R	-	cfs	Combined discharge from two upstream channels to form discharge in imaginary channel.
R1	R	(i)	-	Temporary storage variable used in the assembled matrix formulation. i = maximum number of nodes in a strip or channel
R2	R	(i)	-	Temporary storage variable used in the assembled matrix formulation. i = maximum number of nodes in a strip or channel
RC	R	(i)	-	Column matrix of the known quantities for solution of the element equation. i = square of the maximum number of nodes in a strip or channel
RAD	R	(i)	ft	Hydraulic radius of flow at ith node. i = (maximum number of nodes in a strip or channel) + 1
RCLU	R	(i)	-	(I) Index to reflect the effect of landuse on Manning's roughness coefficient. i = number of land use types
RCOEF	R	(i)	-	(I) Roughness coefficient for each channel element. i = maximum number of elements in a strip or channel
RE1	R	(2)	(ft^2/sec)	Temporary storage variable used in the assembled matrix formulation.

RE2	R	(2)	(ft^2/sec)	Temporary storage variable used in the assembled matrix formulation.
RECMAX	R	-	in	Maximum possible storage recovery during time increment, due to seepage.
RECOV	R	-	in	Actual storage recovery during time increment due to seepage.
REFE	R	(1,1)		Not used.
RELIEF	R	(i)	ft	(I) Relief of each element of a given channel or overland flow strip. i = maximum number of elements in a strip or channel
REQTR	R	(i)	-	Actual required non-dimensional transport for ith particle type. i = number of particle types (8)
REYNOL	R	(i)	-	Calculated particle Reynolds number. i = number of particle types (8)
REYNUM	R	-	-	Particle Reynolds' number from Shields' diagram.
RQ	R	(i)	(cfs/ft)	Lateral flow to each element in a given strip. i = maximum number of elements in a strip or channel
RQQ	R	(i)	(cfs/ft)	Lateral "inflow" (positive or negative) to each element in a flow strip. i = maximum number of elements in a strip or channel
S1	R	(i,2)	-	Temporary storage variable used in the assembled matrix formulation. i = maximum number of nodes in a strip or channel
SDLT	R	-	-	Sum of DELTA's for particle types where TCAP is less than QSED.
SE1	R	(2,2)	-	Temporary storage variable used in the assembled matrix formulation.
SEDCON	R	-	(lb/ft^3)	Sediment concentration.
SEDRAT	R	-	(lb/sec)	Rate of sediment yield from the given strip.
SG	R	(i,j)	-	(I) Specific gravity of the ith particle type of the jth soil type. i = number particles types j = maximum of NDHRUS or NTELES

SIGMA	R	(i)	-	Factor in Yalin equation. i = number particles types
SINE	R	(i)	-	Sine of the slope angle of element NE. i = maximum number of nodes in a strip or channel
SLEX	R	-	-	Slope length exponent for the rill detachment equation.
SLOHRU	R	(i)	-	(I) Slope class of each HRU. i = maximum of NDHRUS or NTELES
SLOPCL	R	(6)	-	Slope classes A, B, C, D, E, F.
SLOPCO	R	(6)	-	Coefficient corresponding to the ith slope class used in depression storage calculations.
SLOPE	R	(i)	(ft/ft)	Slope of each element in a strip. i = maximum number of elements in a strip or channel
SMC	R	-	-	Antecedent soil moisture condition of a given HRU expressed as a fraction of field capacity.
SMCHRU	R	(i)	(in/in)	(I) Antecedent moisture condition expressed as a fraction of field capacity for each HRU. i = maximum of NDHRUS or NTELES
SMCWS	R	-	(in/in)	(I) Antecedent moisture condition for the watershed, expressed as a fraction of field capacity for each HRU.
SMUS	R	-	-	Factor used to distribute excess transport capacity.
SMX	R	-	-	Antecedent soil moisture content.
SPT	R	-	-	Fraction of total transport capacity used.
STO	R	(i)	in	Current value of unfilled soil water storage for each element in a strip. i = maximum number of elements in a strip or channel
STOI	R	(i)	in	Initial value of unfilled soil water storage for each element. i = maximum of NDHRUS or NTELES
STOMAX	R	(i)	in	Maximum soil water storage for each HRU. i = maximum of NDHRUS or NTELES

STOT	R			
TA	R	-	hr	Time interval necessary for rainfall in a given time increment to infiltration.
TAREAD	R	(2)		
TCAP	R	(i)	-	Transport capacity of ith particle type in a mixture. i = number of particle types (8)
TESTIN	R	-	in	Difference between rainfall and EPS1. Equal to total infiltration when TA(FA) G TESTIN.
TI	R			
TINIM	R			
TOTLIF	R	-	-	Total excess (or deficit) of lift force exerted by flow.
TOTSED	R	-	lbs	Total sediment yield from the given strip.
TWIDTH	R	(i)	ft	(I) Top width of the downstream node of each element in a given strip. i = maximum number of nodes in a strip or channel
TYPE	R	(i,j)	-	Percent of ith particle in jth soil type. i = number of particle types (8) j = maximum of NDHRUS or NTELES
UTRANS	R	(i)	-	Nondimensional transport for uniform material of ith particle type. i = number of particle types (8)
VOLT1	R	(i)	ft	Volume of flow at the ith node at time T1 for a given time increment. i = maximum number of nodes in a strip or channel
VOLT2	R	(i)	ft	Volume of flow at the ith node at time T2 of given time increment. i = maximum number of nodes in a strip or channel
VOLDT	R	-	ft	Average rate of flow on the given element during the given time increment.
VSTAR	R	(i)	(ft/sec)	Shear velocity of flow at ith node. i = maximum number of nodes in a strip or channel

VV	R	(i)	(ft/sec) (I) Calculated velocity of flow at the nodes of the overland flow strip or channel. i = maximum number of nodes in a strip or channel	
VVP	R	(i,j)	(ft/sec) Calculated velocity of flow at interior nodes of an overland flow strip or channel, which is stored for printing output. i = the higher value of NHOURC/NOPRIN or NHOURC/NCPRIN j = (maximum number of nodes in a strip or channel) - 4	
WATER	R	-	in	Remaining unfilled storage at the end of time increment.
WOUT	R	-	in	Amount of water leaving soil profile.
XI	R	(i,j)	(in/hr) Intensity of precipitation during the current precipaitation input time interval. i = number raingages j = number of rainfall increments	
XINC	R	-	-	Number of rainfall increments in 30 minutes.
XINF	R	-	in	Volume of rainfall infiltrated during time increment.
XINT	R	-	in	Temporary storage of maximum rainfall intensity.
XI30	R	(i)	(in/hr) Maximum 30 - minute intensity for the ith raingage for the storm. i = number of raingages	
XKCP	R	(i)	(tons/acre)(acre/100 ft-tons)(hr/in) Product of USLE terms used in the detachment equation. i = maximum number of nodes in a strip or channel	
XKUSLE	R		(tons/acre)(acre/100 ft-tons)(hr/in) USLE soil erodibility factor for the ith HRU.	
XL	R	(i)	ft	Temporary storage of variable XLEN. i = maximum number of elements in a strip or channel
XLEN	R	(i)	ft	(I) Length of each element in a given strip. i = maximum number of elements in a strip or channel

XLEVEL	R	-	-	Level of moisture in soil profile.
XP	R	-	in	Unfilled storage after all rain for a given time increment is assumed to infiltrate.
XXP	R	-	in	Unfilled storage during successive iteration cycles with Holtan equation.
YLIFT	R	(i)	-	Lift force exerted by flow for particular particle type. i = number of particle types (8)

11.3 APPENDIX C: FESHM PROGRAM LISTING

```
C$JOB           ,TIME=(3)
C*************************************************************************
C       MODIFIED BY: W. CULLY HESSION
C
C       THIS VERSION OF FESHM IS A SLIGHTLY MODIFIED VERSION OF THE
C       MODEL USED IN M.L. WOLFE'S THESIS.  IT WAS MODIFIED SO THAT
C       IT WOULD RUN ON FORTRAN 77 AND WATFIV COMPILERS.  THE SEDIMENT
C       SECTION HAS NOT BEEN UPDATED TO WATFIV YET.  THIS VERSION ALSO
C       MAKES IT POSSIBLE TO RUN ON A WATERSHED SCALE. THE PREVIOUS
C       VERSION DEVELOPED BY HEATWOLE AND WOLFE REQUIRED ELEMENTS TO
C       COINCIDE WITH HRU'S.  THIS WAS FOUND TO BE IMPRACTICAL FOR
C       LARGE WATERSHEDS AND A SUBROUTINE (EFFHRU) WAS ADDED WHICH
C       USES AREA WEIGHTING TO CREATE EFFECTIVE HRUS FOR EACH ELEMENT.
C
C*************************************************************************
C                              MAIN PROGRAM
C*************************************************************************
C         THIS IS THE MAIN PROGRAM FOR THE VERSION OF THE FINITE ELEMENT
C    STORM HYDROGRAPH MODEL THAT INCLUDES TRANSMISSION LOSSES AND
C    SEDIMENT CALCULATIONS.
C*************************************************************************
C
C    COMMON BLOCKS:
C
       COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
      1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
      2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
       COMMON/BLK2/REFE(1,1),NRGAGE(80)
       COMMON /BLK3/ QOUT(80,1000),QCONF(4500,17),WIDINF(20)
       COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
      &,DSLU(60),DSAC(163),ERCOEF(163)
       COMMON/BLK6/NODE1(20),NCONF1(20),NCONF2(20)
       COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
      &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
      &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
      &NHOURC,NDAMS,NTSSX,NOWTIM
       COMMON /BLK10/ FAW(163),FGW(163),DEPTH(163),AFLU(60),SMCHRU(163)
       COMMON/BLK13/NPOVER(40),NPCHAN(40),NPSTRP(40,40)
       COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
      &DIA(8,163),TYPE(8,163)
       COMMON /BLK33/ XKUSLE(163),CUSLE(163),PUSLE(163),EFFK(163),
      &EFFC(163),EFFP(163)
       COMMON /BLK35/ QSED(8,11),TOTSED,ACCSED
       COMMON /BLK36/ IELE,NGREAT,KDET,XI30(4)
       COMMON /BLK38/ INCLAS
C
C    PROGRAM:
C
CULLY CHANGE: SLOHRU DEFINED AS CHARACTER (MUST BE IN EVERY SUBROUTINE
C             WHICH USES BLK1 TO AVOID WARNINGS IN WATFIV
       CHARACTER*1 SLOHRU
CHANGE(WATFIV): SETTING KN TO 0 FOR USE IN ASSEMB
       KN=0
```

```
CHANGE(WATFIV): INITIALIZING PRECIP VALUES
      DO 10 I1=1,4
      DO 10 J1=1,100
      PRECIP(I1,J1)=0.0
10    CONTINUE
C
CHANGE(WATFIV): INITIALIZING NTYPE WHICH NEEDS TO BE DONE IF NO SED
CHANGE(WATFIV): I SET IT = 1 BECAUSE IT DOESN'T LIKE DO LOOP OF 0
      NTYPE=1
C
CHANGE(WATFIV): INITIALIZING QSED FOR SUBROUTINE OUTPUT WHEN NSED=0
      DO 11 I2=1,8
      DO 11 J2=1,11
      QSED(I2,J2)=0.0
11    CONTINUE
CHANGE(WATFIV): SAME AS ABOVE
      TOTSED=0.0
      ACCSED=0.0
C
CHANGE(WATFIV): INITIALIZING TWIDTH(1) WHICH IS UNDEFINED BECAUSE
C               WHEN IT IS READ IN IT IS ASSIGNED SUBSCRIPT (I+1)
      NZIP=1
      CALL INPUT
      CALL START
      NZIP=8
      CALL OUTPUT(I,K,NTIME,NPRINC,NHEAD)
      NZIP=1
      CALL OUTPUT(I,K,NTIME,NPRINC,NHEAD)
      NZIP=6
      CALL INPUT
      IF(NSED.EQ.1)CALL INTENS
      INCLAS=0
      NELEM=0
      DO 85 NSSHED=1,NTSS
      CALL OVERL (KN)
85    CALL CHANL
      STOP
      END

      SUBROUTINE ASSEMB (NE,NN,DTO,K,KN)
C*********************************************************************
C
C   ARGUMENTS:
C
C     NE  - THE NUMBER OF ELEMENTS IN THE FLOW STRIP
C     NN  - THE NUMBER OF NODES IN THE FLOW STRIP
C     DTO - THE OVERLAND FLOW ROUTING TIME INCREMENT
C     K   - THE NUMBER OF THE FLOW STRIP
C
C   PURPOSE:
C
C       THE PURPOSE OF THIS SUBROUTINE IS TO DETERMINE ELEMENT COMPATI-
C   BILTIY BASED ON CONTINUITY OF FLOW, ASSEMBLE COMPATIBLE ELEMENTS,
C   ROUTE FLOWS, AND ASSIGN ROUTED FLOW AT EACH NODE.
C*********************************************************************
C
C   COMMON BLOCKS:
```

```
C
      COMMON /BLK4/ XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11)
     &          ,QQ(11),AREA(10),VV(11),DD(11)
      COMMON /BLK8/ SLOPE(10),RCOEF(10),RELIEF(10)
      COMMON /BLK22/ PL(10),RQQ(10)
C
C
C    PROGRAM:
C
      DIMENSION NCOMP(11),AOT(11,2),QOT(11,2),NPOS(10),XL(10)
C
C                                                    THIS BLOCK DETERMINES
C                                                       IF A NEW FLOW STRIP
C                                                       BEING CONSIDERED.
C                                                       IF NOT, CONTROL IS
C                                                       PASSED TO STATEMENT
C                                                       80.
      IF (K.EQ.KN) GO TO 80
         KN=K
C        WRITE (9,20) K
C  20    FORMAT (//,10X,13HFLOW STRIP # ,I2,/)
C                                                    THESE LOOPS DETERMINE
C                                                       THE LENGTH OF EACH
C                                                       ELEMENT AND INITIAL-
C                                                       IZE THE VARIABLES
C                                                       FOR THE NEW FLOW
C                                                       STRIP.
         DO 40 I=1,NE
   40    XL(I)=XLEN(I)
         DO 60 I=1,11
            NCOMP(I)=0
            QQ(I)=0.0
            VV(I)=0.0
            DD(I)=0.0
            DO 50 J=1,2
               AOT(I,J)=0.0
               QOT(I,J)=0.0
   50       CONTINUE
   60    CONTINUE
   80 CONTINUE
C                                                    THIS LOOP DETERMINES
C                                                       ELEMENT COMPATIBIL-
C                                                       ITY BASED ON EXCESS
C                                                       FLOW.  THE CONDITION
C                                                       FOR CONTINUITY IS:
C                                                        Q(I-1)  > 0, SUB-
C                                                       TO THE CONSTRAINT:
C                                                       THAT THE X-SECTIONAL
C                                                       AREA OF FLOW IS LESS
C                                                       THAN OR EQUAL TO
C                                                       ZERO AT TIME T AT
C                                                       BOTH THE UPPER AND
C                                                       LOWER NODES OF THE
C                                                       ELEMENT.
      DO 120 I=2,NN
         IF (NCOMP(I).EQ.1) GO TO 110
            IF (AOT(I,1).NE.0.0) GO TO 100
```

```
                IF (RQQ(I-1).LE.0.0) GO TO 90
                   NCOMP(I)=1
                   IF (AOT(I,2).GT.0.0) NCOMP(I)=2
   90           CONTINUE
  100        CONTINUE
  110     CONTINUE
  120 CONTINUE
C     WRITE (9,140) (NCOMP(M),M=1,NN)
C 140       FORMAT (7H** 1 **,10I3)
C                                                    THIS BLOCK DETERMINES
C                                                       INITIAL X-SECTIONAL
C                                                       AREA OF FLOW, INI-
C                                                       TIAL DISCHARGE, LAT-
C                                                       ERAL INFLOW, AND
C                                                       LENGTH OF THE ELE-
C                                                       MENT FOR NODES AT
C                                                       WHICH THE FLOW IS
C                                                       CONTINUOUS (NCOMP(I)
C                                                       = 1).
      NNT=0
      NET=0
      IND=0
      NNN=2
  160 CONTINUE
      IF (NCOMP(NNN).NE.1) GO TO 200
         IF (IND.EQ.1) GO TO 180
            IF (NCOMP(NNN).EQ.2) NCOMP(NNN)=0
            NNN=NNN-1
            L=2
  180    CONTINUE
         IF (NNN.EQ.NN) GO TO 220
         NET=NET+1
         NNT=NET+1
         IND=1
         NPOS(NET)=NNN
         AO(NET)=AOT(NNN,L)
         QO(NET)=QOT(NNN,L)
         RQ(NET)=RQQ(NNN)
         XLEN(NET)=XL(NNN)
         L=1
         GO TO 300
C                                                    THIS BLOCK ASSEMBLES
C                                                       COMPATIBLE GROUPS OF
C                                                       ELEMENTS, ROUTES
C                                                       FLOWS, AND ASSIGNS
C                                                       ROUTED FLOW AT EACH
C                                                       NODE.
  200 CONTINUE
      IF (NET.EQ.0) GO TO 300
         NCOMP(NNN)=0
  220    CONTINUE
         AO(NNT)=AOT(NNN,1)
         QO(NNT)=QOT(NNN,1)
         CALL ROUTE (NET,NNT,DTO)
         I=NPOS(1)
         QOT(I,2)=0.0
         AOT(I,2)=AA(1)
```

```
        QQ(I)=0.0
        DO 280 J=2,NNT
           I=NPOS(J-1)
           IF (AA(J).LE.0.0) GO TO 240
              DD(I+1)=AA(J)/TWIDTH(I+1)
              VV(I+1)=(1.49*SQRT(SLOPE(I))*DD(I+1)**0.67)/RCOEF(I)
              QQ(I+1)=VV(I+1)*AA(J)
              GO TO 260
  240      CONTINUE
              QQ(I+1)=0.0
              VV(I+1)=0.0
              DD(I+1)=AA(J)/TWIDTH(I+1)
  260      CONTINUE
              AOT(I+1,1)=AA(J)
              QOT(I+1,1)=QQ(I+1)
              IF (J.EQ.NNT) GO TO 280
              AOT(I+1,2)=AOT(I+1,1)
              QOT(I+1,1)=QOT(I+1,1)
  280    CONTINUE
        NET=0
        IND=0
  300 CONTINUE
      NNN=NNN+1
      IF (NNN.LE.NN) GO TO 160
      AA(1)=AOT(1,2)
      DO 320 I=2,NN
         AA(I)=AOT(I,1)
  320 CONTINUE
C                                                    THIS LOOP DETERMINES
C                                                       ELEMENT COMPATIBIL-
C                                                       ITY BASED ON NODAL
C                                                       FLOWS. THE CONDITION
C                                                       FOR CONTINUITY IS
C                                                       THAT THE X-SECTIONAL
C                                                       AREA OF FLOW AT THE
C                                                       UPPER NODE OF THE
C                                                       ELEMENT BE GREATER
C                                                       THAN ZERO AT TIME T.
      DO 380 I=2,NN
         IF (NCOMP(I).NE.1) GO TO 340
            IF (AOT(I,1).GT.0.0) GO TO 360
            NCOMP(I)=0
            QOT(I,2)=0.0
            AOT(I,2)=AOT(I,1)
            GO TO 360
  340    CONTINUE
            NCOMP(I)=0
            IF (AOT(I,1).LE.0.0) GO TO 360
               NCOMP(I)=1
360      CONTINUE
380   CONTINUE
C      WRITE (9,400) (NCOMP(I),I=1,NN)
C400   FORMAT (7H** 2 **,10I3)
C                                                    THIS LOOP CALCULATES
C                                                       THE POTENTIAL FLOW
C                                                       LOSS FOR EACH ELE-
C                                                       MENT OF A STRIP FOR
```

```
C                                                          THE ROUTING TIME IN-
C                                                          CREMENT.
      DO 460 I=1,NE
         I1=I+1
         IF (AOT(I,2).GT.0.0.OR.AOT(I1,1).GT.0.0) GO TO 420
            PL(I)=0.0
            GO TO 440
  420    CONTINUE
            PL(I)=(AOT(I,2)+2.*AOT(I1,1))/(3.*DTO)+(QOT(I,2)
     &         -QOT(I1,1))/XL(I)
            PL(I)=AMAX1(PL(I),0.0)
  440    CONTINUE
  460 CONTINUE
      RETURN
C     DEBUG UNIT(12),SUBCHK
      END

      SUBROUTINE CHANL
C*************************************************************************
C
C   PURPOSE:
C
C      THE PURPOSE OF THIS SUBROUTINE IS TO ASSEMBLE THE FLOWS
C   FROM ALL THE STRIPS IN THE SUBSHED AND PASS THEM ON TO THE
C   ROUTING SUBROUTINE.
C*************************************************************************
C   COMMON BLOCKS:
C
      COMMON /BLK3/ QOUT(80,1000),QCONF(4500,17),WIDINF(20)
      COMMON /BLK4/ XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11)
     &          ,QQ(11),AREA(10),VV(11),DD(11)
      COMMON/BLK6/NODE1(20),NCONF1(20),NCONF2(20)
      COMMON /BLK8/ SLOPE(10),RCOEF(10),RELIEF(10)
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK13/ NPOVER(40),NPCHAN(40),NPSTRP(40,40)
C
C   PROGRAM:
C
       DIMENSION HYDRAD(11)
C                                                     THIS BLOCK INITIALIZES
C                                                        VALUES OF VARIABLES
C                                                        REQUIRED FOR ROUTING
C                                                        CHANNEL FLOWS AND
C                                                        READS IN CHANNEL
C                                                        ELEMENT DESCRIPTORS.
      NPRINC=NCPRIN
      NTIME=0
      NE=NSTRPS/2
      NN=NE+1
      NZIP=4
      CALL INPUT
      DT=DTC
CHANGE(WATFIV): DOESN'T LIKE NE=0
      IF(NE.EQ.0)GO TO 21
```

```
C
      DO 20 I=1,NE
         SLOPE(I)=RELIEF(I)/XLEN(I)
   20 CONTINUE
C                                                    THESE LOOPS DETERMINE
C                                                       THE SLOPE OF EACH
C                                                       ELEMENT AND INITIAL-
C                                                       IZE THE VALUES OF X-
C                                                       SECTIONAL AREA AND
C                                                       VOLUME OF FLOW AT
C                                                       EACH NODE.
   21 DO 40 I=1,NN
         AO(I)=0.0
         QO(I)=0.0
   40 CONTINUE
60    JT=NTIME/IFIX(DTO)+1
      LS=NSTRPS/2
C                                                    THIS LOOP DETERMINES
C                                                       THE LATERAL INFLOW
C                                                       TO EACH CHANNEL ELE-
C                                                       MENT FROM THE OVER-
C                                                       LAND FLOW STRIPS.
CHANGE(WATFIV): DOESN'T LIKE LS=0
      IF(LS.EQ.0)GO TO 100
C
      DO 80 I=1,LS
         RQ(I)=QOUT(2*I-1,JT)+QOUT(2*I,JT)
   80 CONTINUE
  100 CONTINUE
      LT=NTIME/IFIX(DTC)+1
      CALL ROUTE (NE,NN,DT)
      VV(1)=0.0
      QQ(1)=0.0
      DD(1)=SQRT(ABS(AA(1))/350.0)
      IF (AA(1).LT.0.0) DD(1)=-1*DD(1)
      IF (NTSS.EQ.1) GO TO 140
C                                                    THIS BLOCK DETERMINES
C                                                       THE VOLUME, DEPTH,
C                                                       AND VELOCITY OF FLOW
C                                                       WHERE THERE IS A
C                                                       CONFLUENCE.
         IF (NODE1(NSSHED).EQ.0) GO TO 130
            NPC1=NCONF1(NSSHED)
            NPC2=NCONF2(NSSHED)
            QQ(1)=QCONF(LT,NPC1)+QCONF(LT,NPC2)
            DD(1)=SQRT((4.0*ABS(AA(1)))/TWIDTH(2))
            IF (AA(1).LE.0.0) GO TO 120
               VV(1)=QQ(1)/AA(1)
               GO TO 140
  120       CONTINUE
               VV(1)=0.0
               DD(1)=-1*DD(1)
  130    CONTINUE
  140 CONTINUE
C                                                    THESE LOOPS DETERMINE
C                                                       THE DEPTH, VOLUME,
C                                                       AND VELOCITY OF FLOW
```

```
C                                                    AT EACH NODE AND THE
C                                                    HYDRAULIC RADIUS OF
C                                                    FLOW AT EACH NODE
C                                                    WHERE FLOW IS
C                                                    GREATER THAN ZERO.
      DO 160 I=2,NN
         DD(I)=SQRT((4.0*ABS(AA(I)))/TWIDTH(I))
         IF (AA(I).LT.0.0) DD(I)=-1*DD(I)
160   CONTINUE
      DO 200 I=2,NN
         IF (AA(I).GT.0.0) GO TO 180
            VV(I)=0.0
            QQ(I)=0.0
            GO TO 200
  180    CONTINUE
            HYDRAD(I)=AA(I)/(2.0*SQRT(DD(I)**2.0+(AA(I)/DD(I))**2.0))
            VV(I)=(1.49*SQRT(SLOPE(I-1))*HYDRAD(I)**0.67)/RCOEF(I-1)
            QQ(I)=VV(I)*AA(I)
  200 CONTINUE
C                                                 THIS BLOCK INCREMENTS
C                                                    THE ROUTING TIME AND
C                                                    AND PRINTS OUT CHAN-
C                                                    NEL FLOW INFORMATION
C                                                    IF REQUESTED.
      IF (NTSS.NE.1) QCONF(LT,NSSHED)=QQ(NN)
      NTIME=NTIME+IFIX(DTC)
      IF (NTIME/NCPRIN*NCPRIN.NE.NTIME) GO TO 240
         IF (NPCHAN(NSSHED).EQ.0) GO TO 230
            NZIP=4
            CALL OUTPUT (I,K,NTIME,NPRINC,NHEAD)
  230    CONTINUE
  240 CONTINUE
C                                                 THIS LOOP DETERMINES
C                                                    THE INITIAL VALUE OF
C                                                    AREA AND VOLUME OF
C                                                    FLOW AT EACH NODE
C                                                    FOR THE NEXT ROUTING
C                                                    INCREMENT.
      DO 260 I=1,NN
         AO(I)=AA(I)
         QO(I)=QQ(I)
  260 CONTINUE
C                                                 THIS BLOCK TRANSFERS
C                                                    CONTROL TO THE
C                                                    APPROPRIATE STATE-
C                                                    MENT BASED ON THE
C                                                    ELAPSED SIMULATION
C                                                    TIME AND THE OVER-
C                                                    LAND FLOW ROUTING
C                                                    INCREMENT.
      IF (NTIME.GE.NSECC) GO TO 280
         IF (NTIME/IFIX(DTO)*IFIX(DTO).EQ.NTIME) GO TO 60
         GO TO 100
  280 CONTINUE
C                                                 THIS BLOCK PRINTS OUT
C                                                    CHANNEL FLOW INFOR-
C                                                    MATION IF REQUESTED
```

```
C                                                       AND RETURNS CONTROL
C                                                       TO MAIN.
      IF (NTSS.EQ.1) GO TO 310
         IF (NTSSX.GT.(NSSHED+1)) GO TO 300
            IF (NODE1(NTSSX).EQ.0) GO TO 290
               NZIP=9
               CALL OUTPUT (I,K,NTIME,NPRINC,NHEAD)
  290       CONTINUE
  300    CONTINUE
  310 CONTINUE
      RETURN
      END

      SUBROUTINE DETACH
C*************************************************************************
C
C   PURPOSE:
C
C       THE PURPOSE OF THIS SUBROUTINE IS TO CALCULATE THE AMOUNT OF
C   SOIL DETACHED FROM THE OVERLAND FLOW ELEMENT DURING THE ROUTING TIME
C   INCREMENT.  DETACHMENT ON INTERRILL AND RILL AREAS IS CONSIDERED
C   SEPARATELY.  THE EQUATIONS USED TO DESCRIBE DETACHMENT ARE:
C
C             DI = 0.210 EI (S + 0.014) KCP (PEAK/VOL)
C   AND
C
C   DR = 37983(M)(VOL)(PEAK)**1/3 (X/72.6)**(M-1) S**2 KCP (PEAK/VOL)
C
C   WHERE:
C
C     DI = INTERRILL DETACHMENT RATE (LB/SQ.FT/S)
C     DR = RILL DETACHMENT CAPACITY RATE (LB/SQ.FT/S)
C     EI = WISCHMEIER'S RAINFALL EROSIVITY (ENERGY TIMES 30-MINUTE
C          INTENSITY)  (100(FT-TONS/ACRE)(IN/HR))
C     X = DISTANCE DOWNSLOPE (FT)
C     S = SINE OF SLOPE ANGLE
C     M = SLOPE LENGTH EXPONENT
C     K = USLE SOIL ERODIBILITY FACTOR ((TONS/ACRE)(ACRE/100 FT-TONS)
C          (HR/IN))
C     C = SOIL LOSS RATIO OF THE USLE COVER-MANAGEMENT FACTOR
C     P = USLE CONTOURING FACTOR
C     VOL = RUNOFF VOLUME (VOLUME/UNIT AREA (FT))
C     PEAK = PEAK RUNOFF RATE (VOLUME/UNIT AREA/UNIT TIME (FT/S)).
C
C*************************************************************************
C
C   COMMON BLOCKS:
C
      COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
     1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
     2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
      COMMON/BLK2/REFE(1,1),NRGAGE(80)
      COMMON /BLK4/ XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11)
     &          ,QQ(11),AREA(10),VV(11),DD(11)
      COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
     &,DSLU(60),DSAC(163),ERCOEF(163)
      COMMON /BLK8/ SLOPE(10),RCOEF(10),RELIEF(10)
```

```
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
     &DIA(8,163),TYPE(8,163)
      COMMON /BLK33/ XKUSLE(163),CUSLE(163),PUSLE(163),EFFK(163),
     &EFFC(163),EFFP(163)
      COMMON /BLK34/ TCAP(8),POTSED(8),DITYP(8,11),DRTYP(8,11)
      COMMON /BLK36/ IELE,NGREAT,KDET,XI30(4)
      COMMON /BLK37/ VOLT1(12),VOLT2(12),INTER
      COMMON /BLK38/ INCLAS
C
C    PROGRAM:
C
      DIMENSION XI(4,100),E1(4,100),ENERGY(4,100),EKUSLE(11),ECUSLE(11),
     &          EPUSLE(11),PREDTO(4,100),SINE(11),XKCP(11),DI(11),DR(11)
CULLY CHANGE:
      CHARACTER*1 SLOHRU
C
      IF(KDET.EQ.2)GO TO 70
C                                                    THIS BLOCK DETERMINES
C                                                       THE VALUE OF THE EI
C                                                       TERM IN THE DETACH-
C                                                       MENT EQUATION. IT IS
C                                                       EXECUTED ONCE AT THE
C                                                       BEGINNING OF EACH
C                                                       PRECIP INPUT TIME
C                                                       INTERVAL.
      INTER=1
      JINC=NOWTIM/INTPCS+1
C     IF(JINC.EQ.INCLAS)GO TO 30
      L=NELEM+IELE
      NG=NRGAGE(L)
      NDTO = INTPCS/IFIX(DTO)
      PREDTO(NG,JINC) = PRECIP(NG,JINC)/FLOAT(NDTO)
      IF(PREDTO(NG,JINC).EQ.0.0)GO TO 66
      XI(NG,JINC) = PREDTO(NG,JINC)/DTO*3600.0
      E1(NG,JINC) = 916.0+331.0*ALOG10(XI(NG,JINC))
      ENERGY(NG,JINC) = E1(NG,JINC)*PREDTO(NG,JINC)
      EI =(ENERGY(NG,JINC)*XI30(NG))/100.0
C           WRITE(8,15)PREDTO(NG,JINC),XI(NG,JINC),E1(NG,JINC),
C    &                 ENERGY(NG,JINC)
C  15       FORMAT(' PREDTO = ',F15.6,'XI = ',F15.6,'E1 = ',F15.6,
C     &             ' ENERGY = ',F15.6)
C        WRITE(8,20)EI
C  20    FORMAT(//,' EI = ',F15.6)
C  30 CONTINUE
C     INCLAS=JINC
C                                                    THIS BLOCK COMPUTES
C                                                       THE AMOUNT OF SOIL
C                                                       DETACHED ON THE
C                                                       INTERRILL AREA OF
C                                                       THE I ELEMENT.
      SINE(IELE) = SIN (ATAN (SLOPE(IELE)))
      EKUSLE(IELE)=0.0
      ECUSLE(IELE)=0.0
```

```
      EPUSLE(IELE)=0.0
      L=NELEM+IELE
CULLY      MHRU=NHRU(L)
CULLY         DO 40 N=1,MHRU
CULLY            J=IHRU(L,N)
CULLY            EKUSLE(IELE)=EKUSLE(IELE)+XKUSLE(J)*FHRU(L,N)
CULLY            ECUSLE(IELE)=ECUSLE(IELE)+CUSLE(J)*FHRU(L,N)
CULLY            EPUSLE(IELE)=EPUSLE(IELE)+PUSLE(J)*FHRU(L,N)
CULLY   40    CONTINUE
CULLY CHANGE:
      EKUSLE(IELE)=EFFK(L)
      ECUSLE(IELE)=EFFC(L)
      EPUSLE(IELE)=EFFP(L)
C
      XKCP(IELE)=EKUSLE(IELE)*ECUSLE(IELE)*EPUSLE(IELE)
   50 CONTINUE
      DI(IELE)=(0.21*EI*(SINE(IELE)+0.014)*XKCP(IELE)/DTO)*XLEN(IELE)
         DO 60 J=1,NTYPE
         DITYP(J,IELE)=DI(IELE)*TYPE(J,NS)
   60    CONTINUE
C           WRITE(8,65)DI(IELE),(DITYP(J,IELE),J=1,NTYPE)
C  65       FORMAT(' INTERRILL DETACHMENT = ',F15.6,/,' DITYP =',5F15.6)
         GO TO 69
   66 CONTINUE
      INTER=0
   69 CONTINUE
      RETURN
C                                                    THIS BLOCK CALCULATES
C                                                       THE AMOUNT OF RILL
C                                                       DETACHMENT ON ELE-
C                                                       MENT I.
   70 VOLDT=(VOLT1(IELE)+VOLT2(IELE)+VOLT1(IELE+1)+VOLT2(IELE+1))/4.0
      PEAK=VOLDT/DTO
      SLEX=1.0+5.011/ALOG(XLEN(IELE))
      IF(XLEN(IELE).LT.150.0)SLEX=2.0
      DR(IELE)=(37983.0*SLEX*VOLDT*PEAK**(1./3.)*(XLEN(IELE)/72.6)**(SLE
     &X-1.0)*SINE(IELE)**2.0*XKCP(IELE)/DTO)*XLEN(IELE)
         DO 80 J=1,NTYPE
         DRTYP(J,IELE)=DR(IELE)*TYPE(J,NS)
   80    CONTINUE
C           WRITE(8,85)DR(IELE),(DRTYP(J,IELE),J=1,NTYPE)
C  85       FORMAT(' RILL DETACHMENT = ',F15.6,/,' DRTYP = ',5F15.6)
      RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END

      SUBROUTINE GELB (R,A,M,N,MUD,MLD,EPS,IER)
C     ************************************************************************
C    SUBROUTINE GELB IS TAKEN FROM THE SCIENTIFIC LIBRARY.
C     ************************************************************************
      DIMENSION R(121),A(121)
C     TEST ON WRONG INPUT PARAMETERS
C
C    PROGRAM:
C
      IF (MLD) 940,20,20
C
```

```
   20 CONTINUE
         IF (MUD) 940,40,40
C
   40 CONTINUE
         MC=1+MLD+MUD
         IF (MC+1-M-M) 60,60,940
C     PREPARE INTEGER PARAMETERS
C        MC=NUMBER OF COLUMNS IN MATRIX A
C        MU=NUMBER OF ZEROS TO BE INSERTED IN FIRST ROW OF MATRIX A
C        ML=NUMBER OF MISSING ELEMENTS IN LAST ROW OF MATRIX A
C        MR=INDEX OF LAST ROW IN MATRIX A WITH MC ELEMENTS
C        MZ=TOTAL NUMBER OF ZEROS TO BE INSERTED IN MATRIX A
C        MA=TOTAL NUMBER OF STORAGE LOCATIONS NECESSARY FOR MATRIX A
C        NM=NUMBER OF ELEMENTS IN MATRIX R
C
   60 CONTINUE
      IF (MC-M) 100,100,80
C
   80 CONTINUE
         MC=M
C
  100 CONTINUE
         MU=MC-MUD-1
         ML=MC-MLD-1
         MR=M-ML
         MZ=(MU*(MU+1))/2
         MA=M*MC-(ML*(ML+1))/2
         NM=N*M
         IER=0
         PIV=0
C
      IF (MLD) 280,280,120
C
  120 CONTINUE
         JJ=MA
         J=MA-MZ
         KST=J
         DO 180 K=1,KST
            TB=A(J)
            A(JJ)=TB
            TB=ABS(TB)
            IF (TB-PIV) 160,160,140
C
  140       CONTINUE
               PIV=TB
C
  160       CONTINUE
               J=J-1
               JJ=JJ-1
  180    CONTINUE
C     INSERT ZEROS IN FIRST MU ROWS (NOT NECESSARY IN CASE MZ=0)
      IF (MZ) 280,280,200
C
  200 CONTINUE
          JJ=1
         J=1+MZ
         IC=1+MUD
```

```
          DO 260 I=1,MU
             DO 240 K=1,MC
                A(JJ)=0
                IF (K-IC) 220,220,230
C
  220           CONTINUE
                   A(JJ)=A(J)
                   J=J+1
C
  230           CONTINUE
                   JJ=JJ+1
  240        CONTINUE
             IC=IC+1
  260     CONTINUE
C
  280 CONTINUE
      TOL=EPS*PIV
      KST=1
      IDST=MC
      IC=MC-1
      DO 760 K=1,M
         IF (K-MR-1) 320,320,300
300      IDST=IDST-1
320      ID=IDST
         ILR=K+MLD
         IF (ILR-M) 360,360,340
340      ILR=M
360      II=KST
C        PIVOT SEARCH IN FIRST COLUMN (ROW INDEXES FROM I=K UP TO I=ILR)
C
         PIV=0
         DO 440 I=K,ILR
            TB=ABS(A(II))
            IF (TB-PIV) 400,400,380
C
  380       CONTINUE
               PIV=TB
            J=I
            JJ=II
C
  400       CONTINUE
            IF (I-MR) 430,430,420
C
  420       CONTINUE
               ID=ID-1
C
  430       CONTINUE
               II=II+ID
  440     CONTINUE
C        TEST ON SINGULARITY
         IF (PIV) 940,940,460
460      IF (IER) 520,480,520
480      IF (PIV-TOL) 500,500,520
500      IER=K-1
520      PIV=1./A(JJ)
C        PIVOT ROW REDUCTION AND ROW INTERCHANGE IN RIGHT HAND SIDE R
         ID=J-K
```

```
          DO 540 I=K,NM,M
             II=I+ID
             TB=PIV*R(II)
             R(II)=R(I)
             R(I)=TB
  540     CONTINUE
C         PIVOT ROW REDUCTION AND ROW INTERCHANGE IN COEFFICIENT MATRIX A
          II=KST
          J=JJ+IC
          DO 560 I=JJ,J
             TB=PIV*A(I)
             A(I)=A(II)
             A(II)=TB
             II=II+1
  560     CONTINUE
C         ELEMENT REDUCTION
          IF (K-ILR) 580,680,680
580       ID=KST
          II=K+1
          MU=KST+1
          MZ=KST+IC
          DO 660 I=II,ILR
C         IN MATRIX A
             ID=ID+MC
             JJ=I-MR-1
             IF (JJ) 620,620,600
  600        ID=ID-JJ
  620        PIV=-A(ID)
             J=ID+1
             DO 640 JJ=MU,MZ
                A(J-1)=A(J)+PIV*A(JJ)
                J=J+1
  640        CONTINUE
             A(J-1)=0
C            IN MATRIX R
             J=K
             DO 650 JJ=I,NM,M
                R(JJ)=R(JJ)+PIV*R(J)
  650        CONTINUE
          J=J+M
  660     CONTINUE
680       KST=KST+MC
          IF (ILR-MR) 720,700,700
700       IC=IC-1
720       ID=K-MR
          IF (ID) 760,760,740
740       KST=KST-ID
760       CONTINUE
C         END OF DECOMPOSITION LOOP
C         BACK SUBSTITUTION
       IF (MC-1) 920,920,780
780    IC=2
       KST=MA+ML-MC+2
       II=M
       DO 900 I=2,M
          KST=KST-MC
          II=II-1
```

```
          J=II-MR
          IF (J) 820,820,800
C
  800     CONTINUE
             KST=KST+J
C
  820     CONTINUE
          DO 860 J=II,NM,M
             TB=R(J)
             MZ=KST+IC-2
             ID=J
             DO 840 JJ=KST,MZ
                ID=ID+1
                TB=TB-A(JJ)*R(ID)
  840        CONTINUE
                R(J)=TB
  860     CONTINUE
C
          IF (IC-MC) 880,900,900
C
  880     CONTINUE
             IC=IC+1
C
900    CONTINUE
  920  CONTINUE
       RETURN
C      ERROR RETURN
940    IER=-1
       RETURN
       END

       SUBROUTINE HOLTAN (L,K,I,J,DTO,INTPCS,MONTH)
C*************************************************************************
C
C   ARGUMENTS:
C
C         L = K + NELEM
C         K = THE NUMBER OF ELEMENTS IN THE STRIP
C         I = THE NUMBER OF THE RAINGAGE ASSIGNED TO THE ELEMENT
C         J = ELAPSED SIMULATION TIME "INCREMENT"
C         DTO = THE ROUTING TIME INCREMENT FOR OVERLAND FLOW ROUTING
C         INTPCS = THE TIME INTERVAL (SECS.) AT WHICH PRECIPITATION
C                  RECORDS ARE ENTERED
C         MONTH = MONTH OF THE EVENT
C
C*************************************************************************
C   PURPOSE:
C
C       THE PURPOSE OF THIS SUBROUTINE IS TO DETERMINE THE AMOUNT OF
C   INFILTRATION, THE AMOUNT OF RAINFALL EXCESS OR FLOW LOSS, AND THE
C   RESULTING SOIL WATER STORAGE FOR EACH HRU FOR EACH OVERLAND FLOW
C   TIME ROUTING INCREMENT.
C   THE HOLTAN EQUATION:
C
C              F1 = AFAC(L) * STO(K)**CEXP(L) +FC(L)
C
C   IS USED TO CALCULATE THE INFILTRATION RATE.
```

```
C*************************************************************************
C
C    COMMON BLOCKS:
C
       COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
      1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
      2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
       COMMON /BLK10/ FAW(163),FGW(163),DEPTH(163),AFLU(60),SMCHRU(163)
       COMMON /BLK22/ PL(10),RQQ(10)
C
C    PROGRAM:
C
C                                                      THIS BLOCK DETERMINES
C                                                         THE MAXIMUM POSSIBLE
C                                                         STORAGE RECOVERY DUE
C                                                         TO SEEPAGE AND THE
C                                                         TOTAL WATER AVAIL-
C                                                         ABLE FOR INFILTRA-
C                                                         TION DURING THE
C                                                         OVERLAND FLOW ROUT-
C                                                         ING TIME INCREMENT.
CULLY CHANGE:
       CHARACTER*1 SLOHRU
       STOT=STO(K)
       DTOH=DTO/3600.
       RECMAX=FC(L)*DTOH
       PRECP=0.0
       IF(J.LE.3600)PRECP=PRECIP(I,J)*DTO/FLOAT(INTPCS)
       AVAIL=PRECP+PL(K)+ACCDP(L)
C                                                      THIS BLOCK DETERMINES
C                                                         THE AMOUNT OF RAIN-
C                                                         FALL INFILTRATED,
C                                                         THE RAINFALL EXCESS,
C                                                         OR FLOW LOSS, AND
C                                                         THE VALUE OF UNFILL-
C                                                         ED SOIL WATER STOR-
C                                                         AGE AFTER INFILTRA-
C                                                         TION FOR EACH HRU
C                                                         FOR EACH TIME INCRE-
C                                                         MENT.
C
       IF(AFAC(L).LE.0.0) GO TO 15
       IF(STO(K).EQ.0.0.AND.FC(L).EQ.0.0) GO TO 20
       IF(STO(K).GT.0.0) GO TO 5
          XINF=RECMAX
          GO TO 40
     5 F1=GINDEX(MONTH)*AFAC(L)*STO(K)**CEXP(L)+FC(L)
       XP=STO(K)-AVAIL
       F2=FC(L)
       IF (XP.GT.0.0) F2=GINDEX(MONTH)*AFAC(L)*XP**CEXP(L)+FC(L)
       FA=(F1+F2)/2.0
       TA=AVAIL/FA
       EPS1=0.0
       IF (TA.LE.DTOH) GO TO 10
       TESTIN=AVAIL/2.0
       GO TO 8
     7 CONTINUE
```

```
      TESTIN=TESTIN/2.0
    8 CONTINUE
C           EPS1=EPS1+0.000001
C           TESTIN=AVAIL-EPS1
            XXP=STO(K)-TESTIN
            F2=FC(L)
            IF (XXP.GT.0.0) F2=GINDEX(MONTH)*AFAC(L)*XXP**CEXP(L)+FC(L)
            FA=(F1+F2)/2.0
            TA=TESTIN/FA
            IF (TA.GT.DTOH) GO TO 7
               XINF=TESTIN
               GO TO 30
   10 CONTINUE
      XINF=AVAIL
      IF (XINF.LE.STO(K)) GO TO 30
         XINF=STO(K)
         GO TO 40
   15 CONTINUE
      XINF=0.0
      ELEXC(K)=PRECP
      IF(ELEXC(K).LE.0.0)ELEXC(K)=0.0
      GO TO 150
   20    CONTINUE
         XINF=0.0
         GO TO 40
   30 STO(K)=STO(K)-XINF
      IF(STO(K).LT.0.0)STO(K)=0.0
   40 CONTINUE
      ACC=PRECP-XINF
      IF(DEPSTO(L).LE.0.0)GO TO 130
      IF(ACC.GE.0.0)GO TO 50
      IF (PL(K).LE.0.0)GO TO 43
         EX=PL(K)-ABS(ACC)
      IF(EX.GE.0.0)GO TO 47
         ELEXC(K)=(-1.0)*PL(K)
         ACCDP(L)=ACCDP(L)+EX
         GO TO 140
   43 CONTINUE
         ELEXC(K)=0.0
         ACCDP(L)=ACCDP(L)+ACC
         GO TO 140
   47 CONTINUE
      ELEXC(K)=ACC
      GO TO 140
   50    CONTINUE
         ACCDP(L)=ACCDP(L)+ACC
      IF(ACCDP(L).LE.DEPSTO(L))GO TO 60
         ELEXC(K)=ACCDP(L)-DEPSTO(L)
         ACCDP(L)=DEPSTO(L)
         GO TO 140
   60 CONTINUE
      ELEXC(K)=0.0
      GO TO 140
  130    CONTINUE
         ELEXC(K)=ACC
  140 CONTINUE
C                                                    THIS BLOCK DETERMINES
```

```
C                                                          HOW MUCH STORAGE IS
C                                                          RECOVERED THROUGH
C                                                          SEEPAGE AND ADJUSTS
C                                                          THE VALUE OF UNFILL-
C                                                          ED STORAGE ACCORD-
C                                                          INGLY.
          AVM=FAW(L)*DEPTH(L)
          GRM=STOMAX(L)-AVM
          WATER=STOMAX(L)-STO(K)
          GRWAT=AVM-WATER
        IF(GRWAT.GT.0.0)GO TO 150
        IF (AVAIL.GE.RECMAX) GO TO 150
          RECOV=RECMAX-AVAIL
          IF (RECOV.GT.ABS(GRWAT)) RECOV=ABS(GRWAT)
          STO(K)=STO(K)+RECOV
          IF (STO(K).GT.GRM) STO(K)=GRM
  150 CONTINUE
        RETURN
C       DEBUG UNIT(12),SUBCHK
        END

        SUBROUTINE INPUT
C
C   NOTE: THIS PARTICULAR INPUT ROUTINE WAS EDITED BY WCH 7/86 TO
C         PROVIDE AN ECHO OF THE INPUT DATA ON UNIT # 1.
C         TO CHECK FOR INPUT ERRORS!!!!!!
C
C*************************************************************************
C   PURPOSE:
C        THE PURPOSE OF THIS SUBROUTINE IS TO INPUT VALUES REQUIRED FOR
C   CALCULATIONS PERFORMED IN THE FESHM.
C*************************************************************************
C
C   COMMON BLOCKS:
C
      COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
     1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
     2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
      COMMON/BLK2/REFE(1,1),NRGAGE(80)
      COMMON/BLK4/XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11),QQ(11)
     1,AREA(10),VV(11),DD(11)
      COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
     &,DSLU(60),DSAC(163),ERCOEF(163)
      COMMON/BLK6/NODE1(20),NCONF1(20),NCONF2(20)
      COMMON/BLK8/SLOPE(10),RCOEF(10),RELIEF(10)
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK10/ FAW(163),FGW(163),DEPTH(163),AFLU(60),SMCHRU(163)
      COMMON/BLK11/NESTRP(20)
      COMMON/BLK13/NPOVER(40),NPCHAN(40),NPSTRP(40,40)
      COMMON/BLK14/AREDAM(2,10),XLENDM(2),RELDAM(2),TWDAM(2),NLEVLS(2),V
     1OLD(2,10),QQD(2,10)
      COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
     &DIA(8,163),TYPE(8,163)
      COMMON /BLK33/ XKUSLE(163),CUSLE(163),PUSLE(163),EFFK(163),
```

```
     &EFFC(163),EFFP(163)
C
C    PROGRAM:
C
      DIMENSION ITITLE(80)
      CHARACTER*1 SLOHRU
      GO TO (99,98,97,96,95,94),NZIP
C***********DATA SET NUMBER 1:  DESCRIPTION OF OUTPUT TABLES***********
C--------IF NTBLHS=1 TABLE LISTING HRU'S AND DESCRIPTIVE CHARACTERISTICS
C           IS PRINTED; IF NTBLHS=0 IT IS NOT
C--------IF NTBLPE=1 TABLE LISTING PRECIPITATION AND PRECIPITATION
C           EXCESS FOR BOTH HRU'S AND ELEMENTS IS PRINTED; IF NTBLPE=0
C           IT IS NOT
C--------NOPRIN = TIME INTERVAL AT WHICH OVERLAND FLOW OUTPUT IS
C           DISPLAYED
C--------NCPRIN = TIME INTERVAL AT WHICH CHANNEL FLOW OUTPUT IS
C           DISPLAYED
99    READ(10,10)NTBLHS,NTBLPE,NOPRIN,NCPRIN
CULLY'S ECHO
      WRITE(1,10)NTBLHS,NTBLPE,NOPRIN,NCPRIN
10    FORMAT(2I5,2I10)
C--------NPOVER = PRINT CODE CONTROLLING OVERLAND FLOW OUTPUT FOR
C           A GIVEN SUB-SHED
C             NPOVER=0; NO OUTPUT
C                    =1; OUTPUT FOR BOTTOM NODES OF STRIPS ONLY
C                    =2; OUTPUT AT ALL NODES OF SELECTED STRIPS
C                        FOR WHICH ADDITIONAL CODES MUST BE READ
      READ(10,100)(NPOVER(K),K=1,40)
CULLY'S ECHO
      WRITE(1,100)(NPOVER(K),K=1,40)
100   FORMAT(40I2)
      DO 104 K=1,40
      IF(NPOVER(K).NE.2)GO TO 104
C--------NPSTRP = PRINT CODE FOR OVERLAND FLOW OUTPUT AT ALL NODES
C        OF SELECTED STRIPS
C             NPSTRP=0; NO OUTPUT FOR STRIP
C                    =1; OUTPUT AT ALL NODES OF THE STRIP
      READ(10,100)(NPSTRP(K,I),I=1,40)
CULLY'S ECHO
      WRITE(1,100)(NPSTRP(K,I),I=1,40)
104   CONTINUE
C--------NPCHAN = PRINT CODE CONTROLLING CHANNEL FLOW OUTPUT FOR
C           A GIVEN SUB-SHED
C             NPCHAN=0; NO OUTPUT
C                    =1; OUTPUT FOR BOTTOM NODE OF CHANNEL ONLY
C                    =2; OUTPUT AT ALL NODES OF THE CHANNEL
      READ(10,100)(NPCHAN(K),K=1,40)
CULLY'S ECHO
      WRITE(1,100)(NPCHAN(K),K=1,40)
      GO TO 40
C**********DATA SET NUMBER 2:  DESCRIPTION OF THE STORM EVENT**********
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C       ENTER TITLE OF DATA SET HERE
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
```

```
95    READ(10,701)ITITLE
CULLY'S ECHO
      WRITE(1,701)ITITLE
701   FORMAT(80A1)
      WRITE(3,702)ITITLE
702   FORMAT(' ',//,' TITLE: ',//' ',80A1,/)
C--------NGAGES = NUMBER OF RAIN GAGES IN THE WATERSHED
C--------NHOURR = NUMBER OF HOURS OF RAINFALL
C--------NHOURC = NUMBER OF HOURS OF SIMULATION
C--------INTPCS = TIME INTERVAL OF PRECIPITATION RECORDS
C--------SMCWS = ANTECEDENT SOIL MOISTURE OF THE WATERSHED AS A FRACTION
C                OF FIELD CAPACITY
C              = 0  IF ANTECEDENT SOIL MOISTURE IS CALCULATED INTERNALLY
C              = -1.0  IF ANTECEDENT SOIL MOISTURE IS GIVEN FOR EACH
C                      HRU (OR ELEMENT)
      READ(4,7)NGAGES,NHOURR,NHOURC,INTPCS,SMCWS
CULLY'S ECHO
      WRITE(1,7)NGAGES,NHOURR,NHOURC,INTPCS,SMCWS
7     FORMAT(4I10,F10.2)
C--------NSTART = STARTING TIME OF STORM
C--------MONTH = MONTH IN WHICH STORM OCCURS
C--------NDAY = DAY IN WHICH STORM OCCURS
C--------NYEAR = YEAR IN WHICH STORM OCCURS
      READ(4,29)NSTART,MONTH,NDAY,NYEAR
CULLY'S ECHO
      WRITE(1,29)NSTART,MONTH,NDAY,NYEAR
29    FORMAT(4I5)
C--------NSECR = NUMBER OF SECONDS OF RAINFALL
      NSECR=3600*NHOURR
C--------NPCINT = NUMBER OF PRECIPITATION INTERVALS FOR THE STORM
      NPCINT=NSECR/INTPCS
C--------INTPCM = PRECIPITATION TIME INTERVAL IN MINUTES
      INTPCM=INTPCS/60
C--------PCINTH = PRECIPITATION TIME INTERVAL IN HOURS
      PCINTH=INTPCM/60.0
      NSECC=3600*NHOURC
      DO 12 I=1,NGAGES
C--------PRECIP = PRECIPITATION RECORDS FOR EACH RAIN GAGE AND
C           TIME INTERVAL
      READ(4,9)(PRECIP(I,JX),JX=1,NPCINT)
CULLY'S ECHO
12    WRITE(1,9)(PRECIP(I,JX),JX=1,NPCINT)
9     FORMAT(8F10.5)
      IF(NGAGES.EQ.1)GO TO 50
C--------NRGAGE = NUMBER OF RAIN GAGE AFFECTING A GIVEN ELEMENT;
C           NOT NECESSARY WHEN NGAGES=1
      READ(4,8)(NRGAGE(L),L=1,80)
CULLY'S ECHO
      WRITE(1,8)(NRGAGE(L),L=1,80)
8     FORMAT(80I1)
      GO TO 52
50    DO 53 L=1,80
53    NRGAGE(L)=1
52    CONTINUE
C--------GINDEX = SEASONAL ADJUSTMENT FACTORS FOR INFILTRATION
      READ(4,55)(GINDEX(I),I=1,12)
CULLY'S ECHO
```

```
      WRITE(1,55)(GINDEX(I),I=1,12)
      IF((IFIX(SMCWS*1000.0).LT.0).OR.SMCWS.GT.0.0)GO TO 54
C--------EVP = MONTHLY EVAPORATION
      READ(4,55)(EVP(I),I=1,12)
CULLY'S ECHO
      WRITE(1,55)(EVP(I),I=1,12)
55    FORMAT(12F6.2)
C--------DAILPC = DAILY RAINFALL FOR 30 DAYS PRECEDING EVENT FOR EACH
C                 RAINGAGE
      DO 58 J=1,NGAGES
      READ(4,56)(DAILPC(J,I),I=1,30)
CULLY'S ECHO
      WRITE(1,56)(DAILPC(J,I),I=1,30)
56    FORMAT(10F8.5)
58    CONTINUE
54    CONTINUE

C*************DATA SET NUMBER 3:  INDEXING CONTROL FOR HRUS*************
C--------NTSS = NUMBER OF SUB-SHEDS IN THE WATERSHED
C--------NTELES = TOTAL NUMBER OF ELEMENTS IN THE WATERSHED
C--------NDHRUS = NUMBER OF DIFFERENT TYPES OF HRU'S IN THE WATERSHED
C--------NLANUS=NUMBER OF DIFFERENT TYPES OF LAND USES IN THE WATERSHED
      READ(2,1)NTSS,NTELES,NDHRUS,NLANUS
CULLY'S ECHO
      WRITE(1,1)NTSS,NTELES,NDHRUS,NLANUS
1     FORMAT(4I10)
      DO 6 I=1,NTELES
C--------NHRU = NUMBER OF HRU'S IN A GIVEN ELEMENT
      READ(2,3)NHRU(I)
CULLY'S ECHO
      WRITE(1,3)NHRU(I)
3     FORMAT(I10)
      N=NHRU(I)
C--------IHRU = IDENTIFYING NUMBER OF AN HRU FOR A GIVEN ELEMENT
      READ(2,4)(IHRU(I,J),J=1,N)
CULLY'S ECHO
      WRITE(1,4)(IHRU(I,J),J=1,N)
4     FORMAT(10I8)
C--------FHRU = AREA OF AN HRU AS A FRACTION OF A GIVEN ELEMENT
      READ(2,5)(FHRU(I,J),J=1,N)
CULLY'S ECHO
6     WRITE(1,5)(FHRU(I,J),J=1,N)
5     FORMAT(10F8.4)
C************DATA SET NUMBER 4:  DESCRIPTION OF HRU PROPERTIES***********
C--------AFLU = VALUE OF 'A' IN HOLTAN'S EQUATION FOR A GIVEN LAND USE
C           TYPE
      READ(2,33)(AFLU(I),I=1,NLANUS)
CULLY'S ECHO
      WRITE(1,33)(AFLU(I),I=1,NLANUS)
C--------DSLU = POTENTIAL DEPRESSION STORAGE NOR A GIVEN LAND USE TYPE
      READ(2,33)(DSLU(I),I=1,NLANUS)
CULLY'S ECHO
      WRITE(1,33)(DSLU(I),I=1,NLANUS)
C--------RCLU = ROUGHNESS COEFFICIENT IN MANNING'S EQUATION FOR A GIVEN
C           LAND USE TYPE
      READ(2,33)(RCLU(I),I=1,NLANUS)
CULLY'S ECHO
```

```
      WRITE(1,33)(RCLU(I),I=1,NLANUS)
33    FORMAT(8F10.2)
      DO 21 I=1,NDHRUS
C--------LANDU = LAND USE NUMBER FOR A PARTICULAR HRU
C--------FAW = AVAILABLE WATER POTENTIAL AS A FRACTION OF SOIL PROFILE
C--------FGW = GRAVITY WATER POTENTIAL AS A FRACTION OF SOIL PROFILE
C--------FC = FINAL INFILTRATION RATE
C--------DEPTH = DEPTH OF THE 'A' HORIZON
C--------SLOHRU = SLOPE CLASS OF A PARTICULAR HRU
C--------SMCHRU = ANTECEDENT SOIL MOISTURE AS A FRACTION OF FIELD
C           CAPACITY FOR EACH INDIVIDUAL HRU
C--------XKUSLE = ERODIBILITY FACTOR K FROM USLE EQUATION
C--------CUSLE = CROPPING-MANAGEMENT FACTOR C FROM USLE EQUATION
C--------PUSLE = CONTOURING FACTOR P FROM USLE EQUATION
C--------NSOIL = SOIL TYPE NUMBER FOR EACH HRU
      READ(2,22)LANDU(I),FAW(I),FGW(I),FC(I),DEPTH(I),SLOHRU(I),
     &SMCHRU(I),XKUSLE(I),CUSLE(I),PUSLE(I),NSOIL(I)
CULLY'S ECHO
21    WRITE(1,22)LANDU(I),FAW(I),FGW(I),FC(I),DEPTH(I),SLOHRU(I),
     &SMCHRU(I),XKUSLE(I),CUSLE(I),PUSLE(I),NSOIL(I)
22    FORMAT(I5,4F8.3,5X,A1,4F8.3,I5)
C*****DATA SET NUMBER 5:  TIME INCREMENTS AND ORDERING OF CHANNELS******
C--------DTO = TIME INCREMENT FOR OVERLAND FLOW CALCULATIONS IN SECONDS
C--------DTC = TIME INCREMENT FOR CHANNEL FLOW CALCULATIONS IN SECONDS
      READ(2,51)DTO,DTC
CULLY'S ECHO
      WRITE(1,51)DTO,DTC
51    FORMAT(2F10.0)
      IF(NTSS.EQ.1)GO TO 40
      NTSSX=NTSS+1
C--------BOUNDARY CONDITION CODE FOR CHANNEL; NOT NECESSARY WHEN NTSS=1
C             NODE1=0; DISCHARGE IS ZERO AT UPSTREAM NODE OF CHANNEL
C                  =1; UPSTREAM NODE OF CHANNEL IS DOWNSTREAM FROM A
C                      STREAM CONFLUENCE
      READ(2,25)(NODE1(I),I=1,NTSSX)
CULLY'S ECHO
      WRITE(1,25)(NODE1(I),I=1,NTSSX)
25    FORMAT(16I5)
      DO 30 I=1,NTSSX
      IF(NODE1(I).EQ.0)GO TO 30
C--------NCONF1 = NUMBER OF FIRST CHANNEL ENTERING CONFLUENCE
C--------NCONF2 = NUMBER OF SECOND CHANNEL ENTERING CONFLUENCE
      READ(2,35)NCONF1(I),NCONF2(I)
CULLY'S ECHO
      WRITE(1,35)NCONF1(I),NCONF2(I)
35    FORMAT(2I5)
30    CONTINUE
      GO TO 40
C**********DATA SET NUMBER 6: VALUES FOR SEDIMENT CALCULATIONS*********
C--------NSED = INDEX INDICATING IF SEDIMENT CALCULATIONS ARE DESIRED.
C               IF NSED=1, SEDIMENT CALCULATIONS ARE PERFORMED.
   94 READ(2,125)NSED
CULLY'S ECHO
      WRITE(1,125)NSED
  125 FORMAT(I5)
      IF(NSED.EQ.0)GO TO 40
C--------NST = NUMBER OF SOIL TYPES IN THE WATERSHED
```

```
C--------NPART = NUMBER OF PARTICLE TYPES IN A PARTICULAR SOIL
C--------DIA = DIAMETER OF A PARTICULAR PARTICLE TYPE (MM)
C--------SG = SPECIFIC GRAVITY OF A PARTICULAR PARTICLE TYPE
C--------TYPE = AMOUNT OF PARTICLE TYPE AS A FRACTION OF TOTAL AMOUNT OF
C               SOIL (EXPRESSED AS A DECIMAL)
      READ(2,130)NST
CULLY'S ECHO
      WRITE(1,130)NST
  130 FORMAT(I5)
         DO 135 I=1,NST
         READ(2,131)NPART(I)
CULLY'S ECHO
         WRITE(1,131)NPART(I)
  131    FORMAT(I5)
         K=NPART(I)
            DO 133 J=1,K
            READ(2,132)DIA(J,I),SG(J,I),TYPE(J,I)
CULLY'S ECHO
            WRITE(1,132)DIA(J,I),SG(J,I),TYPE(J,I)
  132       FORMAT(3F10.3)
  133       CONTINUE
  135    CONTINUE
      GO TO 40
C********DATA SET NUMBER 7:  OVERLAND FLOW ELEMENT DESCRIPTORS**********
C--------NSTRPS = NUMBER OF STRIPS IN A GIVEN OVERLAND FLOW PLANE
98    READ(2,89)NSTRPS
CULLY'S ECHO
      WRITE(1,89)NSTRPS
89    FORMAT(I5)
C--------NESTRP = NUMBER OF ELEMENTS IN A GIVEN STRIP
      READ(2,88)(NESTRP(K),K=1,NSTRPS)
CULLY'S ECHO
      WRITE(1,88)(NESTRP(K),K=1,NSTRPS)
88    FORMAT(16I5)
      GO TO 40
97    DO 70 I=1,NE
C--------XLEN = LENGTH OF THE ELEMENT IN A GIVEN STRIP
C--------RELIEF = RELIEF OF THE ELEMENT IN A GIVEN STRIP
C--------AREA = AREA, IN ACRES, OF THE ELEMENT IN A GIVEN STRIP
C--------TWIDTH = TOP WIDTH OF THE DOWNSTREAM NODE OF THE ELEMENT IN A
C           GIVEN STRIP
C--------NDAMS = NUMBER OF DAMS IN A GIVEN STRIP (SAME VALUE FOR EACH
C           ELEMENT IN THE STRIP)
      READ(2,75)XLEN(I),RELIEF(I),AREA(I),TWIDTH(I+1),NDAMS
CULLY'S ECHO
70    WRITE(1,75)XLEN(I),RELIEF(I),AREA(I),TWIDTH(I+1),NDAMS
75    FORMAT(2F10.0,F10.1,F10.0,I10)
      IF(NDAMS.EQ.0)GO TO 120
C*******DATA SET NUMBER 8:  FLOOD-DETENTION STRUCTURE PROPERTIES********
      DO 110 J=1,NDAMS
C--------AREDAM = AREA, IN ACRES, OF A FLOOD-DETENTION STRUCTURE
C           DRAINAGE AREA LOCATED WITHIN A GIVEN ELEMENT
      READ(2,111)(AREDAM(J,I),I=1,NE)
CULLY'S ECHO
      WRITE(1,111)(AREDAM(J,I),I=1,NE)
111   FORMAT(8F10.1)
C--------XLENDM = LENGTH OF THE FLOOD-DETENTION STRUCTURE DRAINAGE
```

```
C           ELEMENT
C--------RELDAM = RELIEF OF THE FLOOD-DETENTION STRUCTURE DRAINAGE
C           ELEMENT
C--------TWDAM = TOP WIDTH OF THE DOWNSTREAM NODE OF THE FLOOD-
C           DETENTION STRUCTURE DRAINAGE ELEMENT
C--------NLEVLS = NUMBER OF VOLUME-DISCHARGE LEVELS DESCRIBING
C           THE DISCHARGE HYDROGRAPH OF THE FLOOD-DETENTION STRUCTURE
      READ(2,112)XLENDM(J),RELDAM(J),TWDAM(J+1),NLEVLS(J)
CULLY'S ECHO
      WRITE(1,112)XLENDM(J),RELDAM(J),TWDAM(J+1),NLEVLS(J)
112   FORMAT(3F10.0,I10)
      NLS=NLEVLS(J)
C--------VOLD = VOLUME, IN ACRE-FEET, OF THE DETENTION POND FOR
C           A GIVEN VOLUME-DISCHARGE LEVEL
      READ(2,114)(VOLD(J,K),K=1,NLS)
CULLY'S ECHO
      WRITE(1,114)(VOLD(J,K),K=1,NLS)
114   FORMAT(8F10.0)
C--------QQD = DISCHARGE FROM THE FLOOD-DETENTION STRUCTURE FOR
C           A GIVEN VOLUME-DISCHARGE LEVEL
      READ(2,114)(QQD(J,K),K=1,NLS)
CULLY'S ECHO
      WRITE(1,114)(QQD(J,K),K=1,NLS)
110   CONTINUE
120   GO TO 40
C*********DATA SET NUMBER 9:  CHANNEL FLOW ELEMENT DESCRIPTORS**********
C
CHANGE(WATFIV): DOESN'T LIKE NE=0 WHICH OCCURS WHEN NESTRP=1
96    IF(NE.EQ.0)GO TO 40
      DO 90 K=1,NE
C--------XLEN = LENGTH OF THE ELEMENT IN THE CHANNEL
C--------RELIEF = RELIEF OF THE ELEMENT IN THE CHANNEL
C--------RCOEF = ROUGHNESS COEFFICIENT OF THE ELEMENT IN THE CHANNEL
C--------TWIDTH = TOP WIDTH OF THE DOWNSTREAM NODE OF THE ELEMENT
C           IN THE CHANNEL
      READ(2,71)XLEN(K),RELIEF(K),RCOEF(K),TWIDTH(K+1)
CULLY'S ECHO
90    WRITE(1,71)XLEN(K),RELIEF(K),RCOEF(K),TWIDTH(K+1)
   71 FORMAT(F10.0,F10.0,F10.4,F10.0)
40    RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END
      SUBROUTINE INTENS
C*************************************************************************
C   PURPOSE:
C
C        THE PURPOSE OF THIS SUBROUTINE IS TO DETERMINE THE MAXIMUM
C        30-MINUTE INTENSITY FOR THE STORM FOR EACH RAINGAGE.
C*************************************************************************
C
C   COMMON BLOCKS:
C
      COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
     1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
     2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
```

```
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK36/ IELE,NGREAT,KDET,XI30(4)
C
C   PROGRAM:
C
CULLY CHANGE:
      CHARACTER*1 SLOHRU
C
      DO 120 K=1,NGAGES
      NMIN = NHOURR*60
      XINT=0.0
      IF(INTPCM.GT.30)GO TO 60
C                                                    THIS BLOCK CALCULATES
C                                                       THE INTENSITY WHEN
C                                                       INTPCM IS LESS THAN
C                                                       OR EQUAL TO 30.
      XINC=30.0/FLOAT(INTPCM)
      NINC=IFIX(XINC)
      FINC=XINC-FLOAT(NINC)
         DO 20 KK=1,NINC
         SUM = PRECIP(K,KK)
   20    CONTINUE
      SUM=SUM+FINC*PRECIP(K,NINC+1)
      XINT = SUM
         SUM=SUM-(1.0-FINC)*PRECIP(K,1)+(1.0-FINC)*PRECIP(K,NINC+1)
         IF(SUM.GT.XINT)XINT=SUM
         IF(((NINC+1)*INTPCM).GT.NMIN)GO TO 100
         N=2
   40 CONTINUE
         SUM=SUM-PRECIP(K,N)+PRECIP(K,N+NINC)
         IF(SUM.GT.XINT)XINT=SUM
         N=N+1
         IF(((NINC+N)*INTPCM).LE.NMIN)GO TO 40
         GO TO 100
C                                                    THIS BLOCK CALCULATES
C                                                       THE INTENSITY WHEN
C                                                       INTPCM IS LESS THAN
C                                                       OR EQUAL TO 30.
   60 CONTINUE
         XINC=FLOAT(INTPCM)/30.0
         N=1
   70 CONTINUE
         SUM=PRECIP(K,N)/FLOAT(INTPCM)*30.0
         IF(SUM.GT.XINT)XINT=SUM
         N=N+1
         IF(FLOAT(N).GT.XINC)GO TO 100
         GO TO 70
  100 CONTINUE
      XI30(K) = XINT*2.0
C        WRITE(8,110)K,XI30(K)
C 110    FORMAT(' MAXIMUM 30-MINUTE INTENSITY FOR RAINGAGE',3X,I1,'  = '
C    &   ,F10.5)
  120 CONTINUE
      RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END
```

```
      SUBROUTINE OUTPUT (I,K,NTIME,NPRINC,NHEAD)
C     ******************************************************************
C
C    PURPOSE:
C
C        THE PUPOSE OF THIS SUBROUTINE IS TO PRINT OUT ALL INFORMATION
C    REQUESTED DURING EXECUTION OF THE PROGRAM.
C
C
C    COMMON BLOCKS:
C
      COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
     1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
     2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
      COMMON/BLK2/REFE(1,1),NRGAGE(80)
      COMMON /BLK3/ QOUT(80,1000),QCONF(4500,17),WIDINF(20)
      COMMON /BLK4/ XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11)
     &          ,QQ(11),AREA(10),VV(11),DD(11)
      COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
     &,DSLU(60),DSAC(163),ERCOEF(163)
      COMMON/BLK6/NODE1(20),NCONF1(20),NCONF2(20)
      COMMON /BLK8/ SLOPE(10),RCOEF(10),RELIEF(10)
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK10/ FAW(163),FGW(163),DEPTH(163),AFLU(60),SMCHRU(163)
      COMMON /BLK11/ NESTRP(20)
      COMMON /BLK13/ NPOVER(40),NPCHAN(40),NPSTRP(40,40)
      COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
     &DIA(8,163),TYPE(8,163)
      COMMON /BLK35/ QSED(8,11),TOTSED,ACCSED
C
C    PROGRAM:
C
      DIMENSION NUMBER(24),QP(200,4),AAP(200,4),VVP(200,4),DDP(200,4
     &),NPER(163)
CULLY CHANGE: SLOHRU DEFINED AS CHARACTER
      CHARACTER*1 SLOHRU
C
CHANGE(WATFIV): INITIALIZING TWIDTH(1) WHICH IS UNDEFINED BECAUSE
C               WHEN IT IS READ IN IT IS ASSIGNED SUBSCRIPT (I+1)
      TWIDTH(1)=0.0
C
      GO TO (200,100,580,600,700,420,20,360,1220), NZIP
C                                                  THIS BLOCK IS CALLED BY
C                                                     SUBROUTINE START AND
C                                                     IS EXECUTED ONCE. IT
C                                                     PRINTS THE STORM
C                                                     DATE, TIME, AND THE
C                                                     INITIAL MOISTURE
C                                                     CONDITION OF THE
C                                                     WATERSHED.
20    WRITE(3,40) MONTH,NDAY,NYEAR
40    FORMAT (1X,13HSTORM EVENT--,I2,1H/,I2,1H/,I2)
      WRITE(3,60) NSTART
60    FORMAT (1X,15HSTARTING TIME--,I2,3H:00)
```

```
      IF(SMCWS.EQ.0.0)GO TO 90
      IF(SMCWS.LT.0.0)GO TO 95
      NPERCT=IFIX(100.0*SMCWS+0.5)
      WRITE(3,80) NPERCT
80    FORMAT (1X,46HINITIAL MOISTURE CONDITION FOR THE WATERSHED--,I3,19
     &H% OF FIELD CAPACITY)
      GO TO 1320
   90 CONTINUE
      WRITE(3,92)
   92 FORMAT(1X,'INITIAL MOISTURE CONDITION FOR THE WATERSHED-- DETERMIN
     &ED INTERNALLY FOR EACH HRU')
      GO TO 1320
   95 CONTINUE
      WRITE(3,96)
   96 FORMAT(//,' INITIAL MOISTURE CONDITION OF THE WATERSHED:',/)
         DO 99 I=1,NDHRUS
         NPER(I)=IFIX(100.0*SMCHRU(I)+0.5)
         WRITE(3,97)I,NPER(I)
   97    FORMAT(50X,'HRU(',I3,') --- ',I3,'% OF FIELD CAPACITY')
   99    CONTINUE
         GO TO 1320
C                                                    THIS BLOCK IS CALLED BY
C                                                       SUBROUTINE START IF
C                                                       NTBLHS = 1. IT IS
C                                                       EXECUTED ONCE AND
C                                                       PRINTS A TABLE OF
C                                                       HRU DESCRIPTIONS.
100   WRITE(3,120)
120   FORMAT (1H1,46X,36HSUMMARY OF HYDROLOGIC RESPONSE UNITS)
      WRITE(3,140)
140   FORMAT(//2X,'HRU',1X,'LANDUSE',1X,'SLOPE',1X,'MANNINGS',1X,'DEPRES
     1SION',1X,'HOLTANS',1X,'FRACTION OF',3X,'FRACTION OF',4X,'EXPONENT'
     2,4X,'FINAL INFIL-',3X,'DEPTH OF THE',4X,'MAXIMUM'/3X,'NO',4X,'NO',
     33X,'CLASS',5X,'N',6X,'STORAGE',5X,'A',4X,'AVAIL WATER',2X,'GRAVITY
     4 WATER',7X,'C',7X,'TRATION RATE',5X,'A HORIZON',5X,'STORAGE'/'  ')
      DO 160 I=1,NDHRUS
      J=LANDU(I)
160   WRITE(3,180)I,LANDU(I),SLOHRU(I),ERCOEF(I),DEPSTO(I),AFAC(I),
     1FAW(I),FGW(I),CEXP(I),FC(I),DEPTH(I),STOMAX(I)
180   FORMAT(I5,I6,5X,A1,F9.3,3F10.3,3X,F10.3,5X,F10.3,4X,F10.3,5X,F10.2
     1,2X,F10.2)
      GO TO 1320
C                                                    THIS BLOCK PRINTS THE
C                                                       PRECIPITATION FOR
C                                                       EACH RAINGAGE FOR
C                                                       EACH INCREMENT OF
C                                                       THE STORM.
200   DO 340 I=1,NGAGES
      WRITE(3,220) I,INTPCM
220   FORMAT (1H1,48X,33HPRECIPITATION FOR RAINGAGE NUMBER,I2,/,45X,8HFO
     &R EACH,1X,I2,30H-MINUTE INCREMENT OF THE STORM)
      AINT=NPCINT
      NTAB=AINT/24.0+.99
      NUMTAB=1
      L=0
      LH=1
      DO 340 MN=1,NTAB
```

```
      WRITE(3,240)
240   FORMAT (//39X,56HPRECIPITATION INCREMENTS FROM THE BEGINNING OF TH
     &E STORM)
      DO 260 M=1,24
      L=L+1
260   NUMBER(M)=L
      WRITE(3,280) NUMBER
280   FORMAT (4X,24I5)
      WRITE(3,300)
300   FORMAT (/60X,13HPRECIPITATION)
      KH=24*MN
      IF (MN.EQ.NTAB) KH=NPCINT
      WRITE(3,320) (PRECIP(I,K),K=LH,KH)
320   FORMAT (5X,24F5.2)
      LH=KH+1
340   CONTINUE
      GO TO 1320
C                                                    THIS BLOCK PRINTS THE
C                                                       ROUTING TIME INCRE-
C                                                       MENTS FOR OVERLAND
C                                                       AND CHANNEL FLOW. IT
C                                                       IS CALLED BY THE
C                                                       MAIN PROGRAM.
360   NDTO=IFIX(DTO)
      NDTC=IFIX(DTC)
      WRITE(3,380) NDTO
380   FORMAT (1H1,1X,42HROUTING TIME INCREMENT FOR OVERLAND FLOW--,I4,1X
     &,7HSECONDS)
      WRITE(3,400) NDTC
400   FORMAT (1X,41HROUTING TIME INCREMENT FOR CHANNEL FLOW--,I4,1X,7HSE
     &CONDS)
      GO TO 1320
C
420   IF (NTIME.GT.NPRINC) GO TO 580
      IF (NHEAD.EQ.1) GO TO 460
      WRITE(3,440) NSSHED
440   FORMAT (1H1,41X,45HOVERLAND FLOW INFORMATION FOR SUB-SHED NUMBER,I
     &3)
      NHEAD=1
460   WRITE(3,480)
480   FORMAT (//6X,13HOVERLAND FLOW,10X,7HELEMENT,7X,7HELEMENT,7X,7HELEM
     &ENT,4X,7HELEMENT,4X,7HELEMENT,5X,7HELEMENT,12X,4HNODE,7X,4HNODE/7X
     &,12HSTRIP NUMBER,11X,6HNUMBER,5X,12HAREA (ACRES),5X,6HLENGTH,5X,6H
     &RELIEF,5X,5HSLOPE,5X,9HMANNING N,10X,6HNUMBER,5X,5HWIDTH)
      DO 560 I=1,NE
      J=I+1
      IF (I.GT.1) GO TO 520
      WRITE(3,500) K,I,AREA(I),XLEN(I),RELIEF(I),SLOPE(I),RCOEF(I),J,TW
     &IDTH(J)
500   FORMAT (11X,I2,18X,I2,9X,F7.1,8X,F7.1,4X,F6.1,6X,F5.3,7X,F5.3,14X,
     &I2,5X,F7.1)
      GO TO 560
520   WRITE(3,540) I,AREA(I),XLEN(I),RELIEF(I),SLOPE(I),RCOEF(I),J,TWID
     &TH(J)
540   FORMAT (31X,I2,9X,F7.1,8X,F7.1,4X,F6.1,6X,F5.3,7X,F5.3,14X,I2,5X,F
     &7.1)
560   CONTINUE
```

```
580   IF (NPOVER(NSSHED).EQ.1) GO TO 1120
      GO TO 720
600   IF (NTIME.GT.NPRINC) GO TO 700
      WRITE(3,620) NSSHED
620   FORMAT (1H1,41X,44HCHANNEL FLOW INFORMATION FOR SUB-SHED NUMBER,I3
     &)
      WRITE(3,640)
640   FORMAT (//15X,7HELEMENT,7X,7HELEMENT,7X,7HELEMENT,7X,7HELEMENT,8X,
     &7HELEMENT,12X,4HNODE,7X,17HNODE TOP WIDTH AT/16X,6HNUMBER,8X,6HLEN
     &GTH,8X,6HRELIEF,8X,5HSLOPE,8X,9HMANNING N,10X,6HNUMBER,9X,10H2 FT
     &DEPTH)
      DO 680 K=1,NE
      L=K+1
      WRITE(3,660) K,XLEN(K),RELIEF(K),SLOPE(K),RCOEF(K),L,TWIDTH(L)
660   FORMAT (17X,I2,10X,F7.1,7X,F6.1,9X,F5.3,10X,F5.3,14X,I2,13X,F5.1)
680   CONTINUE
700   IF (NPCHAN(NSSHED).EQ.1) GO TO 1120
720   IF (NTIME.GT.NPRINC) GO TO 940
      L=1
      LL=2
      LLL=3
      LLLL=4
      NWRITE=4
      IF (NN.GE.4) GO TO 880
      NWRITE=NN
740   GO TO (760,800,840), NWRITE
760   WRITE(3,780) L
780   FORMAT (/20X,4HNODE,I3/2X,4HTIME,3X,9HDISCHARGE,2X,4HAREA,2X,4HRAT
     &E,2X,5HDEPTH)
      GO TO 920
800   WRITE(3,820) L,LL
820   FORMAT (/20X,4HNODE,I3,24X,4HNODE,I3/2X,4HTIME,3X,9HDISCHARGE,2X,4
     &HAREA,2X,4HRATE,2X,5HDEPTH,3X,9HDISCHARGE,2X,4HAREA,2X,4HRATE,2X,5
     &HDEPTH)
      GO TO 920
840   WRITE(3,860) L,LL,LLL
860   FORMAT (/20X,4HNODE,I3,24X,4HNODE,I3,24X,4HNODE,I3/2X,4HTIME,3X,9H
     &DISCHARGE,2X,4HAREA,2X,4HRATE,2X,5HDEPTH,3X,9HDISCHARGE,2X,4HAREA,
     &2X,4HRATE,2X,5HDEPTH,3X,9HDISCHARGE,2X,4HAREA,2X,4HRATE,2X,5HDEPTH
     &)
      GO TO 920
880   WRITE(3,900) L,LL,LLL,LLLL
900   FORMAT (/20X,4HNODE,I3,24X,4HNODE,I3,24X,4HNODE,I3,24X,4HNODE,I3/2
     &X,4HTIME,3X,9HDISCHARGE,2X,4HAREA,2X,4HRATE,2X,5HDEPTH,3X,9HDISCHA
     &RGE,2X,4HAREA,2X,4HRATE,2X,5HDEPTH,3X,9HDISCHARGE,2X,4HAREA,2X,4HR
     &ATE,2X,5HDEPTH,3X,9HDISCHARGE,2X,4HAREA,2X,4HRATE,2X,5HDEPTH)
920   IF (LLLL.GT.4) GO TO 1000
940   HOUR=FLOAT(NTIME)/3600.0
      WRITE(3,960) HOUR,(QQ(I),AA(I),VV(I),DD(I),I=1,NWRITE)
960   FORMAT (1X,F5.2,4(F10.2,F8.2,F6.2,F7.2))
C     WRITE (10,980) HOUR,QQ(2)
C     WRITE (11,980) HOUR,QQ(3)
C     WRITE (12,980) HOUR,QQ(4)
C980  FORMAT (2F10.5)
      GO TO 1060
1000  NPRTS=NSECC/NPRINC
      DO 1020 NTI=1,NPRTS
```

```
      HOUR=FLOAT(NTI*NPRINC)/3600.0
1020  WRITE(3,1040) HOUR,(QP(NTI,I),AAP(NTI,I),VVP(NTI,I),DDP(NTI,I),I=
     &M,MMMM)
1040  FORMAT (1X,F5.2,4(F10.2,F8.2,F6.2,F7.2))
      IF (NN.GT.LLLL) GO TO 1100
      GO TO 1320
1060  IF (NN.LE.4) GO TO 1320
      NNA=NN-4
      TI=NTIME/NPRINC
      DO 1080 I=1,NNA
      QP(TI,I)=QQ(I+4)
      AAP(TI,I)=AA(I+4)
      VVP(TI,I)=VV(I+4)
1080  DDP(TI,I)=DD(I+4)
      IF (NTIME.LT.NSECC) GO TO 1320
1100  L=L+4
      LL=LL+4
      LLL=LLL+4
      LLLL=LLLL+4
      M=L-4
      MMMM=LLLL-4
      IF (NN.GE.LLLL) GO TO 880
      NWRITE=NN-MMMM
      MMMM=NWRITE
      GO TO 740
1120  IF (NTIME.GT.NPRINC) GO TO 1160
      WRITE(3,1140)
1140  FORMAT (/5X,50HFLOW CHARACTERISTICS AT THE LAST NODE OF THE STRIP
     &//60X,'SEDIMENT LOAD',8X,'ACCUMULATED SEDIMENT',5X,'SEDIMENT CONCE
     &NTRATION',
     &/6X,4HTIME,3X,9HDISCHARGE,4X,4HAREA,6X,4HRATE,5X,5HDEPTH,8X,
     &'(LBS)',6X,'(GRAMS)',12X,'(GRAMS)',19X,'(MG/L)')
1160  HOUR=FLOAT(NTIME)/3600.0
      QQTT=QQ(NN)*92.5
      TINIM=HOUR*60.
C      WRITE (4,1180) HOUR,QQ(NN)
C1180  FORMAT (2F10.5)
C             SEDRAT = TOTAL SEDIMENT FROM THE STRIP IN LBS/SEC
C             TOTSED = TOTAL SEDIMENT FROM THE STRIP IN LBS
C             GRAMS = TOTAL SEDIMENT IN GRAMS
C             SEDCON = SEDIMENT CONCENTRATION IN LBS/CU FT
C             CONMET = SEDIMENT CONCENTRATION IN MG/L
C             ACCSED = ACCUMULATED SEDIMENT IN GRAMS
C
        IF(QQ(NN).LE.0.0)GO TO 1195
        SEDRAT=0.0
        DO 1190 J=1,NTYPE
        SEDRAT=SEDRAT+(QSED(J,NE)*TWIDTH(NE))
 1190   CONTINUE
        GRAMS=TOTSED*453.5924
        ACCSED=ACCSED+GRAMS
        SEDCON=SEDRAT/QQ(NN)
        CONMET=SEDCON*16016.596
        GO TO 1199
 1195   CONTINUE
        SEDCON=0.0
        CONMET=0.0
```

```
 1199    CONTINUE
C
      WRITE(3,1200) HOUR,QQ(NN),AA(NN),VV(NN),DD(NN),TOTSED,GRAMS,
     &ACCSED,CONMET
1200  FORMAT (5F10.4,F15.8,1X,F15.8,4X,F15.8,11X,F15.8)
         TOTSED=0.0
      GO TO 1320
1220  WRITE(3,1240) NTSSX
1240  FORMAT (1H1,42X,42HCHANNEL FLOW FOR IMAGINARY SUB-SHED NUMBER,I3)
      WRITE(3,1260)
1260  FORMAT (/56X,4HTIME,3X,9HDISCHARGE)
      NPRTS=NSECC/NPRINC
      DO 1280 NTI=1,NPRTS
      HOUR=FLOAT(NTI*NPRINC)/3600.0
      JT=NTI*NCPRIN/IFIX(DTC)
      NPC1=NCONF1(NTSSX)
      NPC2=NCONF2(NTSSX)
      QQX=QCONF(JT,NPC1)+QCONF(JT,NPC2)
1280  WRITE(3,1300) HOUR,QQX
1300  FORMAT (50X,2F10.2)
1320  RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END
      SUBROUTINE OVERL (KN)
C     ***********************************************************************
C
C   PURPOSE:
C
C        THE PURPOSE OF THIS SUBROUTINE IS TO
C
C   COMMON BLOCKS:
C
       COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
      1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
      2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
       COMMON /BLK2/ REFE(1,1),NRGAGE(80)
       COMMON /BLK3/ QOUT(80,1000),QCONF(4500,17),WIDINF(20)
       COMMON /BLK4/ XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11)
      &          ,QQ(11),AREA(10),VV(11),DD(11)
       COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
      &,DSLU(60),DSAC(163),ERCOEF(163)
       COMMON /BLK8/ SLOPE(10),RCOEF(10),RELIEF(10)
       COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
      &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
      &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
      &NHOURC,NDAMS,NTSSX,NOWTIM
       COMMON /BLK11/ NESTRP(20)
       COMMON /BLK13/ NPOVER(40),NPCHAN(40),NPSTRP(40,40)
       COMMON /BLK14/ AREDAM(2,10),XLENDM(2),RELDAM(2),TWDAM(2),NLEVLS(2)
      &,VOLD(2,10),QQD(2,10)
       COMMON /BLK21/ STOI(163)
       COMMON /BLK22/ PL(10),RQQ(10)
       COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
      &DIA(8,163),TYPE(8,163)
       COMMON /BLK35/ QSED(8,11),TOTSED,ACCSED
C
C   PROGRAM:
```

```
C
      DIMENSION HYDRAD(11),TAREAD(2),RCDAM(2),SLODAM(2),VOLDAM(2)
     &,QQDAM(2),AADAM(2),DDDAM(2),HRDAM(2),VVDAM(2),QQR(2),REFELE(10),RQ
     &DAM(2),REDAM(2)
CULLY CHANGE
      CHARACTER*1 SLOHRU
C
      NPRINC=NOPRIN
      NZIP=2
      CALL INPUT
      DT=DTO
      NHEAD=0
      INIT=0
C                                                    THIS LOOP IS EXECUTED
C                                                       FOR EACH STRIP IN
C                                                       THE OVERLAND FLOW
C                                                       PLANE.
      DO 420 K=1,NSTRPS
C                                                    THIS STATEMENT CALLS
C                                                       SEDBEG TO INITIALIZE
C                                                       VARIABLES REQUIRED
C                                                       FOR SEDIMENT CALCU-
C                                                       LATIONS.
C
CHANGE(WATFIV):  WHEN SEDBEG IS CALLED THERE IS NO VALUE FOR NN
      NE=NESTRP(K)
      NN=NE+1
C
C
      IF(NSED.EQ.1)CALL SEDBEG
      NTIME=0
      NE=NESTRP(K)
      NN=NE+1
      NZIP=3
      CALL INPUT
C                                                    THIS LOOP CALCULATES
C                                                       SLOPE AND ROUGHNESS
C                                                       COEFFICIENT FOR EACH
C                                                       ELEMENT.
      DO 40 I=1,NE
         PL(I)=0.
         SLOPE(I)=RELIEF(I)/XLEN(I)
         RCOEF(I)=0.0
         L=NELEM+I
CULLY          MHRU=NHRU(L)
CULLY          DO 20 N=1,MHRU
CULLY             J=IHRU(L,N)
CULLY             M=LANDU(J)
CULLY             RCOEF(I)=RCOEF(I)+(RCLU(M)*FHRU(L,N))
CULLY   20     CONTINUE
CULLY CHANGE:
         RCOEF(I)=ERCOEF(L)
C
   40 CONTINUE
C                                                    THIS LOOP INITIALIZES
C                                                       THE VALUES OF INIT-
C                                                       IAL X-SECTIONAL AREA
```

```
C                                                          AND VOLUME OF FLOW
C                                                          AT EACH NODE.
      DO 60 I=1,NN
         AO(I)=0.0
         QO(I)=0.0
   60 CONTINUE
C                                                       THIS LOOP COMPUTES THE
C                                                          VALUES OF VARIABLES
C                                                          OF ANY FLOOD-DETEN-
C                                                          TION STRUCTURES IN
C                                                          THE FLOW STRIP.
      IF (NDAMS.EQ.0) GO TO 140
         DO 120 J=1,NDAMS
            AADAM(J)=0.0
            QQDAM(J)=0.0
            VOLDAM(J)=0.0
            TAREAD(J)=0.0
            RCDAM(J)=0.0
            SLODAM(J)=RELDAM(J)/XLENDM(J)
            DO 80 I=1,NE
               TAREAD(J)=TAREAD(J)+AREDAM(J,I)
   80       CONTINUE
            DO 100 I=1,NE
               RCDAM(J)=RCDAM(J)+((AREDAM(J,I)/TAREAD(J))*RCOEF(I))
  100       CONTINUE
  120    CONTINUE
  140 CONTINUE
C                                                       THIS LOOP COMPUTES THE
C                                                          RAINFALL EXCESS FROM
C                                                          EACH ELEMENT USING
C                                                          SUBROUTINE HOLTAN.
C                                                          IT ALSO COMPUTES THE
C                                                          LATERAL INFLOW TO
C                                                          EACH ELEMENT IN THE
C                                                          FLOW STRIP.
         DO 160 KE=1,NE
            L=NELEM+KE
            I=NRGAGE(L)
            J=NTIME/INTPCS+1
            IF (INIT.EQ.0) STO(KE)=STOI(L)
            CALL HOLTAN (L,KE,I,J,DTO,INTPCS,MONTH)
            RQQ(KE)=ELEXC(KE)*43560.*AREA(KE)/(XLEN(KE)*DTO*12.)
  160    CONTINUE
         INIT=1
C                                                       THIS LOOP CALCULATES
C                                                          THE LATERAL INFLOW
C                                                          TO EACH DAM.
         IF (NDAMS.EQ.0) GO TO 220
            DO 200 J=1,NDAMS
               REDAM(J)=0.0
               DO 180 I=1,NE
                  REDAM(J)=REDAM(J)+((AREDAM(J,I)/TAREAD(J))*REFELE(I))
  180          CONTINUE
               RQDAM(J)=(REDAM(J)/(DTO*12.0))*((43560.0*TAREAD(J))/
     &                        XLENDM(J))
  200       CONTINUE
  220    CONTINUE
```

```
C                                                    THIS BLOCK CALLS ASSEMB
C                                                       TO ASSEMBLE ELEMENTS
C                                                       AND ROUTE FLOWS. IF
C                                                       REQUESTED, SEDCAL IS
C                                                       CALLED TO EXECUTE
C                                                       SEDIMENT CALCU-
C                                                       LATIONS.
C
         CALL ASSEMB (NE,NN,DTO,K,KN)
      NOWTIM=NTIME
      IF(NSED.EQ.1)CALL SEDCAL
C        WRITE(8,230)TOTSED
C 230    FORMAT(F15.8)
C                                                    THIS BLOCK INCREMENTS
C                                                       THE ELAPSED TIME OF
C                                                       SIMULATION.
         NTIME=NTIME+IFIX(DTO)
         JT=NTIME/IFIX(DTO)
C                                                   THIS STATEMENT DETERMINE
         QOUT(K,JT)=QQ(NN)/TWIDTH(NN)
C                                                    THIS BLOCK EXECUTES
C                                                       CALCULATIONS FOR ANY
C                                                       DAMS IN THE FLOW
C                                                       STRIP.
         IF (NDAMS.EQ.0) GO TO 340
            DO 300 J=1,NDAMS
               AADAM(J)=AADAM(J)-(DT*((QQDAM(J)/XLENDM(J))-RQDAM(J)))
               DDDAM(J)=AADAM(J)/TWDAM(J+1)
               HRDAM(J)=DDDAM(J)
               VVDAM(J)=(1.49*SQRT(SLODAM(J))*HRDAM(J)**0.67)/RCDAM(J)
               QQDAM(J)=VVDAM(J)*AADAM(J)
               VOLDAM(J)=VOLDAM(J)+QQDAM(J)*DT
               NLS=NLEVLS(J)
               DO 240 L=2,NLS
                  IF (VOLDAM(J)-(43560.0*VOLD(J,L))) 280,260,240
  240          CONTINUE
C
  260          CONTINUE
                  QQR(J)=QQD(J,L)
                  GO TO 300
  280          CONTINUE
                  QQR(J)=QQD(J,L)-((QQD(J,L)-QQD(J,L-1))*
     &               (((43560.0*VOLD(J,L))-VOLDA
     &               M(J))/(43560.0*(VOLD(J,L)-VOLD(J,L-1)))))
  300       CONTINUE
            QQRALL=0.0
            DO 320 J=1,NDAMS
               VOLDAM(J)=VOLDAM(J)-QQR(J)*DT
               QQRALL=QQRALL+QQR(J)
  320       CONTINUE
            QOUT(K,JT)=QOUT(K,JT)+QQRALL/TWIDTH(NN)
  340    CONTINUE
C                                                   THIS BLOCK DETERMINES
C                                                       IF SUBROUTINE OUTPUT
C                                                       IS CALLED OR NOT.
         IF (NTIME/NOPRIN*NOPRIN.NE.NTIME) GO TO 380
         IF (NPOVER(NSSHED).EQ.0) GO TO 380
```

```
          IF (NPOVER(NSSHED).EQ.1) GO TO 360
          IF (NPSTRP(NSSHED,K).EQ.0) GO TO 380
C
  360     CONTINUE
             NZIP=6
C      WRITE(8,370)NZIP,I,K,NTIME,NPRINC,NHEAD
C 370 FORMAT(' NZIP = ',I3,' I = ',I3,' K = ',I3,' NTIME = ',I6,
C     &' NPRINC = ',I5,' NHEAD = ',I5)
             CALL OUTPUT (I,K,NTIME,NPRINC,NHEAD)
C
  380     CONTINUE
C                                                    THIS LOOP SETS THE INI-
C                                                       TIAL VALUES OF AREA
C                                                       AND VOLUME OF FLOW
C                                                       EQUAL TO THE CALCU-
C                                                       LATED VALUES FROM
C                                                       THE PREVIOUS TIME
C                                                       STEP.
             DO 400 I=1,NN
                AO(I)=AA(I)
                QO(I)=QQ(I)
  400        CONTINUE
C                                                    THIS STATEMENT TRANS-
C                                                       FERS CONTROL TO
C                                                       STATEMENT 140 IF
C                                                       DURATION OF SIMULA-
C                                                       TION HAS NOT BEEN
C                                                       REACHED.
          IF (NTIME.GE.NSECC)GO TO 410
       GO TO 140
C
  410 CONTINUE
          NELEM=NELEM+NE
          INIT=0
420     CONTINUE
          RETURN
C      DEBUG UNIT(12),SUBCHK
          END
       SUBROUTINE ROUTE (NE,NN,DT)
C*************************************************************************
C   PURPOSE:
C
C        THE PURPOSE OF THIS SUBROUTINE IS TO ROUTE FLOWS ON THE
C   OVERLAND AND CHANNEL FLOW ELEMENTS.
C*************************************************************************
C
C   COMMON BLOCKS:
C
       COMMON/BLK4/XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11),QQ(11)
     &,AREA(10),VV(11),DD(11)
C
C
C   PROGRAM:
C
       DIMENSION SE1(2,2),S1(11,2),RE1(2),RE2(2),A1(11,11),A(121),R1(11),
     &R2(11),RC(121)
C                                                    THESE LOOPS INITIALIZE
```

```
C                                                    THE VARIABLES USED
C                                                    FOR TEMPORARY STOR-
C                                                    AGE IN THE ASSEMBLED
C                                                    MATRIX FORMULATION.
      DO 20 I=1,NN
         R1(I)=0.0
         R2(I)=0.0
   20 CONTINUE
      DO 40 I=1,NN
         DO 30 J=1,2
            S1(I,J)=0.0
   30    CONTINUE
   40 CONTINUE
C                                                  THIS BLOCK ASSIGNS
C                                                     VALUES TO VARIABLES
C                                                     IN THE ROUTING
C                                                     MATRIX.
      SE1(1,1)=2.0/3.0
      SE1(1,2)=1.0/3.0
      SE1(2,1)=SE1(1,2)
      SE1(2,2)=SE1(1,1)
      M=0
   60 CONTINUE
         M=M+1
         RE1(1)=(QO(M+1)-QO(M))/(XLEN(M))
         RE1(2)=RE1(1)
         RE2(1)=RQ(M)
         RE2(2)=RE2(1)
         R1(M)=R1(M)+RE1(1)
         R1(M+1)=R1(M+1)+RE1(2)
         R2(M)=R2(M)+RE2(1)
         R2(M+1)=R2(M+1)+RE2(2)
         S1(M,1)=S1(M,1)+SE1(1,1)
         S1(M,2)=S1(M,2)+SE1(1,2)
         S1(M+1,1)=S1(M+1,1)+SE1(2,2)
         IF (M.GE.NE) GO TO 70
      GO TO 60
   70 CONTINUE
      DO 100 I=1,NN
         A1(I,I)=S1(I,1)
         J=I+1
         IF (J.GT.NN) GO TO 120
         A1(I,J)=S1(I,2)
         A1(J,I)=A1(I,J)
         NK=J+1
         IF (NK.GT.NN) GO TO 90
            DO 80 L=NK,NN
               A1(I,L)=0.0
               A1(L,I)=0.0
   80       CONTINUE
   90    CONTINUE
  100 CONTINUE
  120 CONTINUE
C                                                  THIS LOOP COMPUTES THE
C                                                     VALUES IN THE KNOWN
C                                                     COLUMN MATRIX.
      DO 160 I=1,NN
```

```
          SUM=0.0
          DO 140 J=1,NN
             C=A1(I,J)*AO(J)/DT
             SUM=SUM+C
  140     CONTINUE
          RC(I)=SUM+R2(I)-R1(I)
  160 CONTINUE
C                                                    THIS LOOP CONVERTS THE
C                                                        A1  MATRIX FROM A
C                                                       TWO-DIMENSIONAL MA-
C                                                       TRIX TO A ONE-DIMEN-
C                                                       SIONAL MATRIX  A .
      LL=0
      LC=0
      DO 200 I=1,NN
         LL=LL+1
         LB=2
         IF (I.EQ.1.OR.I.EQ.NN) LB=1
         LE=LL+LB
         DO 180 J=LL,LE
            LC=LC+1
            A(LC)=A1(I,J)
  180    CONTINUE
         IF (I.EQ.1) LL=0
  200 CONTINUE
C                                                    THIS BLOCK SOLVES FOR
C                                                        AA , THE CALCULATED
C                                                       AREA OF FLOW AT THE
C                                                       NODES.
      CALL GELB (RC,A,NN,1,1,1,5.0E-7,IER)
      DO 220 I=1,NN
         AA(I)=RC(I)*DT
  220 CONTINUE
      RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END
      SUBROUTINE SEDBEG
C*****************************************************************************
C   PURPOSE:
C
C        THE PURPOSE OF THIS SUBROUTINE IS TO INITIALIZE VARIABLES, READ
C   IN VALUES, AND CALCULATE ANY VALUES THAT REMAIN CONSTANT DURING THE
C   SEDIMENT CALCULATIONS OF A GIVEN FLOW STRIP.
C*****************************************************************************
C
C   COMMON BLOCKS:
C
       COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
       COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
     &DIA(8,163),TYPE(8,163)
       COMMON /BLK35/ QSED(8,11),TOTSED,ACCSED
       COMMON /BLK36/ IELE,NGREAT,KDET,XI30(4)
       COMMON /BLK37/ VOLT1(12),VOLT2(12),INTER
C
```

```
C    PROGRAM:
C
C                                                        THIS BLOCK INITIALIZES
C                                                           THE VALUES OF DIS-
C                                                           CHARGE.
           DO 20 J=1,NN
           VOLT1(J)=0.0
           VOLT2(J)=0.0
   20      CONTINUE
C                                                        THIS BLOCK INITIALIZES:
C                                                           THE VALUES OF SEDI-
C                                                           MENT YIELD FROM EACH
C                                                           ELEMENT AND FOR EACH
C                                                           PARTICLE TYPE ; THE
C                                                           VALUE OF TOTAL SEDI-
C                                                           MENT LEAVING THE
C                                                           STRIP.
       DO 40 I=1,NE
       NTYPE=NPART(NSOIL(I))
          DO 30 J=1,NTYPE
          QSED(J,I)=0.0
   30     CONTINUE
   40  CONTINUE
          TOTSED=0.0
          ACCSED=0.0
       RETURN
       END

       SUBROUTINE SEDCAL
C*************************************************************************
C    PURPOSE:
C         THE PURPOSE OF THIS SUBROUTINE IS TO COORDINATE SEDIMENT
C    CALCULATIONS.
C*************************************************************************
C
C    COMMON BLOCKS:
C
       COMMON/BLK4/XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11),QQ(11)
      1,AREA(10),VV(11),DD(11)
       COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
      &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
      &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
      &NHOURC,NDAMS,NTSSX,NOWTIM
       COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
      &DIA(8,163),TYPE(8,163)
       COMMON /BLK34/ TCAP(8),POTSED(8),DITYP(8,11),DRTYP(8,11)
       COMMON /BLK35/ QSED(8,11),TOTSED,ACCSED
       COMMON /BLK36/ IELE,NGREAT,KDET,XI30(4)
       COMMON /BLK37/ VOLT1(12),VOLT2(12),INTER
C
C    PROGRAM:
C
       DIMENSION DEP(8,11)
C         WRITE(8,3)NOWTIM
C    3    FORMAT(' SIMULATION TIME INCREMENT = ',I10)
C
C                                                        THIS LOOP IS EXECUTED
```

```
C                                                       FOR EACH ELEMENT IN
C                                                       THE FLOW STRIP.
      DO 500 I=1,NE
         IELE=I
C                                                    THIS LOOP ASSIGNS THE
C                                                       THE VALUES OF DIS-
C                                                       CHARGE CALCULATED
C                                                       FOR TIME T2 OF THE
C                                                       TIME INCREMENT.
            VOLT2(I+1)=(QQ(I+1)*DTO)/(AREA(I)*43560.0)
         NS=NSOIL(I)
         NTYPE=NPART(NSOIL(I))
C             WRITE(8,7)I,NS,NTYPE
C   7        FORMAT(//,' ELEMENT NUMBER',I5,'  HAS SOIL TYPE',I5,
C    &       '  WHICH HAS',I5,'  TYPES OF PARTICLES')
C
C                                                    THIS BLOCK DETERMINES
C                                                       IF THERE IS ANY FLOW
C                                                       LEAVING THE ELEMENT.
C                                                       IF NOT, DEPOSITION
C                                                       EQUALS THE YIELD
C                                                       ENTERING FROM THE
C                                                       UPSLOPE ELEMENT, AND
C                                                       YIELD =0.0.  IF FLOW
C                                                       IS GREATER THAN 0.0,
C                                                       THE POTENTIAL SEDI-
C                                                       MENT LOAD = THE
C                                                       YIELD FROM THE UP-
C                                                       SLOPE ELEMENT.
      KDET = 0
      IF(I.GT.1)GO TO 40
C        WRITE(8,8)AA(I+1)
C   8    FORMAT(' AA = ',F15.6)
      IF(AA(I+1).GT.0.0)GO TO 20
         DO 10 J=1,NTYPE
         DEP(J,I)=0.0
         QSED(J,I)=0.0
   10    CONTINUE
      GO TO 400
   20    DO 30 J=1,NTYPE
         POTSED(J)=0.0
   30    CONTINUE
      GO TO 80
   40 CONTINUE
C        WRITE(8,8)AA(I+1)
      IF(AA(I+1).GT.0.0)GO TO 60
         DO 50 J=1,NTYPE
         DEP(J,I)=QSED(J,I-1)
         QSED(J,I)=0.0
   50    CONTINUE
         GO TO 400
   60    DO 70 J=1,NTYPE
         POTSED(J)=QSED(J,I-1)
   70    CONTINUE
C                                                    THIS BLOCK CALCULATES
C                                                       THE TRANSPORT CAPA-
C                                                       CITY OF THE FLOW AND
```

```
C                                                    COMPARES IT TO THE
C                                                    POTENTIAL SEDIMENT
C                                                    LOAD.  IF THE CAPA-
C                                                    CITY IS LESS, THEN
C                                                    DEPOSITION AND YIELD
C                                                    ARE CALCULATED.
   80 CONTINUE
C        WRITE(8,85)(POTSED(J),J=1,NTYPE)
C  85    FORMAT(' INITIAL POTSED = ',5F15.6)
      CALL TRANS
      IF(NGREAT.EQ.NTYPE)GO TO 95
         DO 90 J=1,NTYPE
         DEP(J,I)=POTSED(J)-TCAP(J)
         QSED(J,I)=TCAP(J)
   90    CONTINUE
      GO TO 400
C                                                  THIS BLOCK INCREASES
C                                                     THE POTENTIAL SEDI-
C                                                     MENT LOAD BY ADDING
C                                                     INTERRILL DETACHMENT
   95 CONTINUE
      KDET = 1
      CALL DETACH
      IF(INTER.EQ.0)GO TO 120
         DO 100 J=1,NTYPE
         POTSED(J)=POTSED(J)+DITYP(J,I)
  100    CONTINUE
C                                                  THIS BLOCK COMPARES
C                                                     CAPACITY AND LOAD.
C                                                     IF CAPACITY IS LESS,
C                                                     DEPOSITION AND YIELD
C                                                     ARE CALCULATED.
C        WRITE(8,105)(POTSED(J),J=1,NTYPE)
C 105    FORMAT(' POTSED WITH INTERRILL DETACHMENT = ',5F15.6)
      CALL TRANS
      IF(NGREAT.EQ.NTYPE)GO TO 120
         DO 110 J=1,NTYPE
         DEP(J,I)=0.0
         QSED(J,I)=TCAP(J)
  110    CONTINUE
      GO TO 400
C                                                  THIS BLOCK INCREASES
C                                                     THE POTENTIAL SEDI-
C                                                     MENT LOAD BY ADDING
C                                                     RILL DETACHMENT.
  120 KDET = 2
      CALL DETACH
         DO 130 J=1,NTYPE
         POTSED(J)=POTSED(J)+DRTYP(J,I)
  130    CONTINUE
C                                                  THIS BLOCK COMPARES
C                                                     CAPACITY AND LOAD
C                                                     AND CALCULATES
C                                                     DEPOSITION AND YIELD
C                                                     ACCORDINGLY.
C        WRITE(8,135)(POTSED(J),J=1,NTYPE)
C 135    FORMAT(' POTSED WITH RILL DETACHMENT = ',5F15.6)
```

```
      CALL TRANS
      IF(NGREAT.EQ.NTYPE)GO TO 150
         DO 140 J=1,NTYPE
         DEP(J,I)=0.0
         QSED(J,I)=TCAP(J)
  140    CONTINUE
      GO TO 400
  150    DO 160 J=1,NTYPE
         DEP(J,I)=0.0
         QSED(J,I)=POTSED(J)
  160    CONTINUE
  400 CONTINUE
C        WRITE(8,91)
C  91    FORMAT(/,' TRANSPORT CAPACITY','     DEPOSITION',
C     &   '     SEDIMENT LEAVING THE ELEMENT',/)
C        DO 93 J=1,NTYPE
C        WRITE(8,92)TCAP(J),DEP(J,I),QSED(J,I)
C  92    FORMAT(F16.8,2X,F16.8,10X,F16.8)
C  93    CONTINUE
  500 CONTINUE
C                                                    THIS LOOP CALCULATES
C                                                       THE TOTAL MASS OF
C                                                       SEDIMENT LEAVING THE
C                                                       STRIP FOR THE TIME
C                                                       INCREMENT (DTO).
         DO 550 J=1,5
         TOTSED=TOTSED+(QSED(J,NE)*TWIDTH(NE))*DTO
  550    CONTINUE
C     WRITE(8,560)TOTSED
C 560 FORMAT(' TOTSED = ',F15.8)
C                                                    THIS BLOCK ASSIGNS THE
C                                                       VALUES OF DISCHARGE
C                                                       FOR TIME T1 OF THE
C                                                       NEXT TIME INCREMENT.
         DO 600 J=1,NN
         VOLT1(J)=VOLT2(J)
  600    CONTINUE
      RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END
      SUBROUTINE START
C     **********************************************************************
C
C   PURPOSE:
C
C        THE PURPOSE OF THIS SUBROUTINE IS
C
C
C   COMMON BLOCKS:
      COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
     1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
     2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
      COMMON/BLK2/REFE(1,1),NRGAGE(80)
      COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
     &,DSLU(60),DSAC(163),ERCOEF(163)
      COMMON/BLK6/NODE1(20),NCONF1(20),NCONF2(20)
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
```

```
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK10/ FAW(163),FGW(163),DEPTH(163),AFLU(60),SMCHRU(163)
      COMMON/BLK21/STOI(163)
C
C    PROGRAM:
C
      DIMENSION SLOPCL(6),SLOPCO(6)
C*************************************************************************
CULLY CHANGE:  SLOPCL AND SLOHRU HAD TO BE CHARACTER VALUES
      CHARACTER*1 SLOPCL,SLOHRU
C*************************************************************************
      DATA SLOPCL/'A','B','C','D','E','F'/
      DATA SLOPCO/1.00,1.00,1.00,1.00,1.00,1.00/
      NZIP=5
      CALL INPUT
CULLY CHANGE
      CALL EFFHRU
C
CC      WRITE(4,13) NDHRUS,NTELES
CC13    FORMAT(1X,'START',2I3)
      NZIP=7
      CALL OUTPUT (I,K,NTIME,NPRINC,NHEAD)
C                                                    THIS LOOP DETERMINES
C                                                       THE VALUE OF
C                                                       HOLTAN'S 'A'; THE
C                                                       EXPONENT, C, USED IN
C                                                       THE INFILTRATION
C                                                       EQUATION; MAXIMUM
C                                                       STORAGE; AND INITIAL
C                                                       VALUE OF UNFILLED
C                                                       SOIL WATER STORAGE
C                                                       FOR EACH HRU.
      DO 20 I=1,NDHRUS
      ACCDP(I)=0.0
      KIHRU(I)=0
         DO 10 K=1,6
         IF(SLOPCL(K).EQ.SLOHRU(I))GO TO 15
   10    CONTINUE
   15 J=LANDU(I)
CULLY       AFAC(I)=AFLU(J)
CULLY       DEPSTO(I)=SLOPCO(K)*DSLU(J)
CULLY CHANGE:  DSAC WAS COMPUTED FOR EACH EFFECTIVE HRU (ELEMENT)
      DEPSTO(I)=SLOPCO(K)*DSAC(I)
      IF(AFAC(I).LE.0.0)GO TO 16
      CEXP(I)=FGW(I)/FAW(I)
      GO TO 17
   16 CEXP(I)=0.0
   17 STOMAX(I)=(FAW(I)+FGW(I))*DEPTH(I)
C
CHANGE(WATFIV): IF SMCWS < 0.0 STOI(I) IS USED IN IF STATEMENT BUT
C               NOT YET DEFINED, THUS AN ERROR.
      STOI(I)=0.0
C
      IF(SMCWS.GT.0.0)STOI(I)=STOMAX(I)-(SMCWS*FAW(I)*DEPTH(I))
      IF(STOI(I).LT.0.0)STOI(I)=0.0
```

```
20     CONTINUE
       IF(SMCWS.GT.0.0)GO TO 50
C                                                        THIS LOOP
       DO 45 I=1,NGAGES
CC          DO 30 L=1,NTELES
CC          IF(NRGAGE(L).NE.I)GO TO 30
CC          N=NHRU(L)
CC             DO 25 M=1,N
CC             MN=IHRU(L,M)
CC             KIHRU(MN)=I
CC    25       CONTINUE
CC    30    CONTINUE
 35       DO 44 K=1,NDHRUS
CC          IF(KIHRU(K).NE.I)GO TO 44
CULLY ADD
          IF(NRGAGE(K).NE.I)GO TO 44
C
          IF(AFAC(K).LE.0.0)GO TO 45
          SMX=SMCWS
          IF(SMCHRU(K).GT.0.0)GO TO 43
          DPAW=FAW(K)*DEPTH(K)
          XLEVEL=0.5*DPAW
          STOI(K)=STOMAX(K)-XLEVEL
             DO 41 L=1,30
             XLEVEL=XLEVEL+DAILPC(I,L)
             IF(XLEVEL.GE.STOMAX(K))XLEVEL=STOMAX(K)
             IF(XLEVEL.GE.DPAW)GO TO 36
             WOUT=0.0
             GO TO 38
    36       DEPSEP=24.0*FC(K)
             IF(L.EQ.30)DEPSEP=FLOAT(NSTART-1)*DEPSEP/24.0
             IF(DEPSEP.GT.(XLEVEL-DPAW))GO TO 37
             WOUT=DEPSEP
             GO TO 38
    37       WOUT=XLEVEL-DPAW
    38      ADJLEV=XLEVEL-WOUT
             EVPOR=EVP(MONTH)
             IF((NDAY+L).LE.30)EVPOR=EVP(MONTH-1)
             WOUT=((ADJLEV/DPAW)*EVPOR)/30.0
             IF(ADJLEV.GT.DPAW)WOUT=EVPOR/30.0
             IF(DAILPC(I,L).GT.0.0)WOUT=WOUT/2.0
             IF(L.EQ.30)WOUT=FLOAT(NSTART-1)*WOUT/24.0
             XLEVEL=ADJLEV-WOUT
             STOI(K)=STOMAX(K)-XLEVEL
    41       CONTINUE
          SMX=XLEVEL/DPAW
          IF(SMX.LE.0.0)SMX=0.0
          WRITE(3,40)K,SMX
    40    FORMAT(I10,F10.3)
          GO TO 44
    43    CONTINUE
          SMX=SMCHRU(K)
          STOI(K)=STOMAX(K)-(SMX*FAW(K)*DEPTH(K))
          IF(STOI(K).LT.0.0)STOI(K)=0.0
    44    CONTINUE
    45 CONTINUE
    50 CONTINUE
```

```
C                                                       THIS BLOCK PRINTS AN
C                                                          HRU DESCRIPTION
C                                                          TABLE, IF REQUESTED.
      IF (NTBLHS.EQ.0) GO TO 80
         NZIP=2
         CALL OUTPUT (I,K,NTIME,NPRINC,NHEAD)
80    CONTINUE
      RETURN
      END
      SUBROUTINE TRANS
C*************************************************************************
C   PURPOSE:
C
C        THE PURPOSE OF THIS SUBROUTINE IS TO COMPUTE THE TRANSPORT
C   CAPACITY FOR EACH PARTICLE TYPE; COMPARE THE TRANSPORT CAPACITY AND
C   THE POTENTIAL SEDIMENT LOAD;CALCULATE ANY EXCESS TRANSPORT CAPACITY;
C   AND DISTRIBUTE THE EXCESS AMONG THE OTHER PARTICLE TYPES.
C*************************************************************************
C
C   COMMON BLOCKS:
C
      COMMON/BLK4/XLEN(10),TWIDTH(11),RQ(10),AO(11),QO(11),AA(11),QQ(11)
     1,AREA(10),VV(11),DD(11)
      COMMON/BLK8/SLOPE(10),RCOEF(10),RELIEF(10)
      COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
     &DIA(8,163),TYPE(8,163)
      COMMON /BLK34/ TCAP(8),POTSED(8),DITYP(8,11),DRTYP(8,11)
      COMMON /BLK35/ QSED(8,11),TOTSED,ACCSED
      COMMON /BLK36/ IELE,NGREAT,KDET,XI30(4)
C
C   PROGRAM:
C
      DIMENSION RAD(12),VSTAR(12),YLIFT(8),REYNOL(8),CRLIFT(8),
     &          DELTA(8),AFACTO(8),SIGMA(8),UTRANS(8),EFTRAN(8),REQTR(8)
     &          ,FLAREA(12),REYNUM(29),CRSHER(29)
      DATA REYNUM/1.0,1.22,1.35,1.57,1.76,2.0,2.62,3.0,3.95,4.0,5.0,6.0,
     &7.0,8.0,9.0,10.0,20.0,30.0,40.0,50.0,60.0,70.0,80.0,90.0,100.0,
     &179.55,200.0,300.0,400.0/
      DATA CRSHER/0.124,0.10,0.09,0.08,0.07,0.06,0.05,0.0457,0.04,0.04,
     &0.0353,0.0333,0.032,0.0313,0.0307,0.03,0.0325,0.035,.03625,0.03813
     &,0.04,0.04,0.0427,0.0436,0.0455,0.05,0.0533,0.0567,0.06/
C
      IF(KDET.EQ.1.OR.KDET.EQ.2)GO TO 62
C                                                       THIS BLOCK CALCULATES
C                                                          DELTA FOR EACH PAR-
C                                                          TICLE TYPE AND SUMS
C                                                          THE DELTA VALUES.
C        WRITE(8,5)AA(IELE+1)
C   5    FORMAT(' AA = ',F15.6)
      FLAREA(IELE+1)=AA(IELE+1)
      IF(FLAREA(IELE+1).LE.0.0)FLAREA(IELE+1)=0.0
      RAD(IELE+1)=FLAREA(IELE+1)/TWIDTH(IELE+1)
      VSTAR(IELE+1)=SQRT(32.2*RAD(IELE+1)*SLOPE(IELE))
      TOTLIF=0.0
         DO 30 J=1,NTYPE
         YLIFT(J)=(VSTAR(IELE+1)**2/((SG(J,NS)-1.0)*32.2*DIA(J,NS)))*304
     &.8
```

```
          REYNOL(J)=((DIA(J,NS)*VSTAR(IELE+1))/0.0000106)*0.0032808
          IF(REYNOL(J).LE.1.0)GO TO 10
             IF(REYNOL(J).GE.400.0)GO TO 9
             DO 7 K=1,29
             IF(REYNOL(J).GT.REYNUM(K).AND.REYNOL(J).LT.REYNUM(K+1))GO
      &      TO 8
     7       CONTINUE
     8       CONTINUE
             PERDIF=(REYNOL(J)-REYNUM(K))/(REYNUM(K+1)-REYNUM(K))
             ADD=(CRSHER(K+1)-CRSHER(K))*PERDIF
             CRLIFT(J)=CRSHER(K)+ADD
          GO TO 20
     9       CONTINUE
             CRLIFT(J)=0.06
             GO TO 20
    10    CRLIFT(J)=0.10*REYNOL(J)**(-0.03)
    20    CONTINUE
C            WRITE(8,22)J,CRLIFT(J),J,YLIFT(J)
C   22       FORMAT(' CRLIFT(',I1,') = ',F15.6,5X,'YLIFT(',I1,') = ',
C     &      F15.6)
          DELTA(J)=YLIFT(J)/CRLIFT(J)-1.0
          IF(YLIFT(J).LE.CRLIFT(J))DELTA(J)=0.0
C            WRITE(8,25)J,DELTA(J)
C   25       FORMAT(' DELTA(',I1,') = ',F15.6)
          TOTLIF=TOTLIF+DELTA(J)
    30    CONTINUE
C            WRITE(8,40)TOTLIF
C   40       FORMAT(' TOTLIF = ',F15.6)
C
C                                                  THIS LOOP CALCULATES
C                                                     A VALUE OF NONDIMEN-
C                                                     SIONAL TRANSPORT FOR
C                                                     UNIFORM MATERIALS OF
C                                                     EACH PARTICLE TYPE.
C                                                     IT ALSO CALCULATES
C                                                     AN EFFECTIVE TRANS-
C                                                     PORT VALUE FOR EACH
C                                                     PARTICLE TYPE.
          DO 50 J=1,NTYPE
          IF(DELTA(J).EQ.0.0)GO TO 45
          AFACTO(J)=2.45*SG(J,NS)**(-0.4)*CRLIFT(J)**0.5
          SIGMA(J)=AFACTO(J)*DELTA(J)
          UTRANS(J)=0.635*DELTA(J)*(1.0-(1.0/SIGMA(J))*ALOG(1.0+SIGMA(J))
      C   )
          EFTRAN(J)=(UTRANS(J)*DELTA(J))/TOTLIF
          GO TO 50
    45    CONTINUE
          SIGMA(J)=0.0
          UTRANS(J)=0.0
          EFTRAN(J)=0.0
    50    CONTINUE
C                                                  THIS LOOP COMPUTES THE
C                                                     TRANSPORT CAPACITY
C                                                     FOR EACH PARTICLE
C                                                     TYPE.
          DO 60 J=1,NTYPE
          TCAP(J)=(EFTRAN(J)*SG(J,NS)*1.94*32.2*DIA(J,NS)*VSTAR(IELE+1))
```

```
     &           *0.0032808
   60    CONTINUE
C           WRITE(8,61)(TCAP(J),J=1,NTYPE)
C  61       FORMAT(' INITIAL TRANSPORT CAPACITY = ',5F15.6)
C
C                                                    THIS BLOCK COMPUTES AND
C                                                       DISTRIBUTES ANY EX-
C                                                       CESS TRANSPORT CAPA-
C                                                       CITY.
   62 NDO=NTYPE
      IF(POTSED(1).NE.0.0)GO TO 65
      NGREAT=NTYPE
      GO TO 180
   65 IF(POTSED(NTYPE).NE.0.0)GO TO 70
      NCHECK=NTYPE-1
         DO 67 J=1,NCHECK
         NUMP=NTYPE-J
         IF(POTSED(NUMP).NE.0.0)GO TO 68
   67    CONTINUE
   68 CONTINUE
         NDO=NUMP
   70 CONTINUE
      SPT=0.0
      SDLT=0.0
         DO 90 J=1,NDO
         IF(TCAP(J).GE.POTSED(J))GO TO 80
         SDLT=SDLT+DELTA(J)
         GO TO 90
   80    REQTR(J)=(POTSED(J)/(SG(J,NS)*32.2*1.94*DIA(J,NS)*VSTAR(IELE+1)
     &            ))*304.8
         IF(UTRANS(J).EQ.0.0)GO TO 90
         SPT=SPT+REQTR(J)/UTRANS(J)
   90    CONTINUE
      EXCESS=1.0-SPT
C           WRITE(8,95)EXCESS
C  95       FORMAT(' EXCESS TRANSPORT CAPACITY = ',F15.6)
         DO 120 J=1,NDO
         IF(TCAP(J).LT.POTSED(J))GO TO 100
         TCAP(J)=POTSED(J)
         GO TO 120
  100    CONTINUE
         IF(SDLT.EQ.0.0)GO TO 115
         TCAP(J)=((DELTA(J)/SDLT)*EXCESS*UTRANS(J)*SG(J,NS)*32.2*1.94*
     &             DIA(J,NS)*VSTAR(IELE+1))*0.0032808
         GO TO 120
  115    CONTINUE
         TCAP(J)=0.0
  120    CONTINUE
C           WRITE(8,125)(TCAP(J),J=1,NTYPE)
C 125       FORMAT(' ADJUSTED TRANSPORT CAPACITY = ',5F15.6)
C
C                                                    THIS BLOCK DETERMINES
C                                                       IF EITHER ALL CAPA-
C                                                       CITIES ARE GREATER
C                                                       THAN LOADS OR ALL
C                                                       CAPACITIES ARE LESS
C                                                       THAN LOADS.  CAPA-
```

```
C                                                       CITIES ARE COMPUTED
C                                                       IF THERE IS ANY EX-
C                                                       CESS.
      NEQUAL=0
      NGREAT=0
      NLESS=0
         DO 140 J=1,NTYPE
         IF(TCAP(J).GT.POTSED(J))GO TO 135
         IF(TCAP(J).EQ.POTSED(J))GO TO 136
         NLESS=NLESS+1
         GO TO 140
  135    NGREAT=NGREAT+1
         GO TO 140
  136    NEQUAL=NEQUAL+1
  140    CONTINUE
         IF((NLESS+NEQUAL).EQ.NTYPE)GO TO 180
         IF((NGREAT+NEQUAL).EQ.NTYPE)NGREAT=NTYPE
C           WRITE(8,145)NLESS,NGREAT
C 145       FORMAT(' NLESS = ',I5,10X,'NGREAT = ',I5)
      IF(NLESS.EQ.NTYPE)GO TO 180
      IF(NGREAT.EQ.NTYPE)GO TO 150
      GO TO 70
  150 SMUS=0.0
         DO 160 J=1,NTYPE
         IF(UTRANS(J).EQ.0.0)GO TO 160
         SMUS=SMUS+(REQTR(J)/UTRANS(J))
  160    CONTINUE
            DO 170 J=1,NTYPE
            TCAP(J)=(1.0/SMUS)*POTSED(J)
  170       CONTINUE
C        WRITE(8,125)(TCAP(J),J=1,NTYPE)
  180 RETURN
C     DEBUG UNIT(12),SUBCHK,SUBTRACE
      END
      SUBROUTINE EFFHRU
C*************************************************************************
C
C     THIS SUBROUTINE WAS CREATED TO PROVIDE FOR MORE VERSATILITY IN
C     THE INPUT DATA.
C     THIS ALLOWS THE INPUT ELEMENTS TO CONTAIN SEVERAL HRU'S AS DID
C     THE ORIGINAL VERSION OF FESHM, AS WELL AS ALLOWING ELEMENTS TO
C     BE DEFINED AS A SINGLE HRU AS REQUIRED BY THE UPDATED VERSION
C     BY HEATWOLE.  UNLIKE THE B.B. ROSS VERSION THIS SUBROUTINE
C     WEIGHTS THE INDIVIDUAL HRU CHARACTERISTICS WITHIN AN ELEMENT
C     AND CREATES AN EFFECTIVE HRU FOR EACH ELEMENT.
C     THE ORIGINAL VERSION OF FESHM COMPUTED EXCESS FOR EACH HRU AND
C     WEIGHTED THESE EXCESSES WITHIN EACH ELEMENT, WHICH WAS NOT
C     POSSIBLE WITH THIS VERSION.
C
C*************************************************************************
C
C    COMMON BLOCKS:
C
       COMMON/BLK1/PRECIP(4,160),STO(10),AFAC(163),FC(163),ELEXC(10)
      1,KIHRU(163),STOMAX(163),CEXP(163),DAILPC(4,30),GINDEX(12),
      2EVP(12),DEPSTO(163),ACCDP(163),SLOHRU(163)
       COMMON /BLK5/ RCLU(60),FHRU(80,60),LANDU(163),NHRU(80),IHRU(80,60)
```

```
     &,DSLU(60),DSAC(163),ERCOEF(163)
      COMMON /BLK9/ NOPRIN,SMCWS,NSECR,PCINTH,DTO,DTC,NSECC,NTBLHS,
     &NTBLPE,NTELES,NDHRUS,NLANUS,NGAGES,NHOURR,INTPCS,NSTART,MONTH,NDAY
     &,NYEAR,NPCINT,INTPCM,NTSS,NSTRPS,NSSHED,NELEM,NZIP,NE,NN,NCPRIN,
     &NHOURC,NDAMS,NTSSX,NOWTIM
      COMMON /BLK10/ FAW(163),FGW(163),DEPTH(163),AFLU(60),SMCHRU(163)
      COMMON /BLK31/ NTYPE,NS,NSED,NPART(8),NSOIL(163),SG(8,163),
     &DIA(8,163),TYPE(8,163)
      COMMON /BLK33/ XKUSLE(163),CUSLE(163),PUSLE(163),EFFK(163),
     &EFFC(163),EFFP(163)
C
C    PROGRAM:
C
      CHARACTER*1 SLOHRU
      DIMENSION EFAW(100),EFGW(100),EFC(100),EDEPTH(100),ESMCHR(100)
C
C
C     THIS BLOCK INITIALIZES THE EFFECTIVE HRU CHARACTERISTICS
C
      DO 100 I=1,NTELES
         AFAC(I)=0.0
         DSAC(I)=0.0
         ERCOEF(I)=0.0
         EFAW(I)=0.0
         EFGW(I)=0.0
         EFC(I)=0.0
         EDEPTH(I)=0.0
         ESMCHR(I)=0.0
         EFFK(I)=0.0
         EFFC(I)=0.0
         EFFP(I)=0.0
C
         MHRU=NHRU(I)
C
C     THIS BLOCK WEIGHTS THE HRU CHARACTERISTICS AND CREATES
C     EFFECTIVE HRU CHARACTERISTICS.
C
         DO 200 J=1,MHRU
C
               K=IHRU(I,J)
               L=LANDU(K)
C
               AFAC(I)=AFAC(I)+FHRU(I,J)*AFLU(L)
               DSAC(I)=DSAC(I)+FHRU(I,J)*DSLU(L)
               ERCOEF(I)=ERCOEF(I)+FHRU(I,J)*RCLU(L)
C
               EFAW(I)=EFAW(I)+FHRU(I,J)*FAW(K)
               EFGW(I)=EFGW(I)+FHRU(I,J)*FGW(K)
               EFC(I)=EFC(I)+FHRU(I,J)*FC(K)
               EDEPTH(I)=EDEPTH(I)+FHRU(I,J)*DEPTH(K)
               ESMCHR(I)=ESMCHR(I)+FHRU(I,J)*SMCHRU(K)
               EFFK(I)=EFFK(I)+FHRU(I,J)*XKUSLE(K)
               EFFC(I)=EFFC(I)+FHRU(I,J)*CUSLE(K)
               EFFP(I)=EFFP(I)+FHRU(I,J)*PUSLE(K)
200      CONTINUE
100   CONTINUE
C
```

```
C     THIS BLOCK DEFINES NEW EFFECTIVE HRU VARIABLES TO OLD
C     VARIABLE NAMES SO NO MAJOR CHANGES ARE NEEDED IN MAIN PROGRAM.
C
      NDHRUS=NTELES
CC      WRITE(4,13) NDHRUS
CC13    FORMAT(1X,'EFFHRU',I3)
      DO 300 II=1,NDHRUS
C
         FAW(II)=EFAW(II)
         FGW(II)=EFGW(II)
         FC(II)=EFC(II)
         DEPTH(II)=EDEPTH(II)
         SMCHRU(II)=ESMCHR(II)
300   CONTINUE
C
C      NOTE: AFAC, DSAC, ERCOEF, EFFK, EFFC, EFFP ARE ALL
C            USED IN THE PROGRAM AS DEFINED.
C
C*************************************************************************
C      THIS BLOCK IS FOR DETERMINING EFFECTIVE SLOHRU.
C      FOR NOW ALL SLOHRUS ARE ASSUMED AS 'A', THIS SECTION WILL
C      BE ADDED LATER.
C
C*************************************************************************
C      THIS BLOCK IS FOR DETERMINING EFFECTIVE NSOIL VALUES.
C      IF SEDIMENT CALCULATIONS ARE IMPORTANT IT IS ADVISED TO
C      DEFINE ELEMENTS SO THAT SOIL TYPES DO NOT VARY GREATELY.
C      THIS SECTION WILL DETERMINE WHICH SOIL OCCUPIES THE MAJORITY
C      OF THE ELEMENT IN QUESTION.
C
C      FOR NOW ALL NSOILS ARE ASSUMED EQUAL TO '1' THIS ROUTINE WILL
C      BE ADDED LATER.
      DO 400 III=1,NDHRUS
         NSOIL(III)=1
         SLOHRU(III)=SLOHRU(1)
         LANDU(III)=1
400   CONTINUE
      RETURN
      END
```

11.4 APPENDIX D: GIS SAMPLE DATA FILES AND PROGRAMS

11.4.1 Digital Soils Map (Millstone Branch Watershed)

```
001   00 00 00 02 02 02 00 00
002   00 00 02 02 02 02 00 00
003   02 02 02 02 02 02 00 00
004   00 03 03 02 02 02 00 00
005   00 00 02 02 02 03 00 00
006   00 00 02 02 02 03 00 00
007   00 00 03 02 02 03 00 00
008   00 00 00 01 01 03 00 00
009   00 00 00 00 01 04 00 00
010   00 00 00 00 00 01 00 00
011   00 00 00 00 00 01 01 00
012   00 00 00 00 00 00 05 00
013   00 00 00 00 00 00 00 05
```

11.4.2 Soil Attribute File (Millstone Branch Watershed)

```
   5
 1   MO     .114     .199     .200    6.0      .280     A
 2   ML     .144     .156     .150    9.0      .280     A
 3  MLV     .210     .117     .150    7.0      .280     A
 4  RSM     .177     .136     .100    6.0      .280     A
 5   JF     .235     .131     .200   10.0      .280     A
```

11.4.3 Digital Land Use Map (Millstone Branch Watershed)

```
001   00 00 00 06 06 06 00 00
002   00 00 06 06 06 06 00 00
003   06 06 06 06 06 06 00 00
004   00 06 06 06 06 06 00 00
005   00 00 06 06 06 06 00 00
006   00 00 04 04 06 06 00 00
007   00 00 06 04 04 06 00 00
008   00 00 00 04 04 06 00 00
009   00 00 00 00 04 06 00 00
010   00 00 00 00 00 06 00 00
011   00 00 00 00 00 06 06 00
012   00 00 00 00 00 00 04 00
013   00 00 00 00 00 00 00 04
```

11.4.4 Land Use Attribute File (Millstone Branch Watershed)

```
 1 SMALL GRAIN      .3       .1       .182     .5
 2 CORN             .2       .1       .3380    .5
 3 HAY              .5       .2       .027     .5
```

4	PASTURE	.8	.25	.006	.5
5	TOBACCO	.2	.1	.338	.5
6	WOODS	1.0	.4	.001	.5
7	IDLE	.9	.3	.001	.5
8	ROAD	0.0	.02	.002	.5
9	SOYBEANS	.4	.15	.338	.5
10	COTTON	.4	.15		.5
11	SORGHUM	.2	.1	.320	.5
12	FALLOWED	.1	.1		.5
13	LIGHT WOODS	.9	.35	.001	.5
14	HOMESTEAD	.9	.25	.0001	.5
15	CEMETARY	.9	.25	.0001	.5
16	BUILDINGS	.8	.02	.002	.5
17	POND	0.0	.02	0.0000	.5
18	NO-TILL CORN	.45	.25	.0300	.5

11.4.5 Digital HRU Map (Millstone Branch Watershed)

```
001     0  0  0  1  1  1  0  0
002     0  0  1  1  1  1  0  0
003     1  1  1  1  1  1  0  0
004     0  2  2  1  1  1  0  0
005     0  0  1  1  1  2  0  0
006     0  0  3  3  1  2  0  0
007     0  0  2  3  3  2  0  0
008     0  0  0  4  4  2  0  0
009     0  0  0  0  4  5  0  0
010     0  0  0  0  0  6  0  0
011     0  0  0  0  0  6  6  0
012     0  0  0  0  0  0  7  0
013     0  0  0  0  0  0  0  7
```

11.4.6 HRU List (Millstone Branch Watershed)

```
(this file lists the unique combination of
 soil and land use types for each HRU)
  1    2  6
  2    3  6
  3    2  4
  4    1  4
  5    4  6
  6    1  6
  7    5  4
```

11.4.7 Digital Element Map (Millstone Branch Watershed)

```
001    00 00 00 03 03 04 00 00
002    00 00 02 03 04 07 00 00
003    02 02 02 06 07 07 00 00
004    00 01 01 05 07 08 00 00
005    00 00 05 05 11 11 00 00
```

```
006    00 00 09 09 09 11 00 00
007    00 00 09 09 09 11 00 00
008    00 00 00 09 09 11 00 00
009    00 00 00 00 10 12 00 00
010    00 00 00 00 00 10 00 00
011    00 00 00 00 00 10 12 00
012    00 00 00 00 00 00 10 00
013    00 00 00 00 00 00 00 12
```

11.4.8 List of Elements and Corresponding Areas

```
 AREA OF ELEMENT    1 =    4.9420 ACRES
 AREA OF ELEMENT    2 =    9.8840 ACRES
 AREA OF ELEMENT    3 =    7.4130 ACRES
 AREA OF ELEMENT    4 =    4.9420 ACRES
 AREA OF ELEMENT    5 =    7.4130 ACRES
 AREA OF ELEMENT    6 =    2.4710 ACRES
 AREA OF ELEMENT    7 =    9.8840 ACRES
 AREA OF ELEMENT    8 =    2.4710 ACRES
 AREA OF ELEMENT    9 =   19.7680 ACRES
 AREA OF ELEMENT   10 =    9.8840 ACRES
 AREA OF ELEMENT   11 =   12.3550 ACRES
 AREA OF ELEMENT   12 =    7.4130 ACRES
```

11.4.9 Listing of HRU.FOR Program

```
C ------------------| HRU.FOR |----------------------------------
C
C****** PROGRAM TO COMBINE LANDUSE GRID AND SOIL GRID TO CREATE A
C       HRU GRID.
C****** ALSO CREATES A LIST OF HRU NO.S AND COINCIDING LANDUSE AND SOIL
C       TYPE.
C****** ALSO CREATES AN HRU CHARACTERISTIC FILE FROM SOIL CHAR AND LU
C       CHAR FILES IN THE CORRECT FORM REQUIRED FOR INPUT INTO
C       THE FESHM.
C
      INTEGER HRUNO(100,100), IHRU(500,2), NSOIL(100,100), NLU(100,100)
      REAL FAW(100), FGW(100), FC(100), DEPTH(100), XKUSLE(100),
     >AFLU(100), RCLU(100), CUSLE(100), PUSLE(100), DSLU(100)
      CHARACTER*1 SLOHRU(100)
C****  DEFINE # OF SOILS AND # OF LANDUSE TYPES
      READ(8,3) ISOIL
      READ(9,3) ILU
3     FORMAT(I5)
C****  DEFINE SIZE OF GRID
      READ(1,33) NROW, NCOL
33    FORMAT(2I5)
C****  READ IN THE SOIL GRID FILE
      DO 5 K1=1,NROW
    5 READ(1,10) IROW, (NSOIL(IROW,I),I=1,NCOL)
C****  READ IN THE LANDUSE GRID FILE
      DO 7 K2=1,NROW
    7 READ(2,10) IROW, (NLU(IROW,J),J=1,NCOL)
C**** FORMAT
   10 FORMAT(I3,2X,21I3)
C
C***** SECTION FOR READING IN SOIL CHARACTERISTICS
C
      DO 1000 IS=1,ISOIL
      READ(8,999) NUMS, FAW(NUMS), FGW(NUMS), FC(NUMS), DEPTH(NUMS),
     >XKUSLE(NUMS),SLOHRU(NUMS)
  999 FORMAT(I3,5X,5F8.3,5X,A1)
 1000 CONTINUE
C
C***** SECTION FOR READING IN LU CHARACTERISTICS
C
      DO 2000 IL=1,ILU
      READ(9,1999) NUML, AFLU(NUML), RCLU(NUML), CUSLE(NUML),PUSLE(NUML)
     >,DSLU(NUML)
 1999 FORMAT(I3,13X,2F8.2,F10.4,F5.1,F8.3)
 2000 CONTINUE
C
C**** NHRU = HRU IDENTITY NUMBER
C
      NHRU=0
C**** BEGIN LOOPS TO ASSIGN EACH GRID (COMBO OF LU & SOIL) TO A
C**** HRU NUMBER.
      DO 200 I=1,NROW
      DO 200 J=1,NCOL
C
```

```
C****  SECTION TO CHECK FOR "OUT OF WATERSHED" OR "UNEQUAL" GRIDS
C
      IF(NSOIL(I,J).EQ.0.AND.NLU(I,J).EQ.0) GOTO 150
      IF((NSOIL(I,J).NE.0.AND.NLU(I,J).EQ.0).OR.(NSOIL(I,J).EQ.0.AND.
     >NLU(I,J).NE.0)) GOTO 175
C****  NSUB IS A REVERSE COUNTER TO TEST NEW S&LU COMBO TO SEE IF ITS
C****  ASSIGNED TO A HRU NO. YET.
C
      NSUB=NHRU
   11 IF(NSUB.LE.0) GO TO 20
C
C****  AGAIN: SECTION TO CHECK FOR "OUT OF WATERSHED" OR "UNEQUAL" GRIDS
C
      IF(NSOIL(I,J).EQ.0.AND.NLU(I,J).EQ.0) GOTO 150
      IF((NSOIL(I,J).NE.0.AND.NLU(I,J).EQ.0).OR.(NSOIL(I,J).EQ.0.AND.
     >NLU(I,J).NE.0)) GOTO 175
C
C**** CHECK IF HRU HAS BEEN DEFINED FOR THIS COMBO OR NOT
C
      IF(NSOIL(I,J).EQ.IHRU(NSUB,1).AND.NLU(I,J).EQ.IHRU(NSUB,2))
     >GOTO 15
      GO TO 17
   15    LHRU=NSUB
         HRUNO(I,J)=LHRU
         GO TO 200
C
   17 NSUB=NSUB-1
      GO TO 11
C
C****    DEFINE A NEW HRU
C
   20 NHRU=NHRU+1
      IHRU(NHRU,1)=NSOIL(I,J)
      IHRU(NHRU,2)=NLU(I,J)
      HRUNO(I,J)=NHRU
      GO TO 200
C
C****  CONTINUATION OF "OUT OF WATERSHED" OR "UNEQUAL" GRIDS
C
  150 HRUNO(I,J)=0
      GO TO 200
  175 HRUNO(I,J)=99999
  200 CONTINUE
C
C****   WRITE OUT A LIST OF HRU NUMBERS AND COINCIDING SOIL & LU
C
      DO 500 KHRU=1,NHRU
      WRITE(3,400) KHRU, IHRU(KHRU,1), IHRU(KHRU,2)
  400 FORMAT(I3,1X,2I3)
  500 CONTINUE
C
C****   WRITE OUT HRU DATA FILE OR GRID FILE
C
      DO 700 KROW=1,NROW
      WRITE(4,600) KROW,(HRUNO(KROW,J),J=1,NCOL)
  600 FORMAT(I3,2X,21I3/(4X,9I3))
  700 CONTINUE
```

```
C
C*****  WRITE OUT HRU CHARACTERISTIC FILE FOR INPUT INTO THE FESHM
C
      WRITE(7,2500) (AFLU(I),I=1,ILU)
      WRITE(7,2500) (DSLU(I),I=1,ILU)
      WRITE(7,2500) (RCLU(I),I=1,ILU)
 2500 FORMAT(8F10.2)
C
      SMCHRU=0.0
      DO 5000 KH=1,NHRU
      NS=IHRU(KH,1)
      NL=IHRU(KH,2)
      IF (NS.EQ.0.OR.NL.EQ.0) GO TO 5000
      WRITE(7,3000) NL, FAW(NS), FGW(NS), FC(NS), DEPTH(NS), SLOHRU(NS),
     >SMCHRU, XKUSLE(NS), CUSLE(NL), PUSLE(NL), NS
 3000 FORMAT(I5,4F8.3,5X,A1,2F8.3,F8.5,F8.3,I5)
 5000 CONTINUE
      STOP
      END
```

11.4.10 Listing of ELEMENT.FOR Program

```
C -----------------------| ELEMENT.FOR |----------------------------
C
C********* PROGRAM FOR CALCULATING % OF EACH HRU TYPE CONTAINED WITHIN
C          EACH ELEMENT.
C********* PRINTS OUT NHRU, IHRU(I), AND FHRU(I) FOR EACH ELEMENT.
C********* ALSO CALCULATES THE AREA OF EACH ELEMENT.
C
      REAL PER(100,200), APER(200), AREA(100)
      INTEGER HRUNO(200,200), ELEM(100,100), KHRU(200)
C
C*****  INITIALIZE VALUES
C
      READ(2,333) NELEM
333   FORMAT(I5)
      READ(1,33) NHRU, NROW, NCOL
33    FORMAT(3I5)
C
C*****  READ IN HRU FILE (GRID)
C
      DO 5 K1=1,NROW
    5 READ(1,10) IROW, (HRUNO(IROW,I),I=1,NCOL)
C
C*****  READ IN ELEMENT INDEX FILE (GRID)
C
      DO 7 K2=1,NROW
    7 READ(2,10) KROW, (ELEM(KROW,J),J=1,NCOL)
   10 FORMAT(I3,2X,21I3)
C
C*****  LOOP INCREMENTING ELEMENT NUMBER
C
      DO 60 L=1,NELEM
      ICOUNT=0
C*****  LOOP INCREMENTING HRU TYPE
C
      DO 40 K=1,NHRU
C*****  INITIALIZING COUNTERS
      NGCOU=0
      NHCOU=0
C
C*****  LOOP INCREMENTING GRID CELLS
C
      DO 20 I=1,NROW
      DO 20 J=1,NCOL
C
C*****  ERROR CHECKING TO MAKE SURE HRU & ELEMENT GRID SIZES ARE EQUAL
C       ONLY USE THIS WHEN CHECKING NOT FOR REGULAR RUNS
C
C     IF((ELEM(I,J).EQ.0.AND.HRUNO(I,J).NE.0).OR.(ELEM(I,J).NE.0.AND.
C    >HRUNO(I,J).EQ.0)) GOTO 700
C     GO TO 15
C 700 WRITE(3,701) I,J
C 701 FORMAT(' PROBLEM AT ROW ',I3,' COL ',I3)
C     GO TO 1000
C
```

```
C*****  CHECKING IF GRID IS PART OF PRESENT ELEMENT
C
   15 IF(ELEM(I,J).NE.L) GO TO 20
      NGCOU=NGCOU+1
C
C*****  COUNTING NUMBER OF GRIDS OF A PARTICULAR HRU IN AN ELEMENT
C
      IF(HRUNO(I,J).NE.K) GO TO 20
      NHCOU=NHCOU+1
   20 CONTINUE
C***** CALCULATING THE AREA OF AN ELEMENT
      AREA(L)=NGCOU*2.471
C
C***** CALCULATING % OF ELEMENT OCCUPIED BY THIS HRU
C
      HCOU=NHCOU
      GCOU=NGCOU
      PER(L,K)=HCOU/GCOU
C
C***** COUNTS NO. OF HRU'S WHICH APPEAR WITHIN THIS ELEMENT AND
C       REDEFINES INTO A NEW ARRAY THE HRU # AND IT'S % FOR OUTPUT
C       PURPOSES
C
      IF(PER(L,K).LE.0.0) GO TO 40
      ICOUNT=ICOUNT+1
      APER(ICOUNT)=PER(L,K)
      KHRU(ICOUNT)=K
   40 CONTINUE
C
C*****  WRITING OUT RESULTS
C
      WRITE(3,300) ICOUNT
  300 FORMAT(I10)
      WRITE(3,400) (KHRU(I),I=1,ICOUNT)
  400 FORMAT(10I8)
      WRITE(3,500) (APER(I),I=1,ICOUNT)
  500 FORMAT(10F8.4)
C*****  WRITING OUT AREAS OF ELEMENTS TO A SEPERATE  FILE
      WRITE(4,600) L, AREA(L)
  600 FORMAT(' AREA OF ELEMENT ',I3,' = ',F8.4,' ACRES')
   60 CONTINUE
 1000 STOP
      END
```

11.5 APPENDIX E: COMPUTER SIMULATION DATA FILES

11.5.1 Brush Creek Watershed "Detailed" Data File

```
   0    0       600       600
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
 BRUSH CREEK WATERSHED: DETAILED DATA BASE, DESIGN STORM 2 (25-YR,6-HR)
        1         6        10       900      1.00
    1    1    1   87
   0.07000   0.08000   0.10000   0.10000   0.12000   0.13000   0.23000   0.27000
   0.79000   0.78000   0.26000   0.23000   0.16000   0.17000   0.14000   0.11000
   0.12000   0.10000   0.11000   0.08000   0.09000   0.09000   0.08000   0.09000
        17        64       108        18
         6
       1         5        13        24        31        73
  0.2353    0.0588    0.0588    0.2941    0.1765    0.1765
        12
       5         8        14        16        19        22        24        26        31        35
      39        42
  0.1765    0.0196    0.0196    0.0588    0.0196    0.0196    0.0784    0.0784    0.2549    0.1176
  0.0196    0.1373
        22
       1         2         4         5         6         8        11        14        16        17
      18        19        23        24        26        31        33        34        35        41
      47        48
  0.0500    0.0333    0.0667    0.2000    0.0500    0.0333    0.0333    0.0500    0.0500    0.0333
  0.0167    0.0667    0.0167    0.0167    0.0167    0.0833    0.0333    0.0167    0.0667    0.0167
  0.0333    0.0167
         7
      19        24        42        55        56        69        73
  0.2381    0.2857    0.0476    0.1429    0.0476    0.1429    0.0952
        13
      16        21        28        31        41        47        63        64        69        75
      78        79        83
  0.1379    0.0690    0.0345    0.0690    0.0345    0.0345    0.2069    0.0345    0.2069    0.0345
  0.0345    0.0690    0.0345
        23
       3         5        16        18        19        21        29        31        40        46
      47        49        53        58        59        68        75        79        81        82
      83        86        91
  0.0779    0.0130    0.0260    0.0130    0.0130    0.1299    0.0909    0.0260    0.1429    0.0779
  0.0649    0.0130    0.0130    0.0260    0.0130    0.0260    0.0909    0.0130    0.0649    0.0130
  0.0130    0.0130    0.0260
        10
       1         4         5         8        13        14        16        19        21        28
  0.2857    0.0476    0.1429    0.0476    0.0476    0.0476    0.1429    0.0476    0.0952    0.0952
         2
      28        29
  0.3333    0.6667
         4
       1         2         3         4
  0.4545    0.0455    0.1364    0.3636
         8
       1         3         4         5         8        24        28        38
```

```
0.2941  0.0588  0.1176  0.2941  0.0588  0.0588  0.0588  0.0588
       4
    28      29      30      40
0.3333  0.4444  0.1111  0.1111
       3
    31      40      53
0.1818  0.3636  0.4545
       7
     3       6       9      10      21      28      29
0.1538  0.0769  0.1538  0.0769  0.2308  0.1538  0.1538
      16
     1       3       4       5       7       8      10      11      12      15
    16      21      22      28      29      30
0.0769  0.2500  0.0385  0.0385  0.1154  0.0577  0.0192  0.0385  0.0192  0.0192
0.0192  0.0962  0.0962  0.0192  0.0577  0.0385
       3
    26      28      29
0.1667  0.5000  0.3333
       2
    19      40
0.2500  0.7500
       5
    24      61      93      94     100
0.0833  0.0833  0.6667  0.0833  0.0833
       3
    19      93     100
0.2500  0.3750  0.3750
       2
    19      61
0.2000  0.8000
       2
    61      69
0.4444  0.5556
       6
    31      74      82      93      94     102
0.3077  0.1538  0.0769  0.1538  0.1538  0.1538
       8
    48      65      74      93     102     105     106     107
0.0667  0.0667  0.2000  0.0667  0.1333  0.2667  0.0667  0.1333
       9
    24      31      48      54      65     103     104     105     108
0.0667  0.1333  0.0667  0.1333  0.1333  0.0667  0.1333  0.2000  0.0667
       4
    19      48      65     103
0.2353  0.0588  0.6471  0.0588
       1
    63
1.0000
       3
    54      63      65
0.1111  0.5926  0.2963
       3
    54      63      65
0.1579  0.2632  0.5789
       6
    19      54      63      65      98     101
0.0357  0.2143  0.1071  0.3214  0.2857  0.0357
```

```
       7
    19      24      33      54      65      98     101
0.2222  0.1111  0.1111  0.1111  0.2222  0.1111  0.1111
       2
    19      33
0.5000  0.5000
       3
    54      65      98
0.1765  0.0588  0.7647
       4
    33      54      65      98
0.0909  0.2727  0.1818  0.4545
       6
    40      54      65      98      99     101
0.0588  0.1176  0.1765  0.2647  0.3235  0.0588
       6
    24      33      52      54      65     101
0.3125  0.1250  0.0625  0.2500  0.0625  0.1875
       4
    19      65     103     104
0.2500  0.2500  0.2500  0.2500
       5
    17      19      28      31      65
0.2857  0.2857  0.1429  0.1429  0.1429
      21
    14      17      19      25      28      31      48      53      54      60
    61      67      68      69      71      72      74      78      89      90
    94
0.0233  0.0233  0.0116  0.0465  0.0465  0.1395  0.0233  0.0349  0.0233  0.0581
0.1163  0.0465  0.0465  0.0581  0.0116  0.0349  0.0349  0.0930  0.0233  0.0698
0.0349
      19
    10      17      18      19      22      31      37      40      46      49
    53      58      60      67      68      70      71      72      74
0.0400  0.1000  0.0400  0.1000  0.0400  0.1000  0.0200  0.0800  0.0200  0.0200
0.0400  0.0200  0.0400  0.1200  0.0200  0.0400  0.0800  0.0200  0.0600
      11
    10      17      18      24      28      29      40      46      47      54
    58
0.0208  0.0417  0.0208  0.0833  0.1250  0.2708  0.1875  0.0208  0.0208  0.1667
0.0417
       8
     1      13      14      18      19      40      66      77
0.1250  0.1667  0.1250  0.0417  0.2083  0.2083  0.0833  0.0417
       1
    19
1.0000
       6
    13      15      16      18      45      52
0.1667  0.1667  0.1667  0.1667  0.1667  0.1667
       6
     1       5      13      16      22      49
0.3529  0.1765  0.1176  0.2353  0.0588  0.0588
       5
    16      18      22      24      31
0.2000  0.3000  0.1000  0.3000  0.1000
       4
```

```
    24      33      54      65
0.5714  0.1429  0.1429  0.1429
      11
     1       3       5       7      10      13      16      22      31      49
    72
0.1176  0.2941  0.0588  0.0588  0.0588  0.0588  0.0588  0.1176  0.0588  0.0588
0.0588
       5
     1       3      22      49      60
0.2222  0.3333  0.2222  0.1111  0.1111
       2
    60      65
0.4545  0.5455
      14
     1       3       5       7      13      14      16      18      22      26
    28      43      60      61
0.0714  0.1071  0.1071  0.1429  0.0357  0.0357  0.0714  0.0357  0.0357  0.0714
0.0357  0.0714  0.1071  0.0714
      16
     1       3      13      14      16      18      20      22      25      28
    31      36      52      54      55      65
0.0667  0.3111  0.0444  0.0222  0.0222  0.0222  0.2222  0.0222  0.0222  0.0444
0.0667  0.0444  0.0222  0.0222  0.0222  0.0222
       3
    15      28      65
0.2000  0.2000  0.6000
       5
    11      17      28      52      62
0.2500  0.2500  0.2500  0.1250  0.1250
       6
    24      41      54      63      96      97
0.2000  0.1000  0.2000  0.2000  0.2000  0.1000
      11
    10      24      40      44      46      76      92      96      97      98
   101
0.0189  0.0377  0.0566  0.0189  0.0755  0.0377  0.0377  0.0755  0.3962  0.1698
0.0755
       8
    10      24      41      63      87      88      95      96
0.0556  0.0556  0.1667  0.1667  0.0556  0.2222  0.2222  0.0556
      11
    24      28      33      41      54      65      80      84      85      87
    88
0.0625  0.0625  0.0313  0.0313  0.0313  0.2813  0.0938  0.2500  0.0625  0.0625
0.0313
      20
     1       3       5      10      14      16      21      26      28      29
    40      41      44      46      49      54      56      65      76      98
0.0811  0.0405  0.0270  0.0541  0.0135  0.0405  0.0676  0.0135  0.0135  0.0270
0.1757  0.0135  0.0270  0.0811  0.0676  0.0135  0.0270  0.0541  0.1351  0.0270
      19
     1       5      11      13      16      18      20      21      22      29
    37      40      45      50      51      53      56      57      62
0.0952  0.0476  0.0476  0.0952  0.0476  0.0238  0.0238  0.0476  0.0238  0.0238
0.0238  0.0238  0.0476  0.0714  0.0952  0.1667  0.0476  0.0238  0.0238
       9
    11      17      18      19      22      28      45      55      56
```

```
0.0714  0.1429  0.0714  0.2143  0.0714  0.0714  0.0714  0.2143  0.0714
        9
     1       3      17      19      20      22      28      44      52
0.0870  0.0870  0.3043  0.1739  0.0870  0.0435  0.0870  0.0435  0.0870
        9
     1       3       5      16      18      19      20      26      27
0.0435  0.0435  0.0435  0.1304  0.1304  0.3043  0.0435  0.2174  0.0435
        4
     5      16      19      20
0.3077  0.0769  0.5385  0.0769
       11
     1       3       5      13      14      17      19      20      21      32
    37
0.3696  0.0870  0.0435  0.0652  0.0870  0.0217  0.0652  0.1304  0.0652  0.0435
0.0217
        7
     1       3       5      13      17      18      19
0.2083  0.2500  0.0833  0.2083  0.0417  0.0833  0.1250
    0.30       0.20       0.50       0.80       0.20       1.00       0.90       0.00
    0.40       0.40       0.20       0.10       0.90       0.90       0.90       0.80
    0.00       0.45
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
    0.00       0.00
    0.10       0.10       0.20       0.25       0.10       0.40       0.30       0.02
    0.15       0.15       0.10       0.10       0.35       0.25       0.25       0.02
    0.02       0.25
  3   0.149   0.151   0.098  16.000     A   0.000   0.280 0.02700   0.500   11
  7   0.149   0.151   0.098  25.000     A   0.000   0.280 0.00100   0.500   10
  6   0.149   0.151   0.098  16.000     A   0.000   0.280 0.00100   0.500   11
  3   0.149   0.151   0.098  25.000     A   0.000   0.280 0.02700   0.500   10
  4   0.149   0.151   0.098  16.000     A   0.000   0.280 0.00600   0.500   11
  7   0.149   0.151   0.098  16.000     A   0.000   0.280 0.00100   0.500   11
  3   0.149   0.151   0.098  16.000     A   0.000   0.240 0.02700   0.500   12
  4   0.149   0.151   0.098  25.000     A   0.000   0.280 0.00600   0.500   10
  7   0.149   0.151   0.098  12.000     A   0.000   0.370 0.00100   0.500   17
  7   0.140   0.160   0.140  13.000     A   0.000   0.320 0.00100   0.500   31
  2   0.149   0.151   0.098  16.000     A   0.000   0.280 0.33800   0.500   11
  2   0.140   0.160   0.140  13.000     A   0.000   0.320 0.33800   0.500   31
  3   0.149   0.151   0.098  12.000     A   0.000   0.370 0.02700   0.500   17
  3   0.153   0.090   0.040  22.000     A   0.000   0.000 0.02700   0.500   21
  2   0.149   0.151   0.098  12.000     A   0.000   0.370 0.33800   0.500   17
  4   0.149   0.151   0.098  12.000     A   0.000   0.370 0.00600   0.500   17
  3   0.153   0.090   0.160  14.100     A   0.000   0.320 0.02700   0.500    6
  4   0.140   0.160   0.140  13.000     A   0.000   0.320 0.00600   0.500   31
  4   0.153   0.090   0.040  22.000     A   0.000   0.000 0.00600   0.500   21
  4   0.149   0.151   0.098  12.000     A   0.000   0.320 0.00600   0.500   18
  6   0.149   0.151   0.098  12.000     A   0.000   0.370 0.00100   0.500   17
  3   0.140   0.160   0.140  13.000     A   0.000   0.320 0.02700   0.500   31
  2   0.149   0.151   0.098  25.000     A   0.000   0.280 0.33800   0.500   10
  4   0.153   0.090   0.160  15.600     A   0.000   0.320 0.00600   0.500    5
  4   0.149   0.151   0.098   4.800     A   0.000   0.370 0.00600   0.500   20
  4   0.106   0.183   0.117  21.000     A   0.000   0.240 0.00600   0.500    2
  4   0.106   0.183   0.117  25.000     A   0.000   0.240 0.00600   0.500    1
  6   0.153   0.090   0.040  22.000     A   0.000   0.000 0.00100   0.500   21
  6   0.106   0.183   0.117  21.000     A   0.000   0.240 0.00100   0.500    2
  6   0.106   0.183   0.117  25.000     A   0.000   0.240 0.00100   0.500    1
```

3	0.153	0.090	0.160	15.600	A	0.000	0.320	0.02700	0.500	5
4	0.149	0.151	0.098	16.000	A	0.000	0.240	0.00600	0.500	12
4	0.153	0.090	0.160	14.100	A	0.000	0.320	0.00600	0.500	6
4	0.140	0.160	0.140	18.000	A	0.000	0.320	0.00600	0.500	30
3	0.140	0.160	0.140	18.000	A	0.000	0.320	0.02700	0.500	30
6	0.149	0.151	0.098	12.000	A	0.000	0.320	0.00100	0.500	18
3	0.149	0.151	0.098	8.000	A	0.000	0.430	0.02700	0.500	19
6	0.140	0.160	0.140	18.000	A	0.000	0.320	0.00100	0.500	30
2	0.153	0.090	0.160	20.500	A	0.000	0.320	0.33800	0.500	4
6	0.106	0.183	0.117	16.000	A	0.000	0.240	0.00100	0.500	3
7	0.153	0.090	0.160	15.600	A	0.000	0.320	0.00100	0.500	5
4	0.153	0.090	0.160	20.500	A	0.000	0.320	0.00600	0.500	4
6	0.149	0.151	0.098	16.000	A	0.000	0.240	0.00100	0.500	12
4	0.106	0.183	0.117	16.000	A	0.000	0.240	0.00600	0.500	3
2	0.153	0.090	0.160	14.100	A	0.000	0.320	0.33800	0.500	6
7	0.106	0.183	0.117	16.000	A	0.000	0.240	0.00100	0.500	3
7	0.153	0.090	0.040	22.000	A	0.000	0.000	0.00100	0.500	21
7	0.153	0.090	0.160	14.100	A	0.000	0.320	0.00100	0.500	6
6	0.140	0.160	0.140	13.000	A	0.000	0.320	0.00100	0.500	31
6	0.149	0.151	0.098	8.000	A	0.000	0.430	0.00100	0.500	19
2	0.106	0.183	0.117	21.000	A	0.000	0.240	0.33800	0.500	2
2	0.153	0.090	0.160	15.600	A	0.000	0.320	0.33800	0.500	5
3	0.106	0.183	0.117	21.000	A	0.000	0.240	0.02700	0.500	2
6	0.153	0.090	0.160	15.600	A	0.000	0.320	0.00100	0.500	5
2	0.153	0.090	0.160	14.100	A	0.000	0.280	0.33800	0.500	8
4	0.149	0.151	0.098	8.000	A	0.000	0.430	0.00600	0.500	19
2	0.149	0.151	0.098	8.000	A	0.000	0.430	0.33800	0.500	19
3	0.106	0.183	0.117	16.000	A	0.000	0.240	0.02700	0.500	3
3	0.106	0.183	0.117	16.000	A	0.000	0.240	0.02700	0.500	33
3	0.153	0.090	0.160	15.600	A	0.000	0.280	0.02700	0.500	7
4	0.153	0.090	0.160	15.600	A	0.000	0.280	0.00600	0.500	7
2	0.153	0.090	0.040	22.000	A	0.000	0.000	0.33800	0.500	21
6	0.141	0.093	0.085	13.700	A	0.000	0.320	0.00100	0.500	27
4	0.141	0.093	0.085	13.700	A	0.000	0.320	0.00600	0.500	27
6	0.153	0.090	0.160	14.100	A	0.000	0.320	0.00100	0.500	6
3	0.140	0.160	0.140	12.000	A	0.000	0.320	0.02700	0.500	32
3	0.153	0.090	0.160	14.100	A	0.000	0.280	0.02700	0.500	8
6	0.153	0.090	0.160	15.600	A	0.000	0.280	0.00100	0.500	7
4	0.153	0.090	0.160	14.100	A	0.000	0.280	0.00600	0.500	8
7	0.153	0.090	0.160	14.100	A	0.000	0.280	0.00100	0.500	8
7	0.153	0.090	0.160	15.600	A	0.000	0.280	0.00100	0.500	7
6	0.153	0.090	0.160	14.100	A	0.000	0.280	0.00100	0.500	8
3	0.141	0.093	0.085	20.200	A	0.000	0.320	0.02700	0.500	15
3	0.153	0.090	0.160	20.500	A	0.000	0.320	0.02700	0.500	4
6	0.141	0.093	0.085	17.500	A	0.000	0.280	0.00100	0.500	29
7	0.106	0.183	0.117	21.000	A	0.000	0.240	0.00100	0.500	2
2	0.140	0.160	0.140	12.000	A	0.000	0.320	0.33800	0.500	32
2	0.153	0.090	0.160	15.600	A	0.000	0.280	0.33800	0.500	7
4	0.141	0.093	0.085	17.500	A	0.000	0.280	0.00600	0.500	29
6	0.141	0.093	0.085	15.300	A	0.000	0.320	0.00100	0.500	16
6	0.141	0.093	0.085	18.500	A	0.000	0.280	0.00100	0.500	28
4	0.141	0.093	0.085	19.500	A	0.000	0.320	0.00600	0.500	25
2	0.141	0.093	0.085	17.500	A	0.000	0.280	0.33800	0.500	29
4	0.141	0.093	0.085	15.300	A	0.000	0.320	0.00600	0.500	16
6	0.141	0.093	0.085	14.700	A	0.000	0.320	0.00100	0.500	14
2	0.141	0.093	0.085	19.500	A	0.000	0.320	0.33800	0.500	25
7	0.141	0.093	0.085	15.300	A	0.000	0.320	0.00100	0.500	16

```
 7   0.141   0.093   0.085  14.700     A   0.000   0.320 0.00100   0.500   14
 6   0.149   0.151   0.098   4.800     A   0.000   0.370 0.00100   0.500   20
 4   0.141   0.093   0.085  10.300     A   0.000   0.000 0.00600   0.500   34
 6   0.141   0.093   0.085  10.300     A   0.000   0.000 0.00100   0.500   34
 4   0.141   0.093   0.085  10.000     A   0.000   0.240 0.00600   0.500    9
 4   0.141   0.093   0.085  18.500     A   0.000   0.280 0.00600   0.500   28
 4   0.141   0.093   0.085  19.500     A   0.000   0.320 0.00600   0.500   13
 7   0.141   0.093   0.085  13.700     A   0.000   0.320 0.00100   0.500   27
 6   0.141   0.093   0.085  14.700     A   0.000   0.320 0.00100   0.500   26
 6   0.141   0.093   0.085  10.000     A   0.000   0.240 0.00100   0.500    9
 6   0.141   0.093   0.085  17.500     A   0.000   0.240 0.00100   0.500   22
 6   0.141   0.093   0.085  12.500     A   0.000   0.240 0.00100   0.500   23
 4   0.153   0.090   0.160  15.600     A   0.000   0.280 0.00600   0.500   35
 4   0.141   0.093   0.085  17.500     A   0.000   0.240 0.00600   0.500   22
 3   0.141   0.093   0.085  19.500     A   0.000   0.320 0.02700   0.500   25
 4   0.153   0.090   0.160  14.000     A   0.000   0.240 0.00600   0.500   24
 6   0.153   0.090   0.160  14.000     A   0.000   0.240 0.00100   0.500   24
 6   0.141   0.093   0.085  19.500     A   0.000   0.320 0.00100   0.500   13
 3   0.141   0.093   0.085  19.500     A   0.000   0.320 0.02700   0.500   13
 7   0.141   0.093   0.085  19.500     A   0.000   0.320 0.00100   0.500   13
 7   0.153   0.090   0.160  14.000     A   0.000   0.240 0.00100   0.500   24
   150        50
0    0    1    0    1    0    0    0    1    1    1    0    0    1    0    1
1
1    2
3    4
7    8
6    9
5   10
12  13
14  15
11  16
0
6
1    1    1    1    1    1
   300        25      10.5      1740
   610        40      31.5      1320
  1020        95      37.1      1470
   360        80      13.0      1740
   800       105      17.9      1320
  1740       155      47.6      1470
  1740        90     .1200     25.00
  1320        50     .1200     25.00
  1470        30     .1200     25.00
4
1    1    1    1
   300        45      13.0      1730
   200        35       1.8       740
   540        40      13.6      1730
   750        45      10.5       740
  1730       110     .1200     25.00
   740        30     .1200     25.00
2
1    1
   280        40       5.6      1200
   280        35       6.7      1200
  1200        15     .0900     50.00
```

```
2
1    1
   280         35        8.0       1600
   650         75       32.1       1600
  1600         95      .1200      25.00
2
1    1
   270         35        3.7        820
   250         45        2.5        820
   820         15      .0900      50.00
8
1    1    1    1    1    1    1    1
   290         55        7.4       1230
   400         40        4.9        570
   380         40        3.1        460
   475         45        5.6        860
   360         25        8.0       1230
   350         35        9.3        770
   580         45        9.3        260
   380         60       10.5        860
  1230        110      .1200      25.00
   570         25      .1200      25.00
   200         10      .1200      25.00
  1120         35      .1200      25.00
6
1    1    1    1    1    1
   280         55        1.8        870
   640         55       16.7        410
   770         60       11.7        720
   610         70       17.3        870
   380         65        5.6        410
   270         40        3.7        720
   870        100      .1200      25.00
   410         20      .1200      25.00
   820         20      .1200      25.00
4
1    1    1    1
   290         60       10.5       1180
   200         55        6.8       1340
   550         75       21.0       1180
   375         45        9.9       1340
  1180        160      .1200      25.00
  1340         60      .1200      25.00
2
1    1
   300         45        2.5        500
   310         35        4.3        500
   500         20      .1200      25.00
4
1    1    1    1
   880        115       53.1       1800
  1220         75       30.9       2230
   615         75       29.6       1800
   310         55       14.8       2230
  1800         35      .0900      50.00
  2230         30      .0900      50.00
2
```

```
1    1
   300         30        2.5        500
   310         45        3.7        500
   500          5      .0900      50.00
6
1    1    1    1    1    1
   250         25       10.5        820
   540         40        6.2        650
   580         35       13.0       1150
   550         45       10.5        820
   520         35        5.6        650
   290         35        6.8       1150
   820         60      .1200      25.00
   650         20      .1200      25.00
  1150         40      .1200      25.00
2
1    1
   300         25       17.3       2120
   340         40       27.8       2120
  2120        140      .1200      25.00
2
1    1
   230         25        3.1        540
   300         35        4.9        540
   540         15      .1200      25.00
4
1    1    1    1
   260         25        6.2        840
  1160        200       32.7        870
   280         35       11.1        840
   900         55       19.8        870
   840         80      .1200      25.00
   870         35      .1200      25.00
4
1    1    1    1
   895         85       45.7       1140
  1100         85       25.9       1200
   610         65        8.6       1140
   465         80       14.2       1200
  1140         30      .0900      50.00
  1200         25      .0900      50.00
4
1    1    1    1
   700         55       14.2       1000
   620         40        8.0       1000
  1190         80       28.4       1000
   640         60       14.8       1000
  1000          7      .0700      75.00
  1000          7      .0700      75.00
```

11.5.2 Brush Creek Watershed "Lumped" Data File

```
    1    1       600       600
 0 0 0 0 0 0 0
 0         0         0         0         0         0         1
BRUSH CREEK LIMITED DATA BASE:  DESIGN STORM 2  (25yr-6hr)
         1         6        10       900      1.00
    1    1    1   87
   0.07000   0.08000   0.10000   0.10000   0.12000   0.13000   0.23000   0.27000
   0.79000   0.78000   0.26000   0.23000   0.16000   0.17000   0.14000   0.11000
   0.12000   0.10000   0.11000   0.08000   0.09000   0.09000   0.08000   0.09000
   .30  0.30  0.30  0.45  0.60  0.80  0.90  0.90  0.75  0.40  0.30  0.30
         7        26         6        18
         2
      1       3
  0.8889  0.1111
         2
      1       3
  0.7273  0.2727
         4
      1       2       3       4
  0.5789  0.2632  0.0789  0.0789
         2
      1       2
  0.8182  0.1818
         3
      1       2       3
  0.2222  0.6111  0.1667
         2
      1       2
  0.6250  0.3750
         1
      1
  1.0000
         2
      1       2
  0.4444  0.5556
         2
      2       5
  0.6667  0.3333
         3
      1       2       5
  0.1667  0.7500  0.0833
         4
      1       2       5       6
  0.1111  0.2222  0.5556  0.1111
         2
      1       2
  0.3000  0.7000
         2
      1       2
  0.9583  0.0417
         2
      1       3
  0.6364  0.3636
         4
```

```
     2       3       5       6
0.2500  0.0833  0.5833  0.0833
       2
     1       3
0.8333  0.1667
       1
     3
1.0000
       2
     1       3
0.5000  0.5000
       2
     1       2
0.6471  0.3529
       4
     1       2       5       6
0.3846  0.1795  0.3333  0.1026
       2
     1       2
0.6667  0.3333
       4
     1       2       3       4
0.5652  0.3478  0.0435  0.0435
       2
     1       4
0.8889  0.1111
       3
     1       3       4
0.6000  0.2000  0.2000
       2
     1       3
0.5000  0.5000
       4
     1       2       3       4
0.6667  0.1333  0.1333  0.0667
    0.30       0.20       0.50       0.80       0.20       1.00       0.90       0.00
    0.40       0.40       0.20       0.10       0.90       0.90       0.90       0.80
    0.00       0.45
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
   00.00       0.00
    0.10       0.10       0.20       0.25       0.10       0.40       0.30       0.02
    0.15       0.15       0.10       0.10       0.35       0.25       0.25       0.02
    0.02       0.25
  4   0.139   0.089   0.335  13.000     A   0.000   0.320 0.00600   0.500     2
  6   0.139   0.089   0.335  13.000     A   0.000   0.320 0.00100   0.500     2
  4   0.139   0.089   0.335  16.000     A   0.000   0.320 0.00600   0.500     1
  6   0.139   0.089   0.335  16.000     A   0.000   0.320 0.00100   0.500     1
  6   0.139   0.089   0.335  10.000     A   0.000   0.320 0.00100   0.500     3
  4   0.139   0.089   0.335  10.000     A   0.000   0.320 0.00600   0.500     3
     150         50
  0    0    0    1    1    0    1
  2    3
  1    4
  5    6
  0
  6
```

```
1    1    1    1    1    1
   500         40        22.2       2500
  1750        120        54.4       1000
  2100        135        93.9       2300
   600        120        27.2       2500
  1200        150        44.5       1000
   500         70        19.8       2300
  2500        120       .1200      45.00
  1000         30       .1200      45.00
  2300         40       .0900      75.00
2
1    1
   300         50        19.8       2750
   600         80        44.5       2750
  2750        210       .1200      45.00
4
1    1    1    1
   350         80         7.4       1000
  1500        150        59.3       1800
   600        180        22.2       1000
   500         90        24.7       1800
  1000        100       .1200      45.00
  1800         70       .1200      45.00
4
1    1    1    1
  1750        110        59.3       1500
  1100        100        27.2       1600
  1100        140        29.6       1500
   600         90        14.8       1600
  1500         20       .0900      75.00
  1600         20       .0900      75.00
2
1    1
   300         30         2.5        400
   500         45         4.9        400
   400         15       .0900      75.00
6
1    1    1    1    1    1
   800         80        42.0       2500
  1750        250        96.4       1000
  1200        130        22.2       1300
  1250        130        56.8       2500
  1000        120        22.2       1000
   300         40        12.4       1300
  2500        110       .1200      45.00
  1000         25       .1200      45.00
  1300         25       .0900      75.00
2
1    1
  1000        100        24.7       1100
  1400        120        37.1       1100
  1100         20       .0700     230.00
```

11.5.3 Millstone Branch Watershed Data File

```
    1    1       600       600
 0 0 0 0 0
 0             0             0             0             1
MILLSTONE BRANCH DATA BASE:  DESIGN STORM 2 (25yr-6hr)
         1         6        10       900      1.00
    1    1    1   87
   0.06000   0.06000   0.08000   0.09000   0.09000   0.10000   0.19000   0.22000
   0.64000   0.63000   0.21000   0.19000   0.13000   0.13000   0.11000   0.10000
   0.09000   0.09000   0.08000   0.07000   0.07000   0.07000   0.07000   0.07000
   .30  0.30  0.30  0.45  0.60  0.80  0.90  0.90  0.75  0.40  0.30  0.30
         5        12         7        18
         1
      2
  1.0000
         1
      1
  1.0000
         1
      1
  1.0000
         1
      1
  1.0000
         1
      1
  1.0000
         1
      1
  1.0000
         1
      1
  1.0000
         4
      1       2       3       4
  0.1250  0.1250  0.5000  0.2500
         3
      4       6       7
  0.2500  0.5000  0.2500
         2
      1       2
  0.2000  0.8000
         3
      5       6       7
  0.3333  0.3333  0.3333
     0.30      0.20      0.50      0.80      0.20      1.00      0.90      0.00
     0.40      0.40      0.20      0.10      0.90      0.90      0.90      0.80
     0.00      0.45
     0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
     0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
     0.00      0.00
     0.10      0.10      0.20      0.25      0.10      0.40      0.30      0.02
```

```
  0.15      0.15      0.10      -0.10      -0.35      0.25      0.25      0.02
  0.02      0.25
6   0.156   0.144   0.150  26.000     A   0.000   0.280 0.00100   0.500    2
6   0.117   0.210   0.150  21.000     A   0.000   0.280 0.00100   0.500    3
4   0.156   0.144   0.150  26.000     A   0.000   0.280 0.00600   0.500    2
4   0.199   0.114   0.200  15.000     A   0.000   0.280 0.00600   0.500    1
6   0.136   0.177   0.100  13.500     A   0.000   0.280 0.00100   0.500    4
6   0.199   0.114   0.200  15.000     A   0.000   0.280 0.00100   0.500    1
4   0.131   0.235   0.200  24.000     A   0.000   0.280 0.00600   0.500    5
  100         10
0   0   1   0   1
1   2
3   4
0
2
1   1
  300         140         4.9        1160
  500         220         9.9        1160
 1160         200       .1200       45.00
2
1   1
  440         180         7.4        1280
  120          80         4.9        1280
 1280         320       .1200       45.00
2
1   1
  520         180         7.4         520
  500         180         2.5         520
  520          40       .1200       45.00
2
1   1
  600         200         9.9         840
  380         120         2.5         840
  840         120       .1200       45.00
4
1   1   1   1
  700         200        19.8        1200
  280         140         9.9        1900
  520         280        12.4        1200
  220         140         7.4        1900
 1200         120       .0900       75.00
 1900         280       .0900       75.00
```

11.5.4 Right Fork Sandlick Creek Watershed Data File

```
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 0 0 0 0 0 0 0
 0       0       0       0       0       0       1
RIGHT FORK SANDLICK CREEK:  DESIGN STORM 2 (25yr-6hr)
        1        6        10        900      1.00
   1    1    1   87
    0.06000   0.06000   0.08000   0.09000   0.09000   0.11000   0.18000   0.22000
    0.64000   0.65000   0.20000   0.19000   0.13000   0.14000   0.11000   0.10000
    0.09000   0.08000   0.09000   0.07000   0.07000   0.07000   0.07000   0.07000
    .30  0.30  0.30  0.45  0.60  0.80  0.90  0.90  0.75  0.40  0.30  0.30
        7        20        1        18
        1
      1
  1.0000
        1
      1
  1.0000
        1
      1
  1.0000
        1
      1
  1.0000
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        1
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      1
  1.0000
        1
      1
  1.0000
        1
      1
  1.0000
        1
      1
  1.0000
        1
```

```
     1
1.0000
       1
     1
1.0000
       1
     1
1.0000
       1
     1
1.0000
       1
     1
1.0000
       1
     1
1.0000
    0.30       0.20       0.50       0.80       0.20       1.00       0.90       0.00
    0.40       0.40       0.20       0.10       0.90       0.90       0.90       0.80
    0.00       0.45
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
    0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
    0.00       0.00
    0.10       0.10       0.20       0.25       0.10       0.40       0.30       0.02
    0.15       0.15       0.10       0.10       0.35       0.25       0.25       0.02
    0.02       0.25
  6   0.111    0.144    0.100  12.000      A   0.000    0.230 0.00100    0.500     1
     150         50
  0    0    1    0    1    0    1
  1    2
  3    4
  5    6
  0
  4
  1    1    1    1
    1600        440       66.7       3000
     800        320       19.8       1600
     600        320       49.4       3000
    2000        520       84.0       1600
    3000        560      .1200      45.00
    1600         60      .1200      45.00
  2
  1    1
     600        280       34.6       3000
     400        200       22.2       3000
    3000        640      .1200      45.00
  4
  1    1    1    1
    2200        640       49.4        700
     800        320       34.6       2200
    1900        540       84.0        700
    1300        520       54.4       2200
     700         15      .0900      75.00
    2200         80      .0900      75.00
  4
  1    1    1    1
     200        100        9.9       1800
```

```
      600        200        4.9        800
      200        100       19.8       1800
     1700        600       51.9        800
     1800        440      .1200      45.00
      800        120      .1200      45.00
   2
   1   1
      700        240       17.3       1200
      800        320       17.3       1200
     1200         40      .0700     230.00
   2
   1   1
      600        250       27.2       2400
     1800        480       89.0       2400
     2400        480      .1200      45.00
   2
   1   1
     1400        560       22.2        700
      600        280       12.4        700
      700                   20          .0700          230.00
/*
//
```

11.6 APPENDIX F: SENSITIVITY ANALYSIS HYDROGRAPH PLOTS

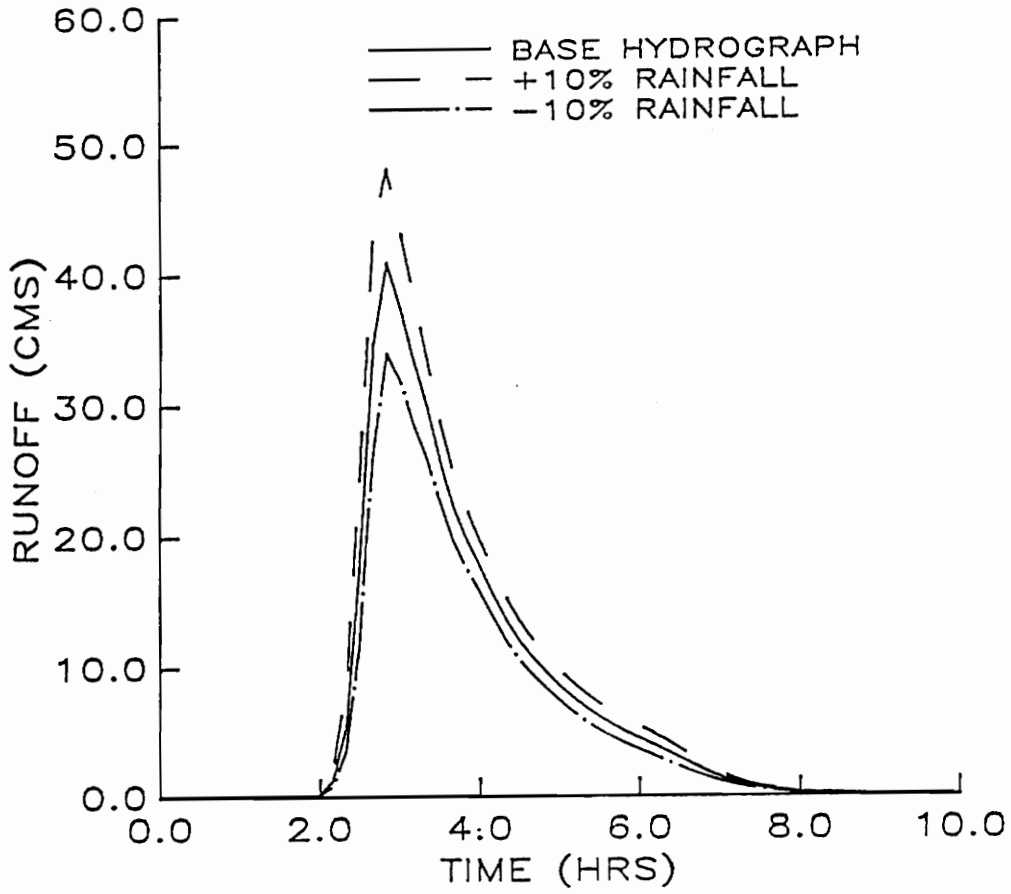

Figure F-1. The effect of rainfall volume on simulated discharge hydrographs from the Brush Creek watershed.

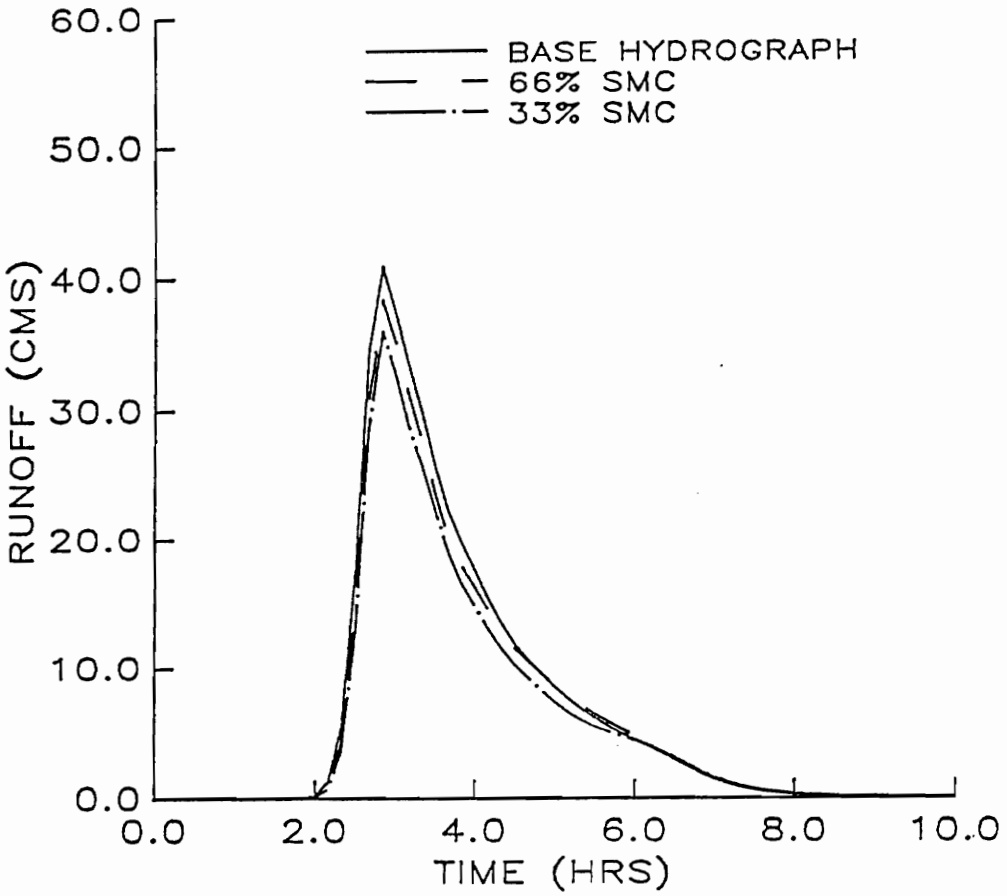

Figure F-2. The effect of antecedent soil moisture content on simulated discharge hydrographs from the Brush Creek watershed.

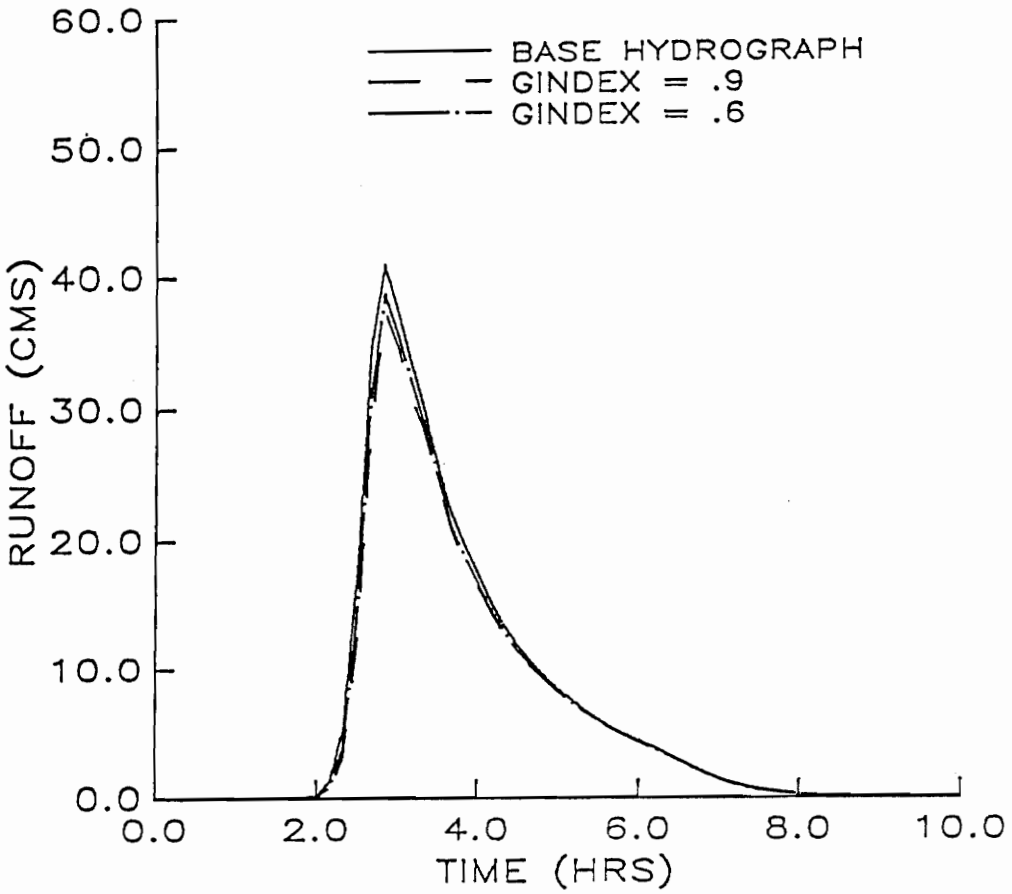

Figure F-3. The effect of growth index on simulated discharge hydrographs from the Brush Creek watershed.

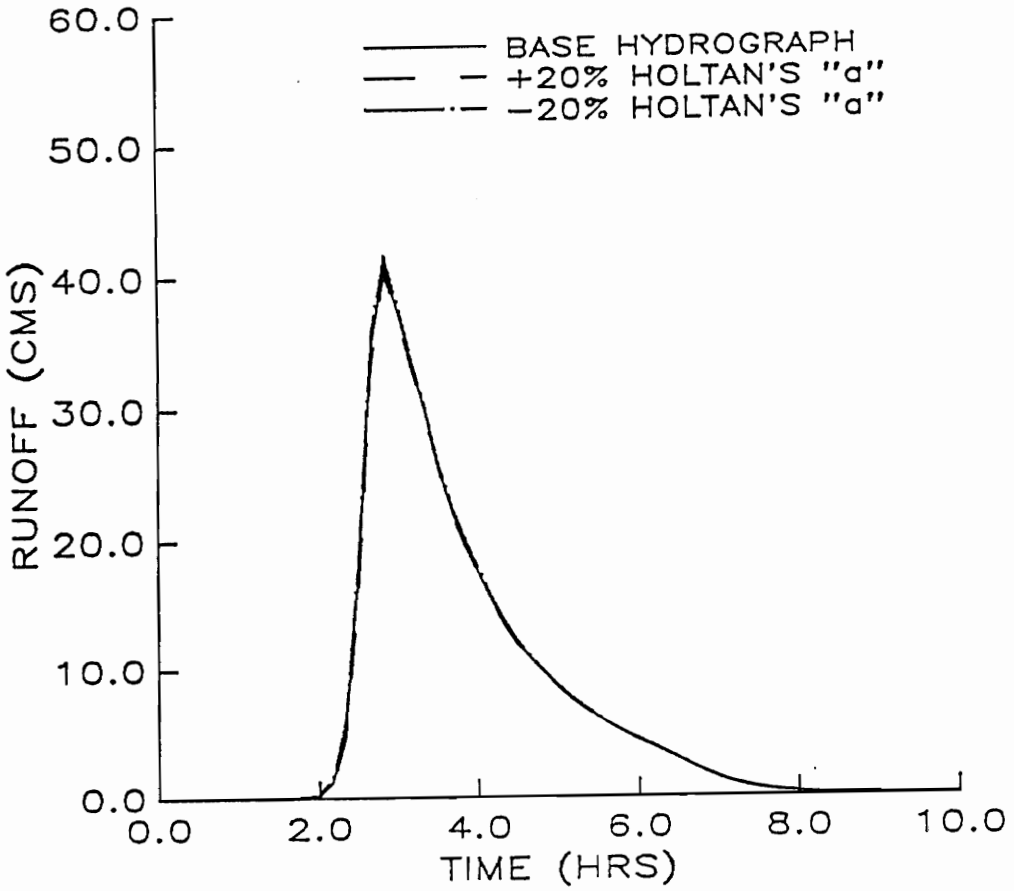

Figure F-4. The effect of Holtan's vegetative index on simulated discharge hydrographs from the Brush Creek watershed.

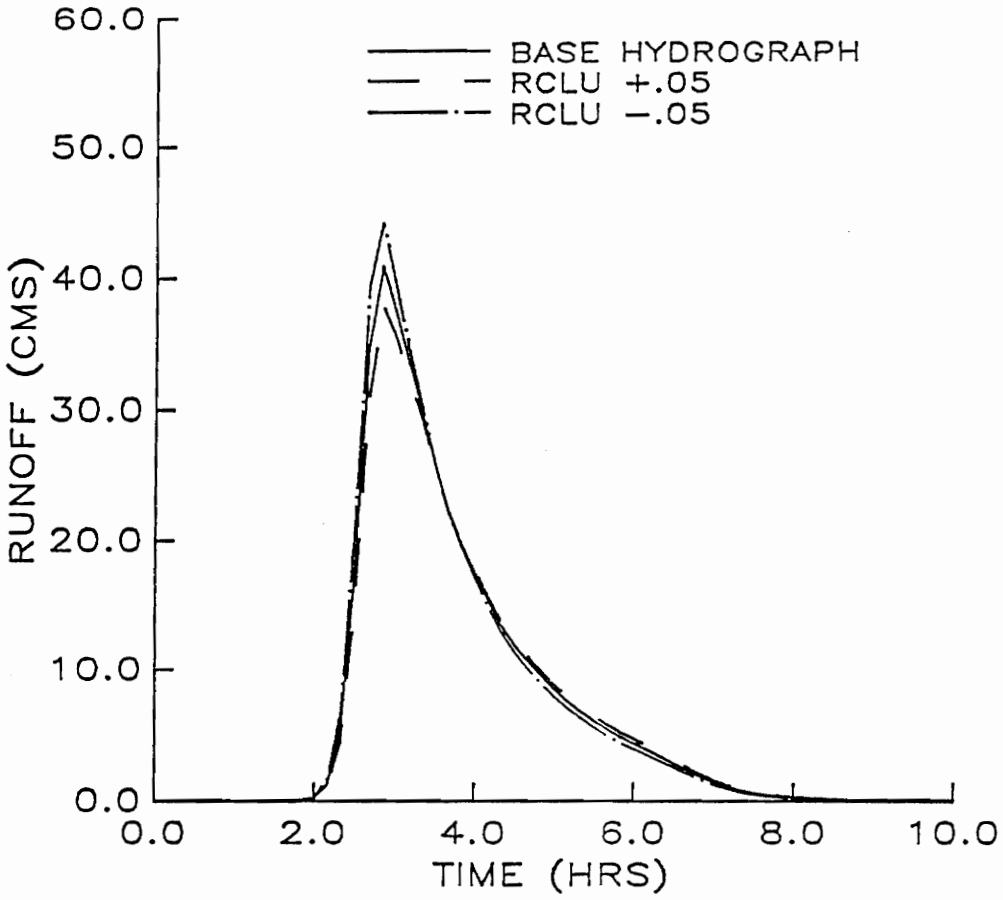

Figure F-5. The effect of overland flow roughness coefficient on simulated discharge hydrographs from the Brush Creek watershed.

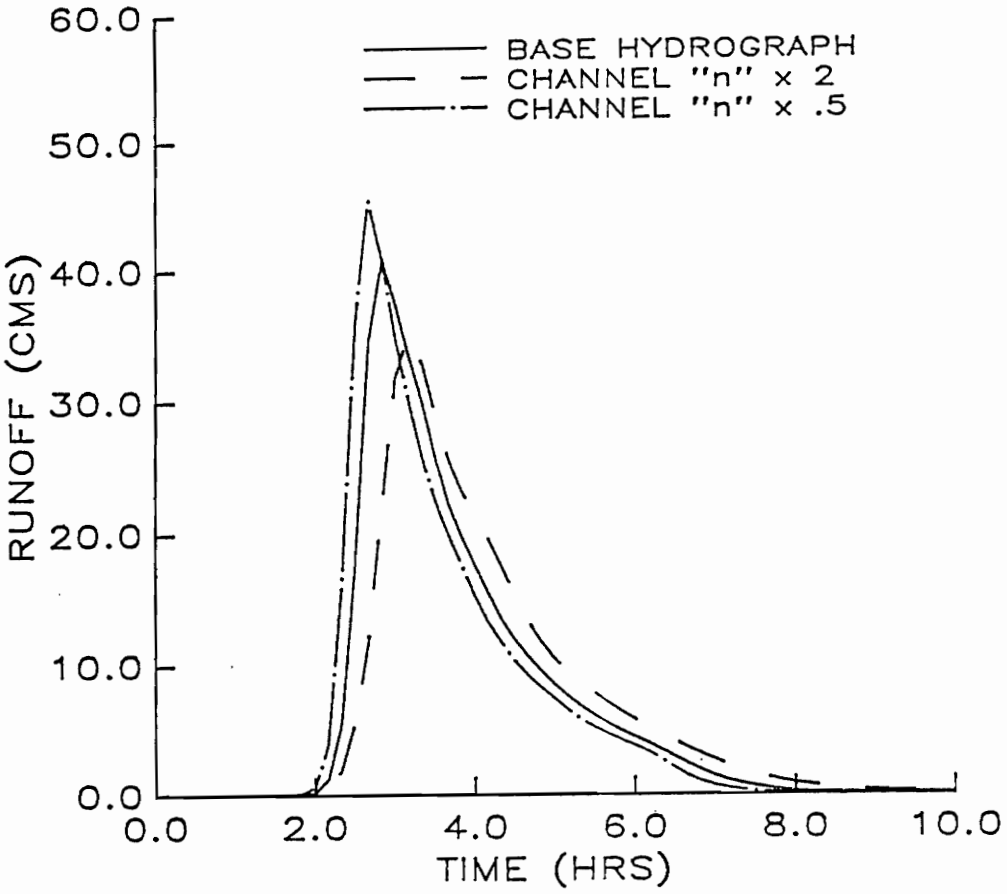

Figure F-6. The effect of channel roughness coefficient on simulated discharge hydrographs from the Brush Creek watershed.

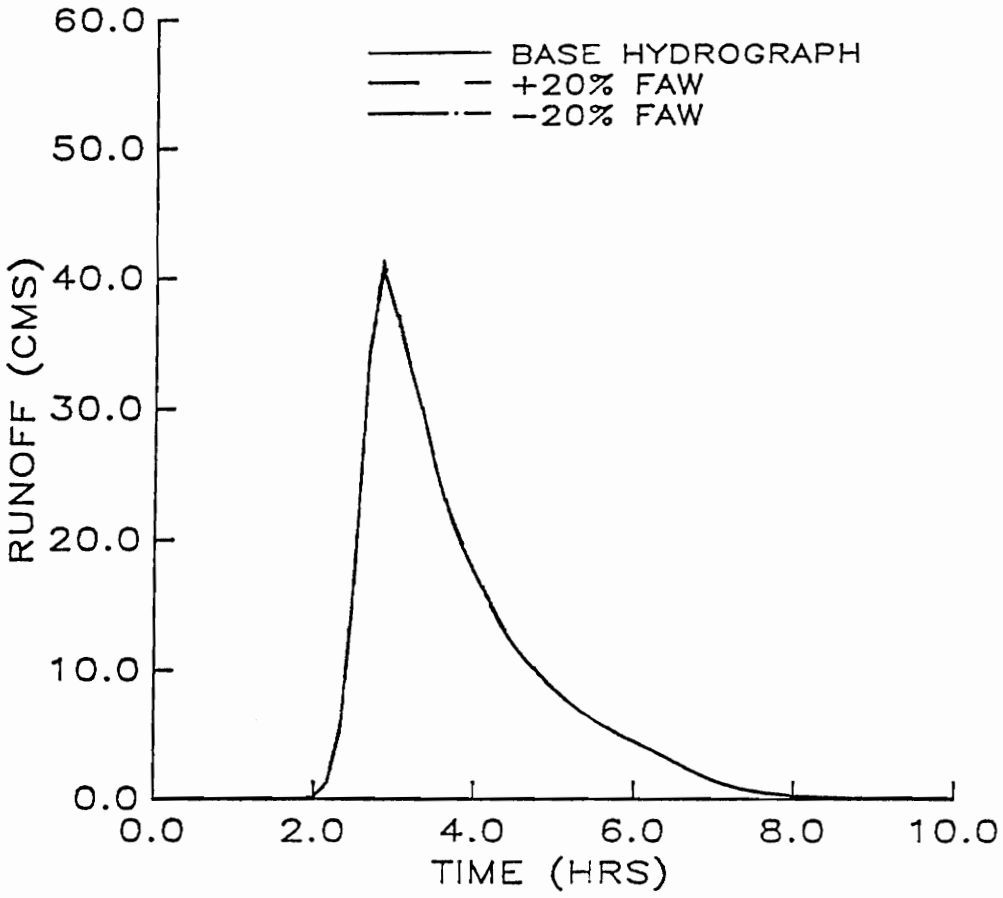

Figure F-7. The effect of plant available water on simulated discharge hydrographs from the Brush Creek watershed.

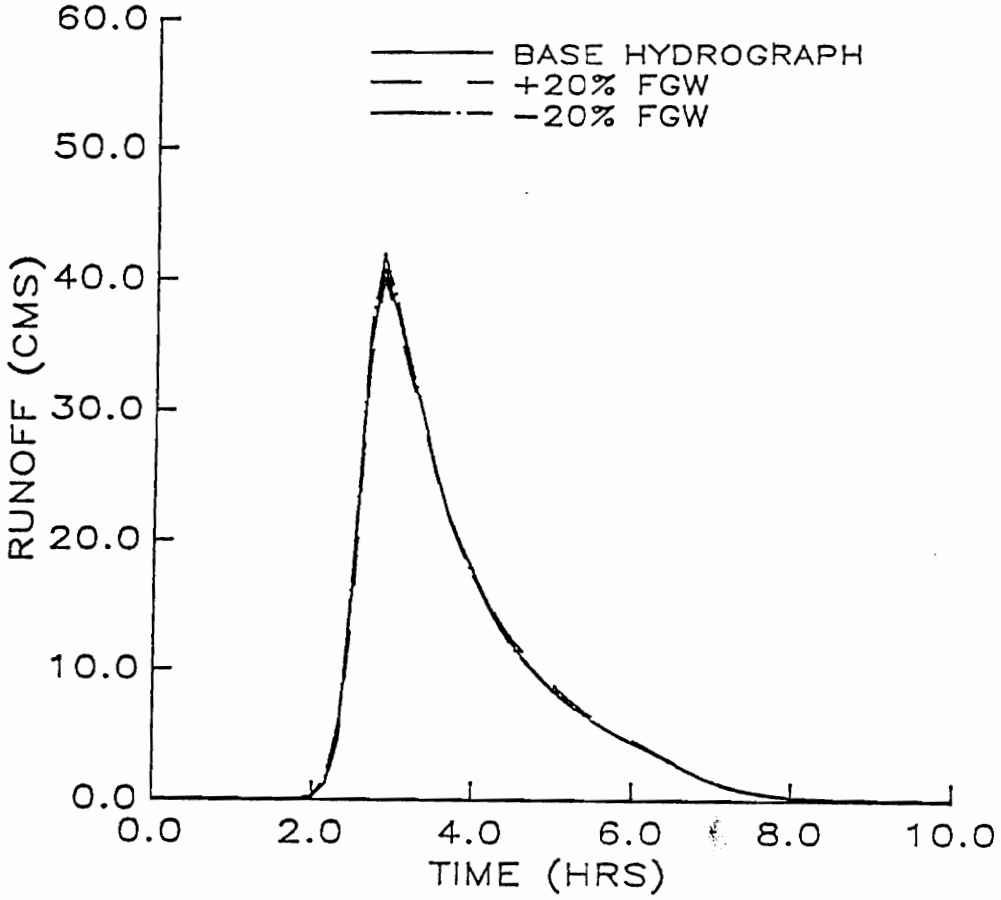

Figure F-8. The effect of gravitational water on simulated discharge hydrographs from the Brush Creek watershed.

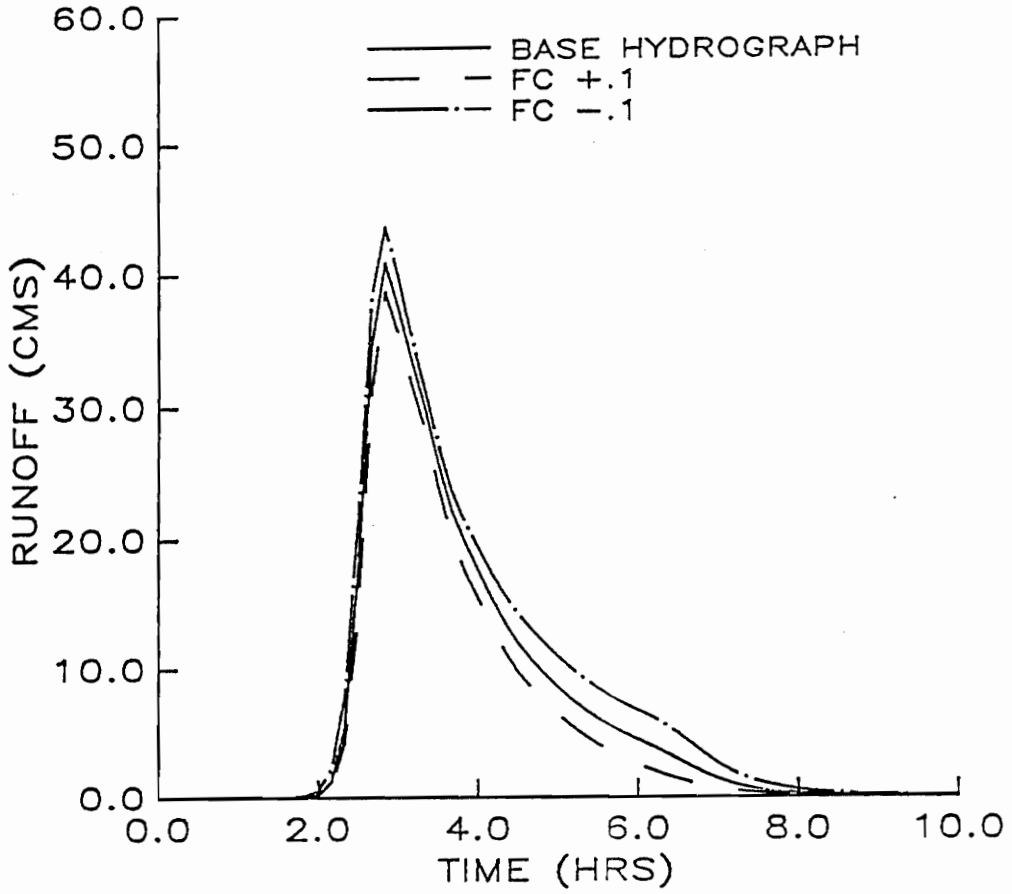

Figure F-9. The effect of final infiltration rate on simulated discharge hydrographs from the Brush Creek watershed.

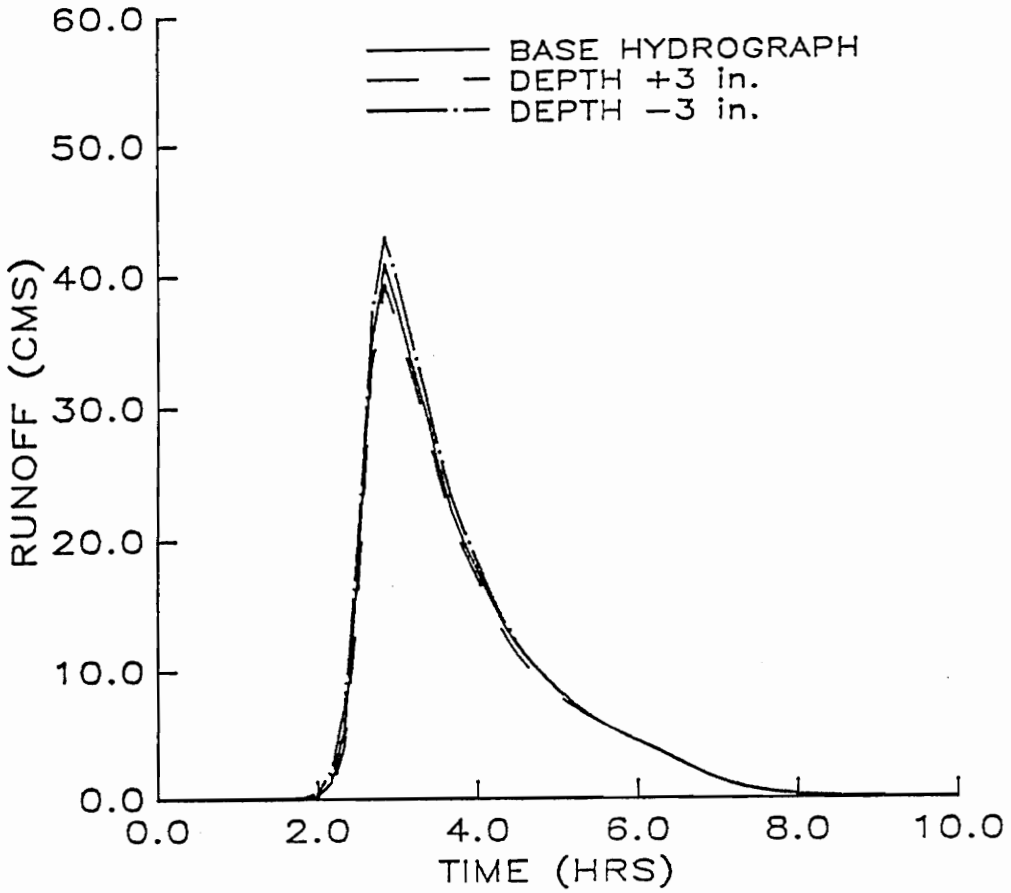

Figure F-10. The effect of depth of soil profile on simulated discharge hydrographs from the Brush Creek watershed.

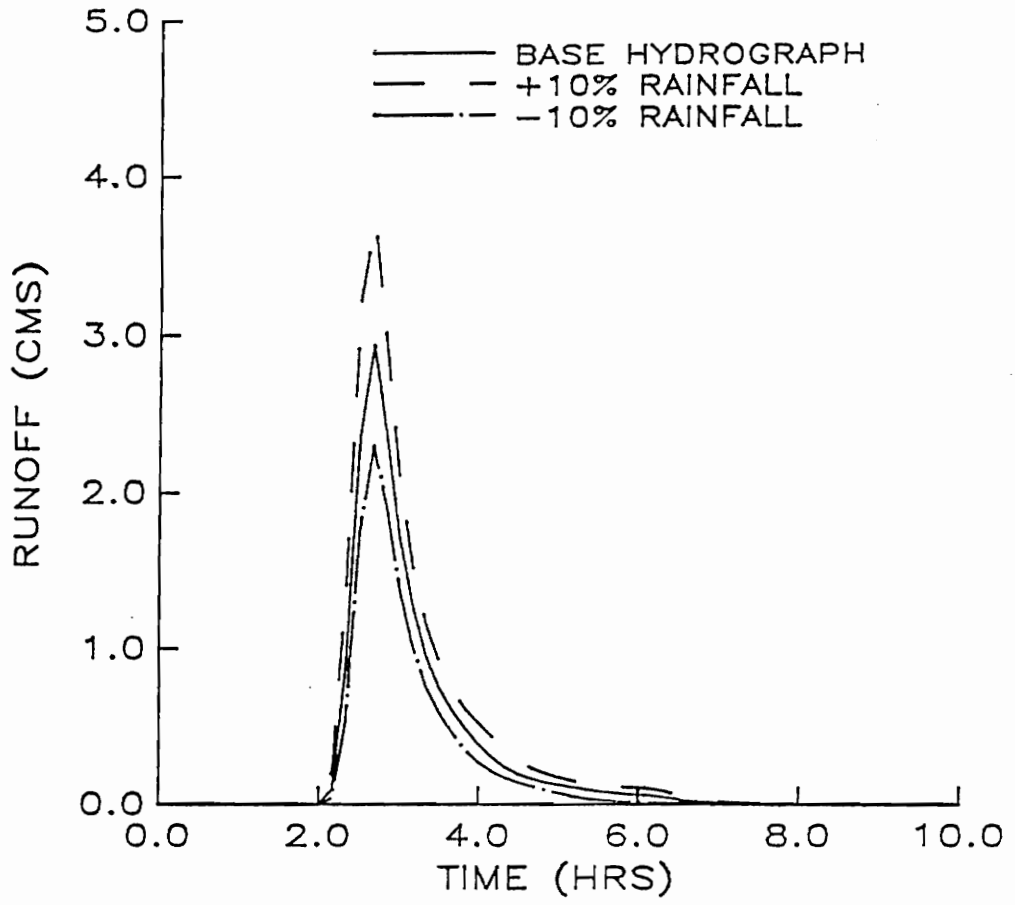

Figure F-11. The effect of rainfall volume on simulated discharge hydrographs from the Millstone Branch watershed.

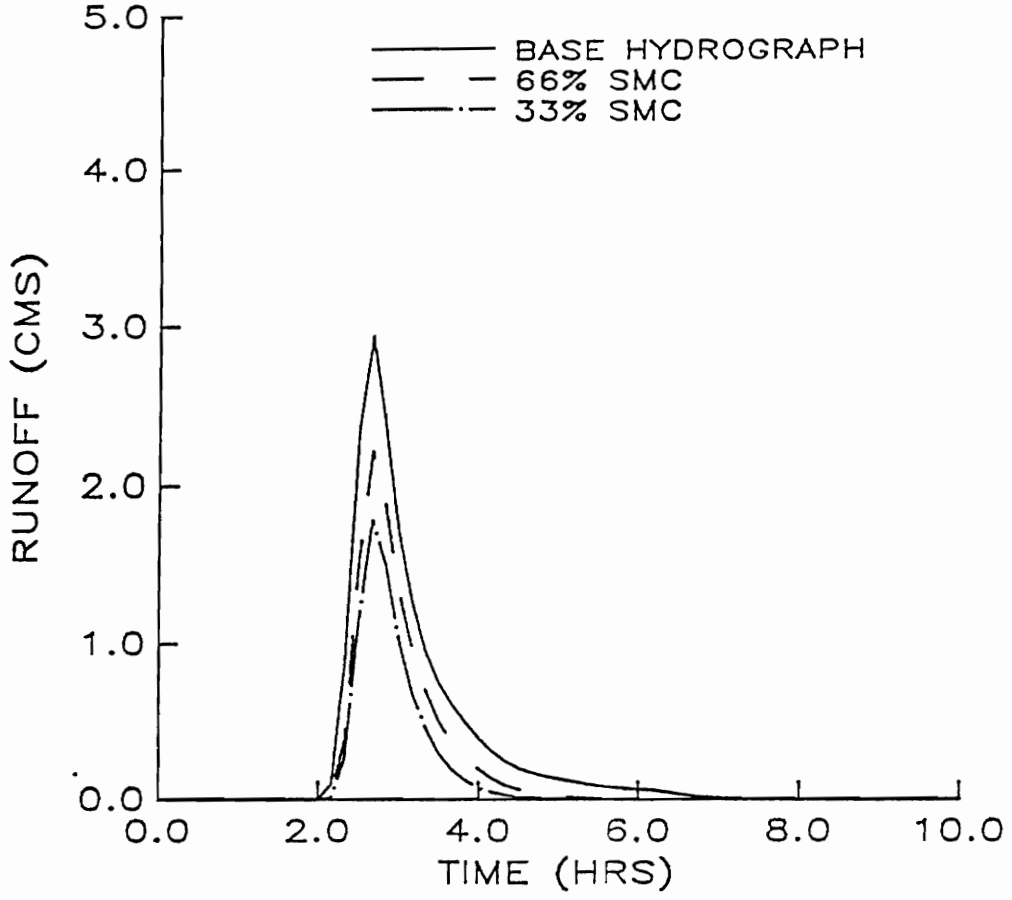

Figure F-12. The effect of antecedent soil moisture content on simulated discharge hydrographs from the Millstone Branch watershed.

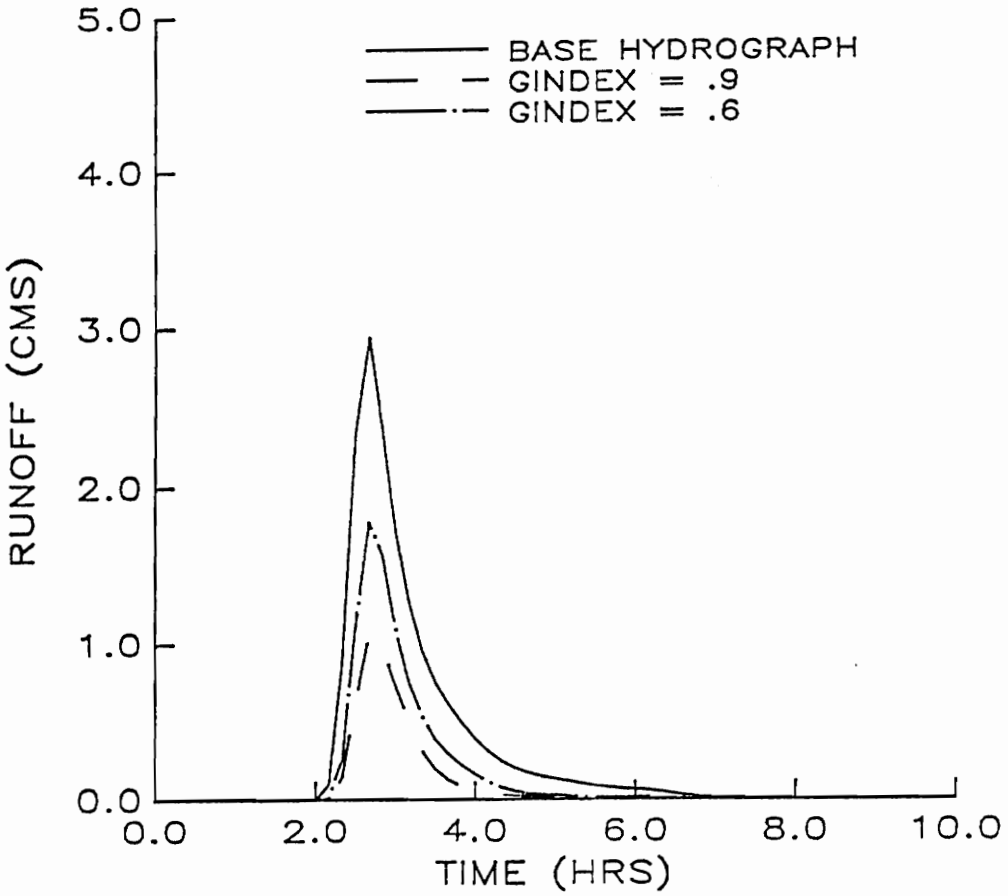

Figure F-13. The effect of growth index on simulated discharge hydrographs from the Millstone Branch watershed.

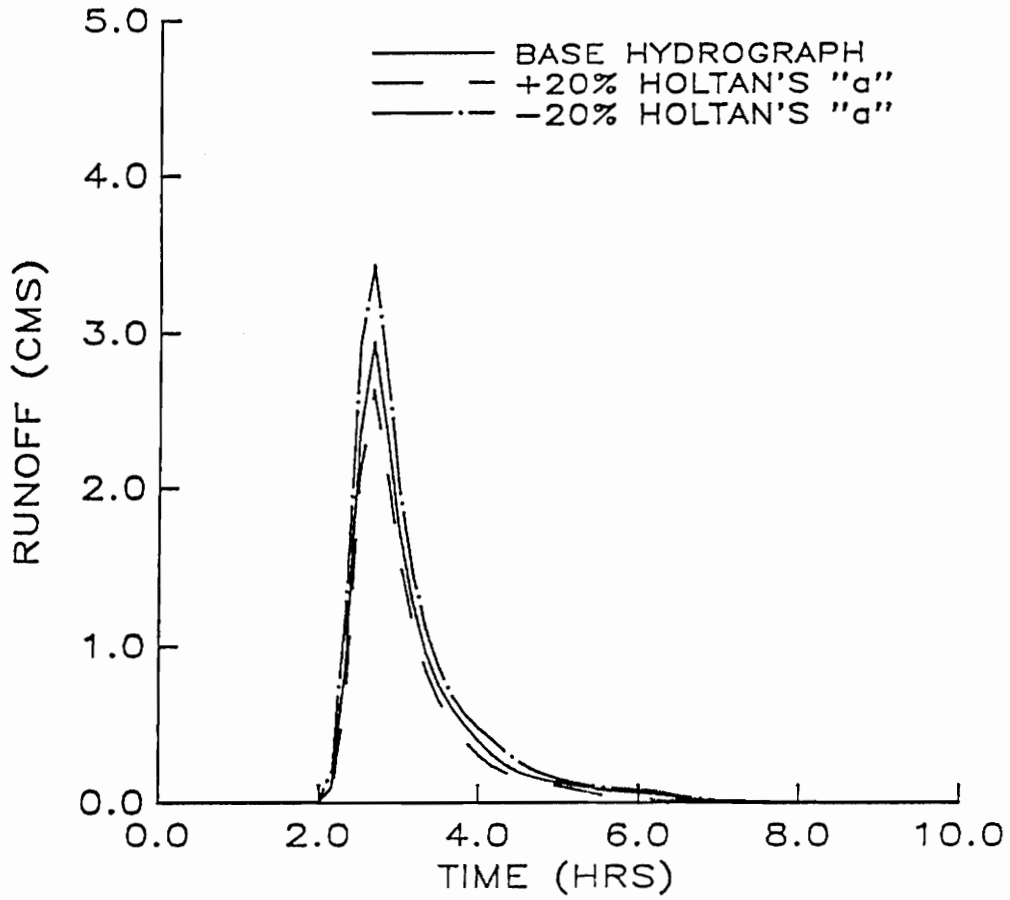

Figure F-14. The effect of Holtan's vegetative index on simulated discharge hydrographs from the Millstone Branch watershed.

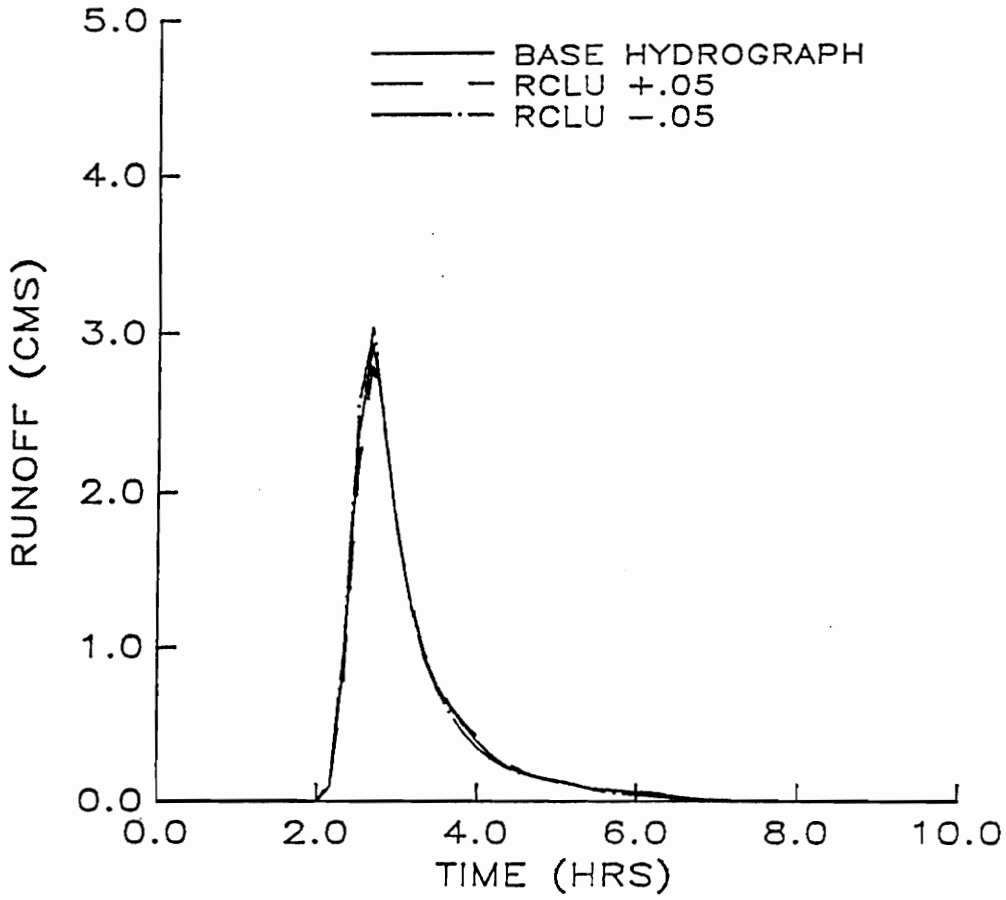

Figure F-15. The effect of overland flow roughness coefficient on simulated discharge hydrographs from the Millstone Branch watershed.

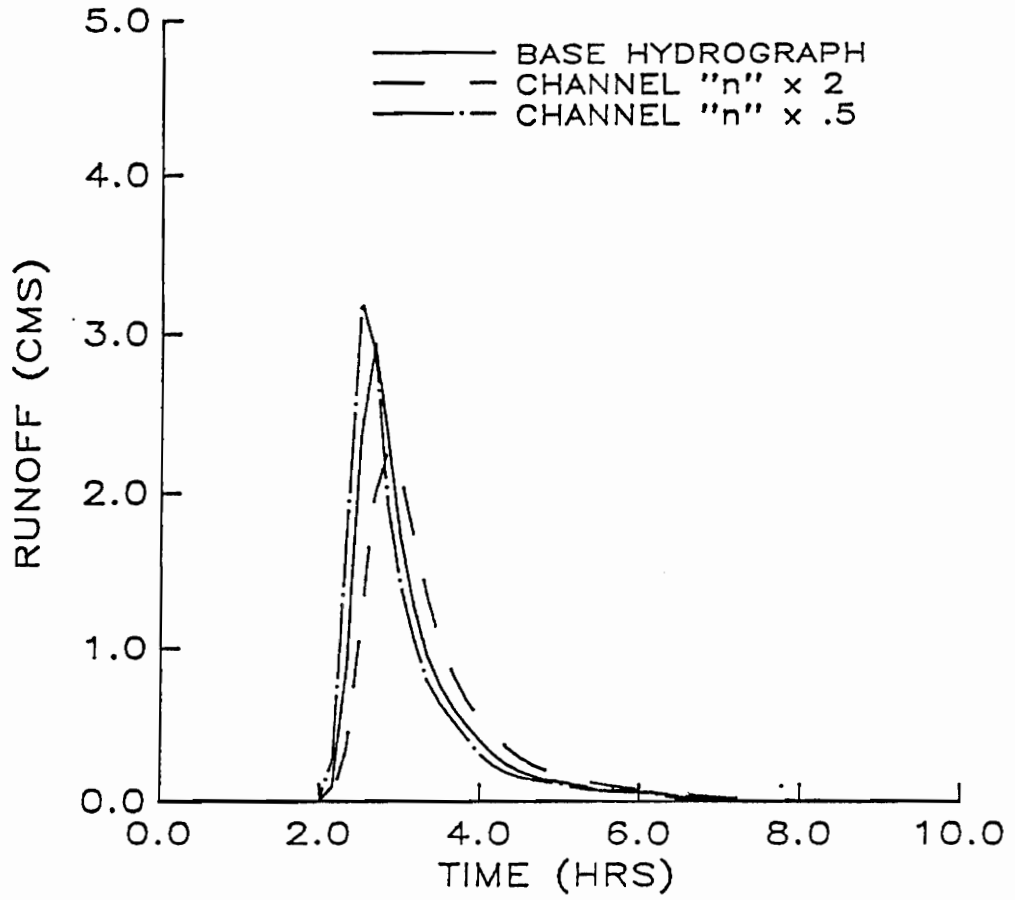

Figure F-16. The effect of channel roughness coefficient on simulated discharge hydrographs from the Millstone Branch watershed.

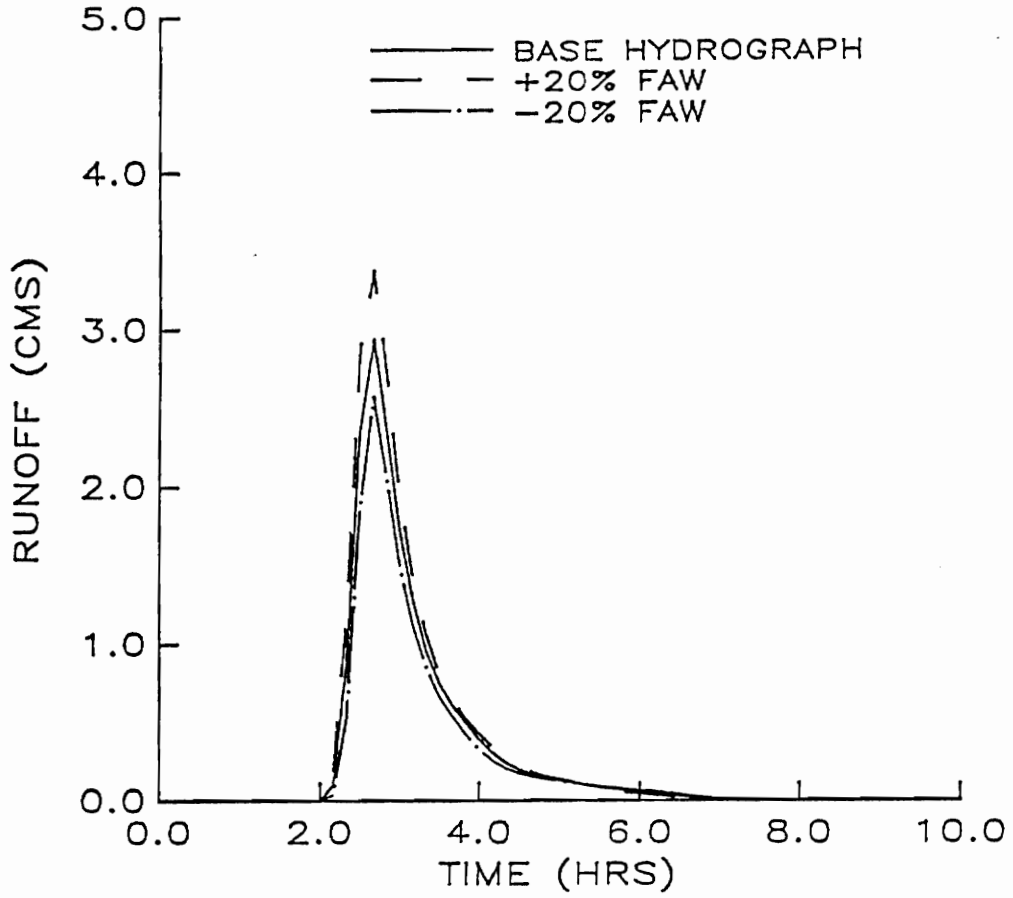

Figure F-17. The effect of plant available water on simulated discharge hydrographs from the Millstone Branch watershed.

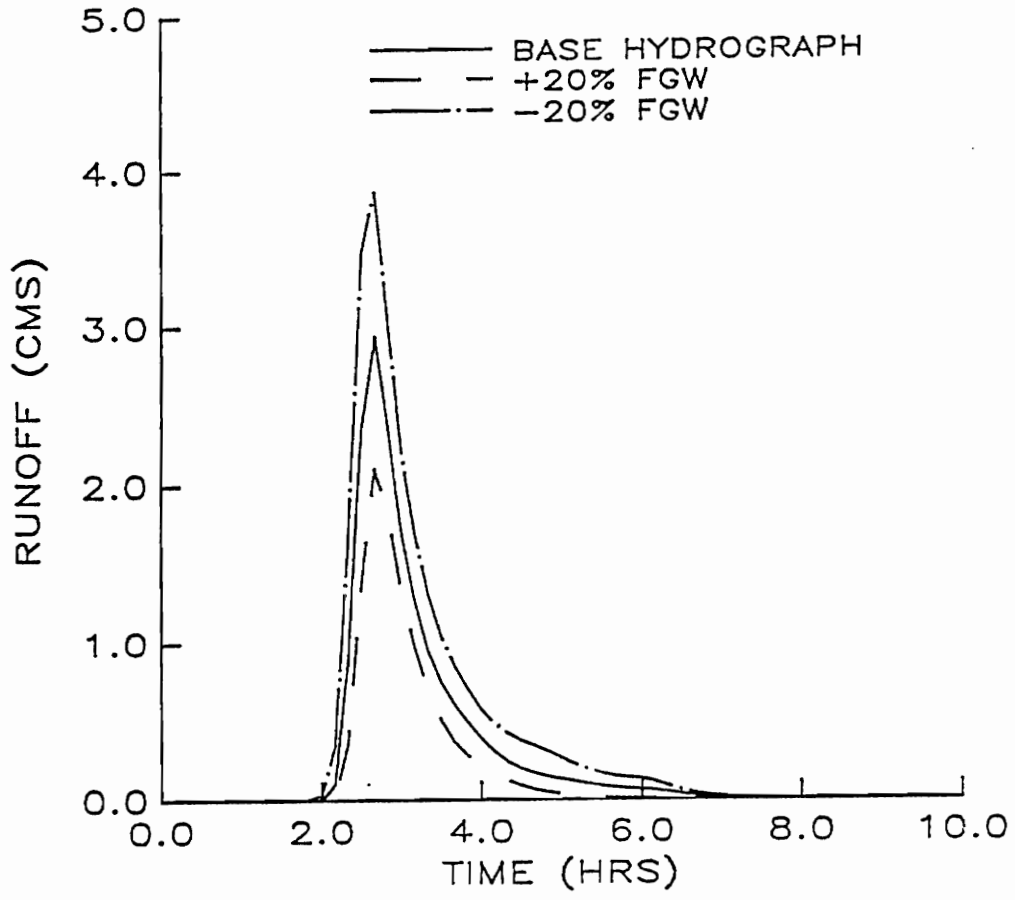

Figure F-18. The effect of gravitational water on simulated discharge hydrographs from the Millstone Branch watershed.

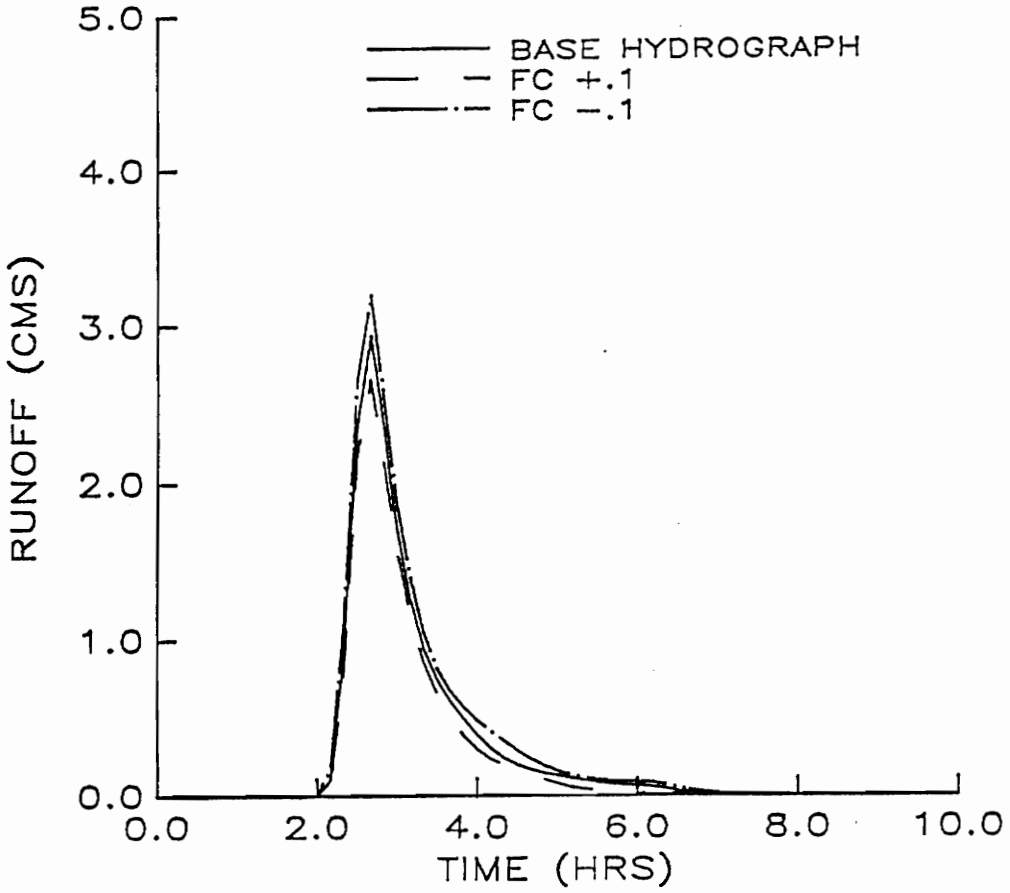

Figure F-19. The effect of final infiltration rate on simulated discharge hydrographs from the Millstone Branch watershed.

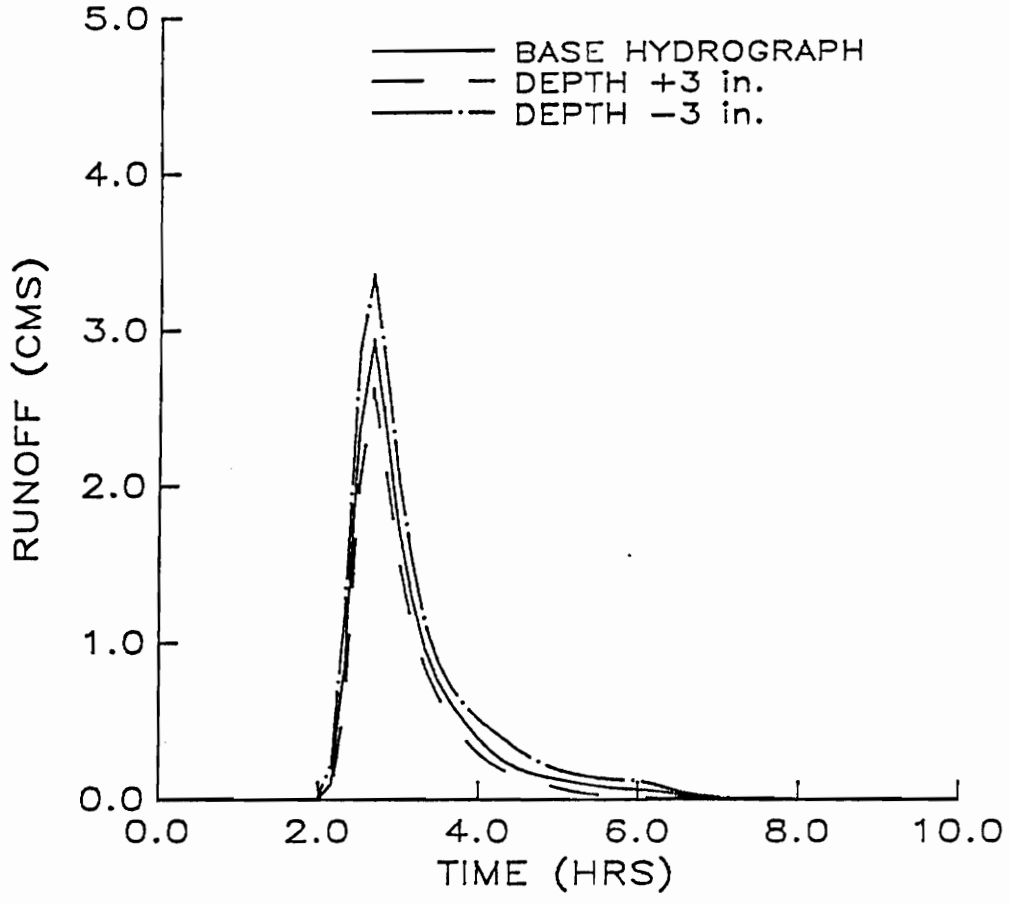

Figure F-20. The effect of depth of soil profile on simulated discharge hydrographs from the Millstone Branch watershed.

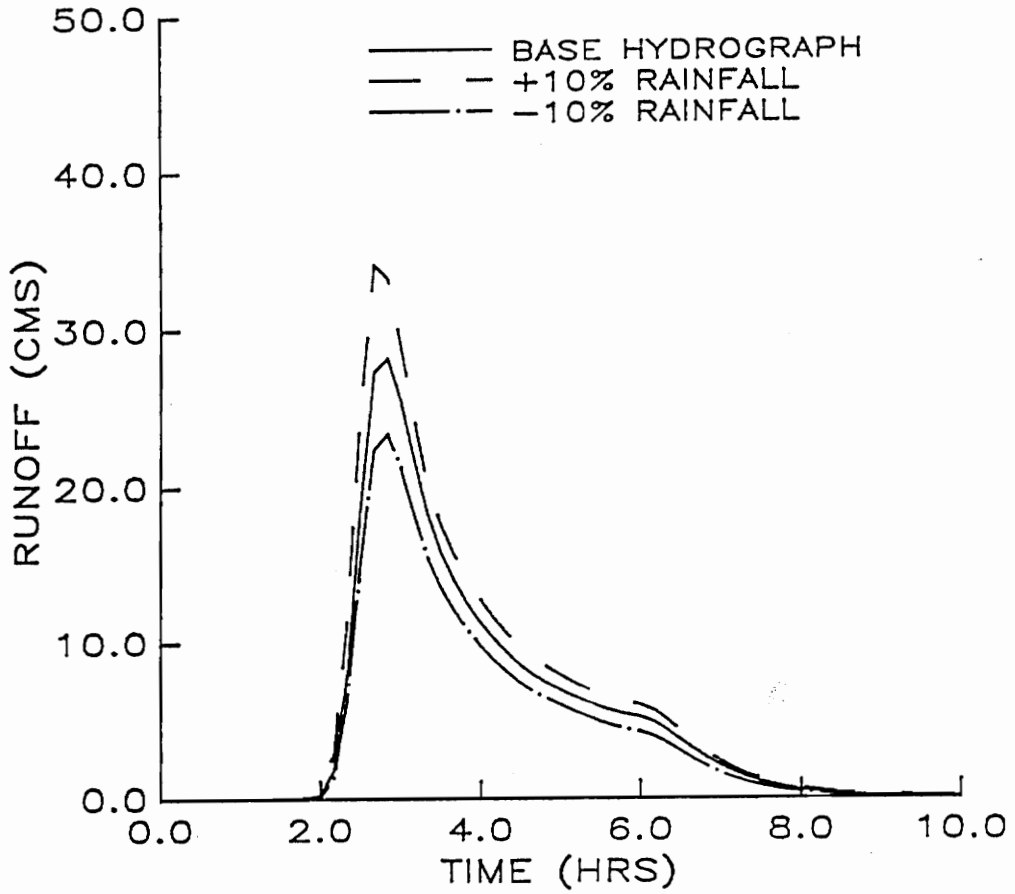

Figure F-21. The effect of rainfall volume on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

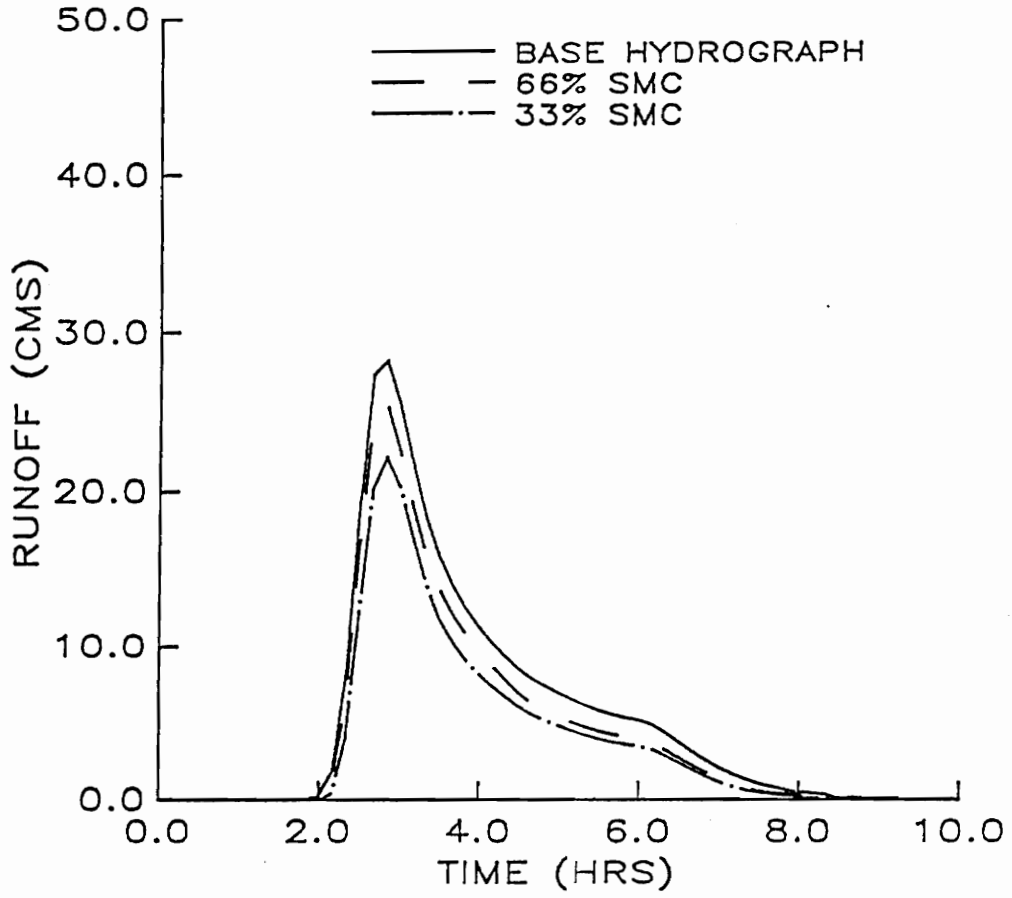

Figure F-22. The effect of antecedent soil moisture content on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

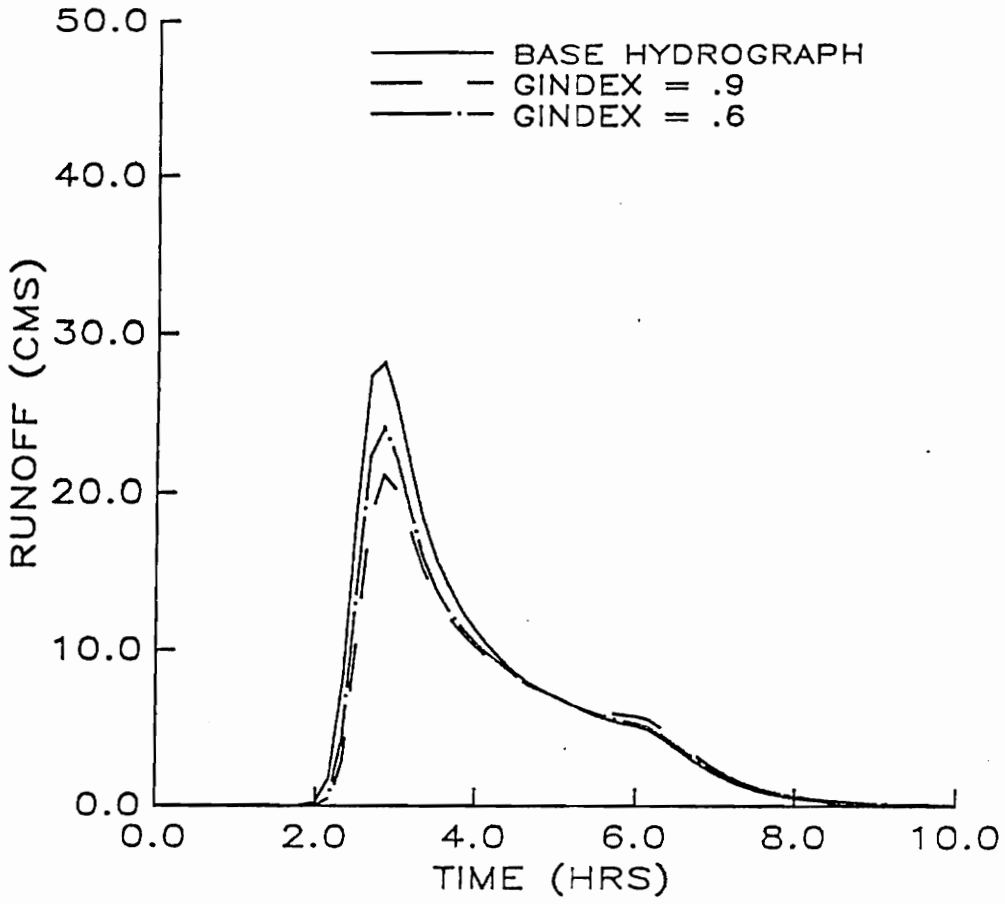

Figure F-23. The effect of growth index on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

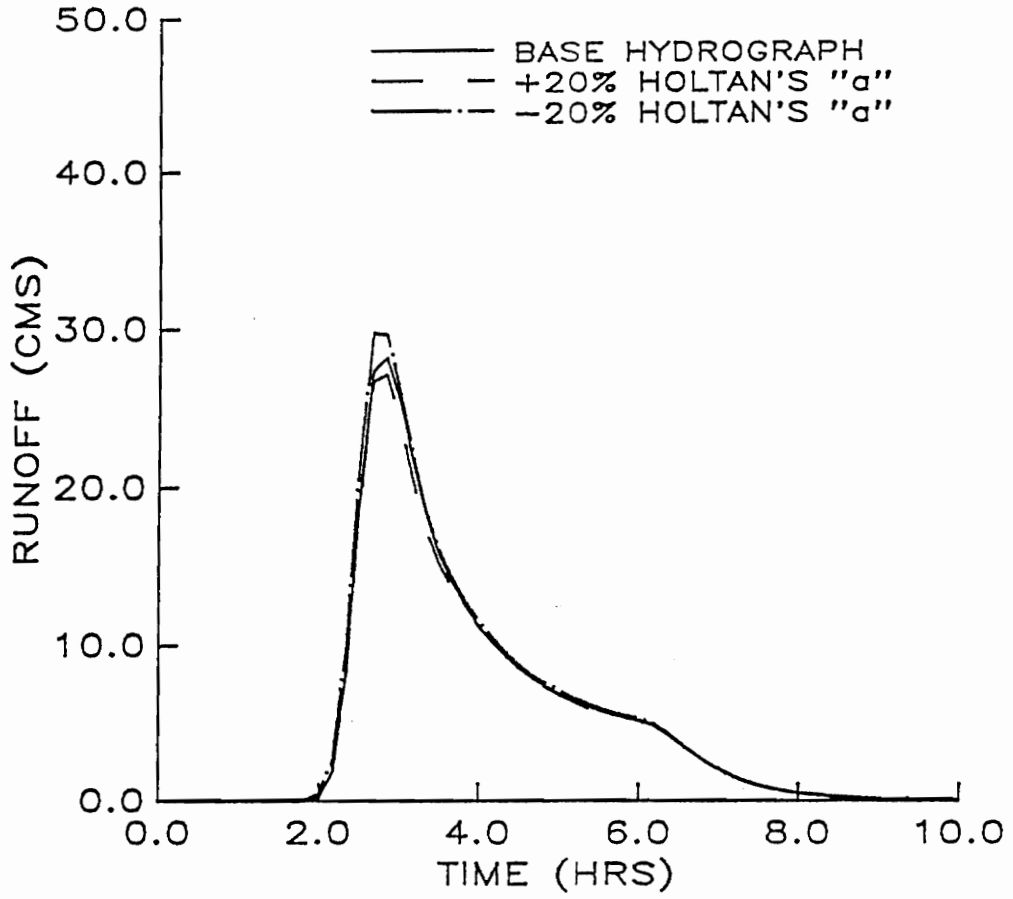

Figure F-24. The effect of Holtan's vegetative index on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

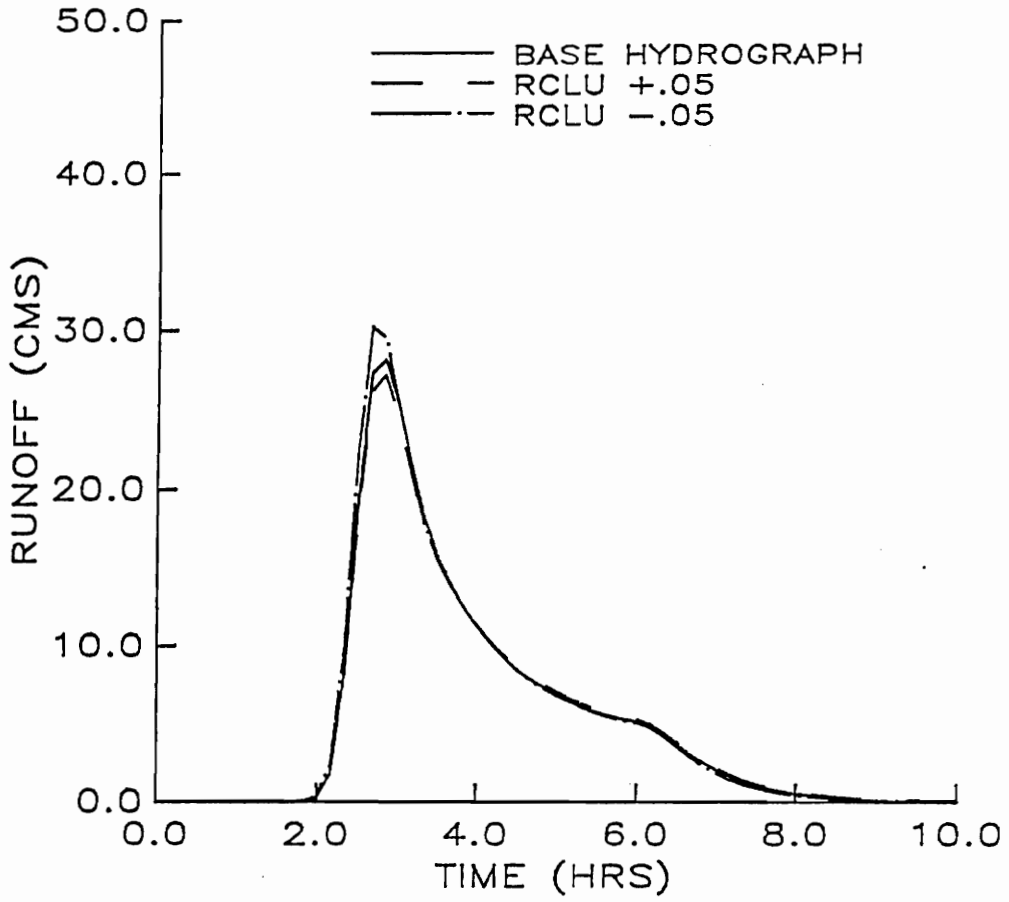

Figure F-25. The effect of overland flow roughness coefficient on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

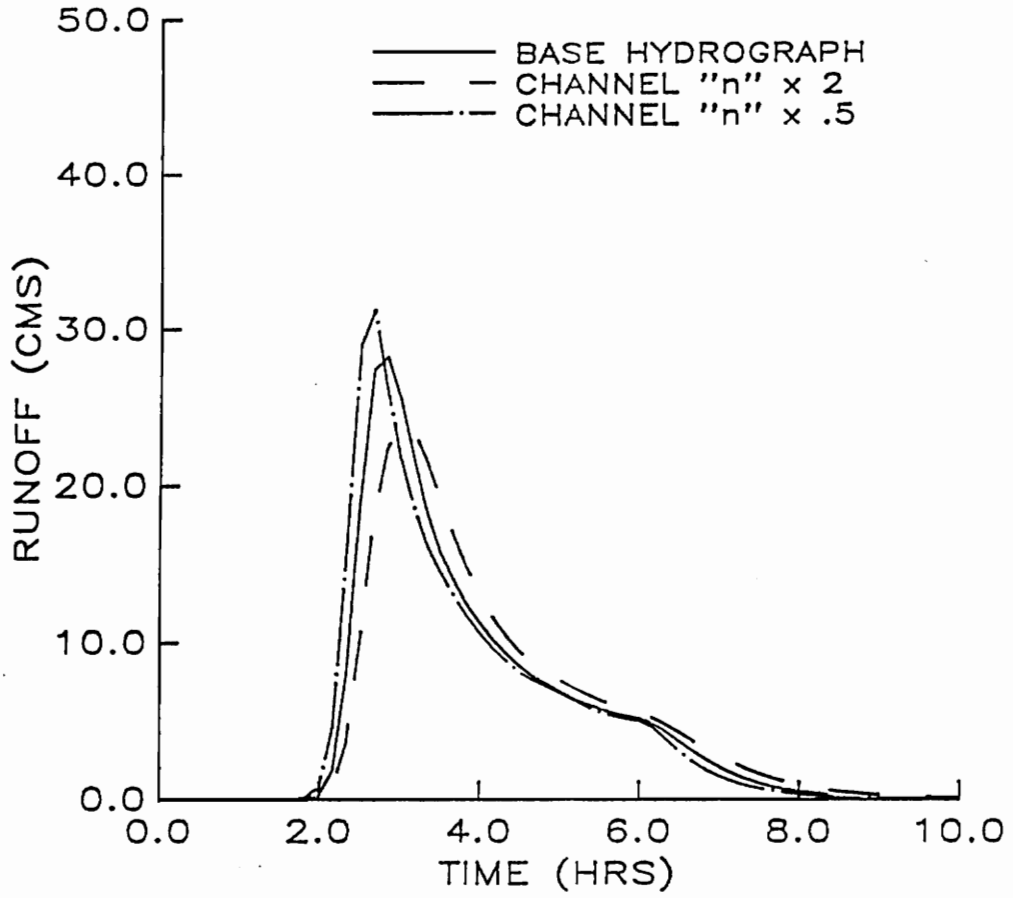

Figure F-26. The effect of channel roughness coefficient on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

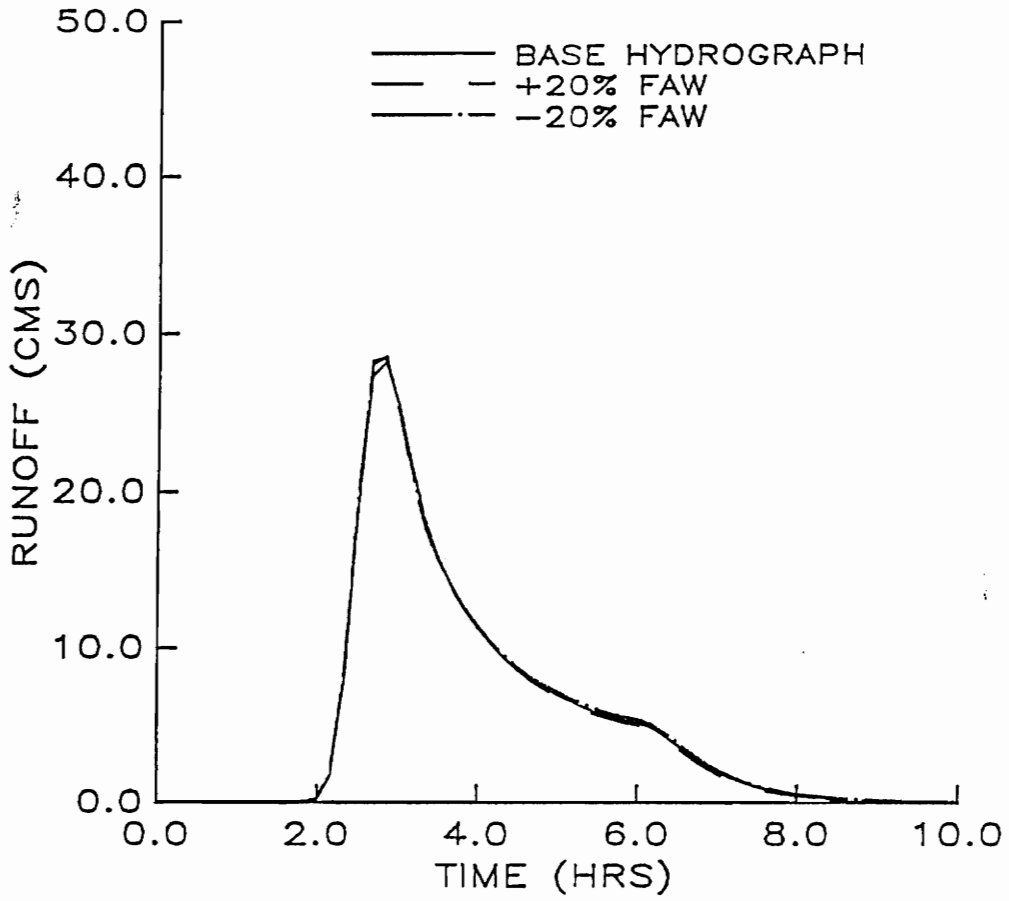

Figure F-27. The effect of plant available water on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

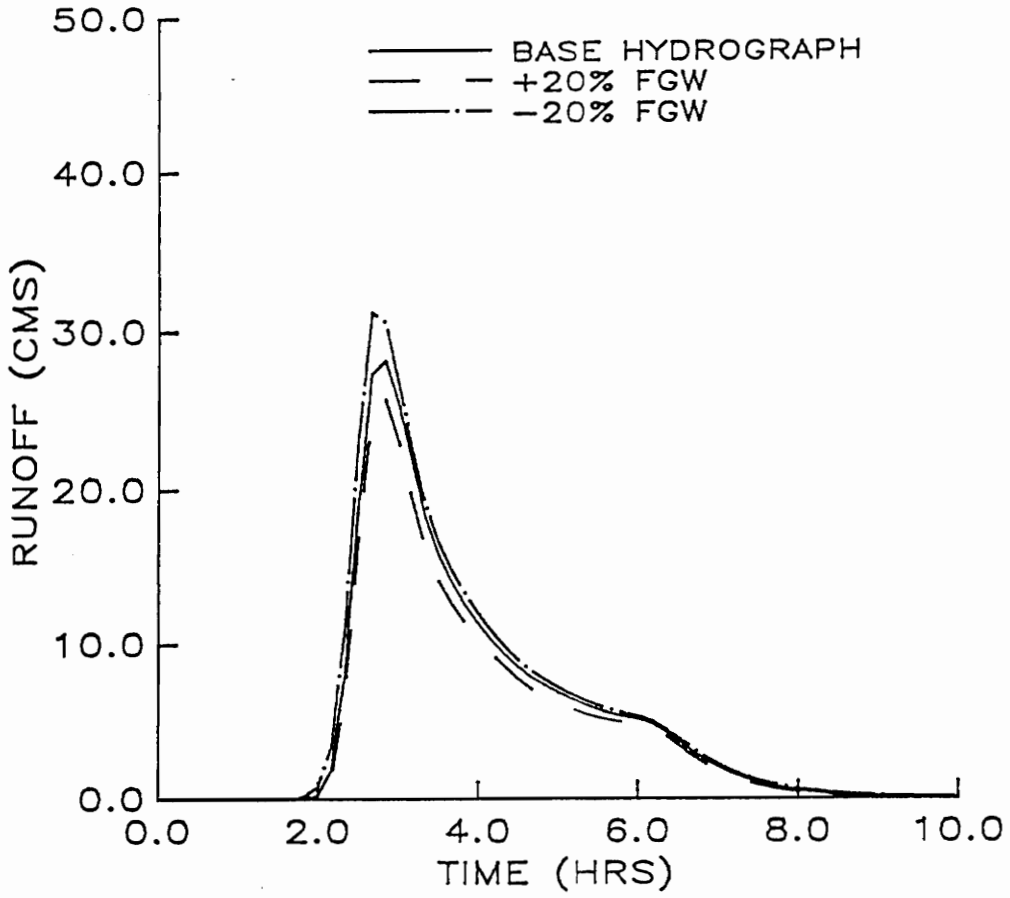

Figure F-28. The effect of gravitational water on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

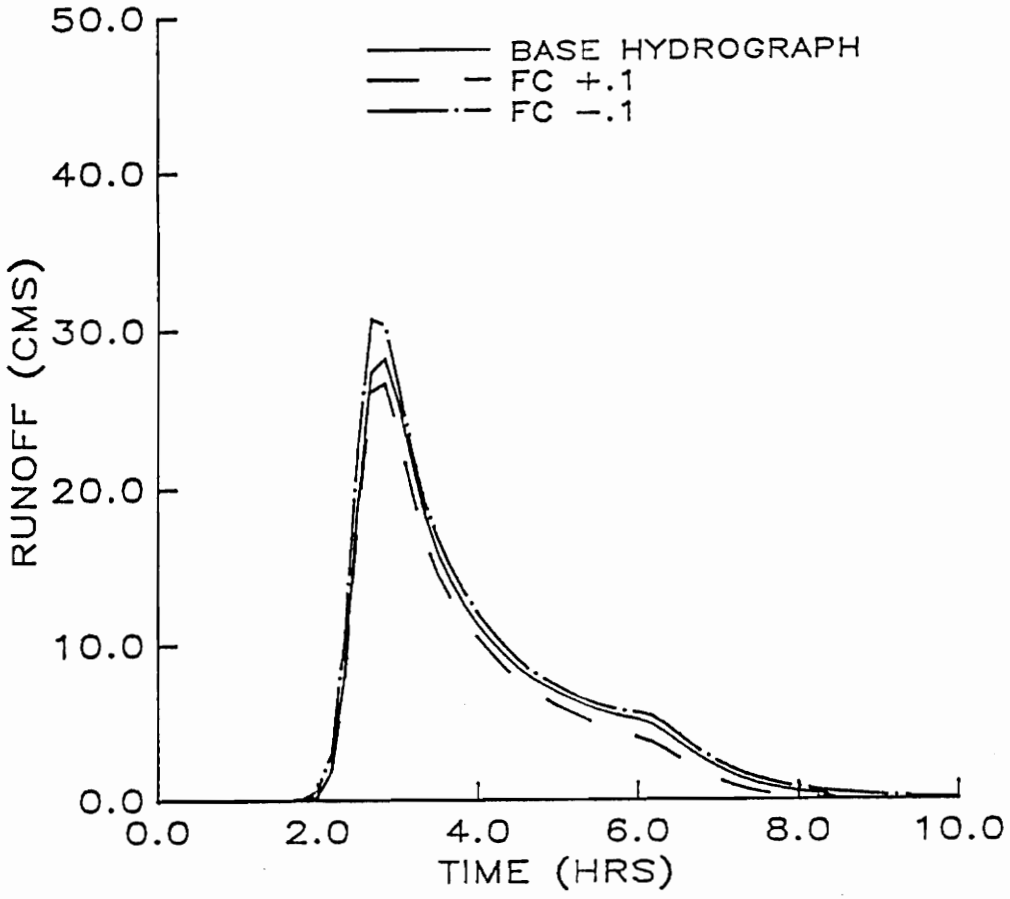

Figure F-29. The effect of final infiltration rate on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

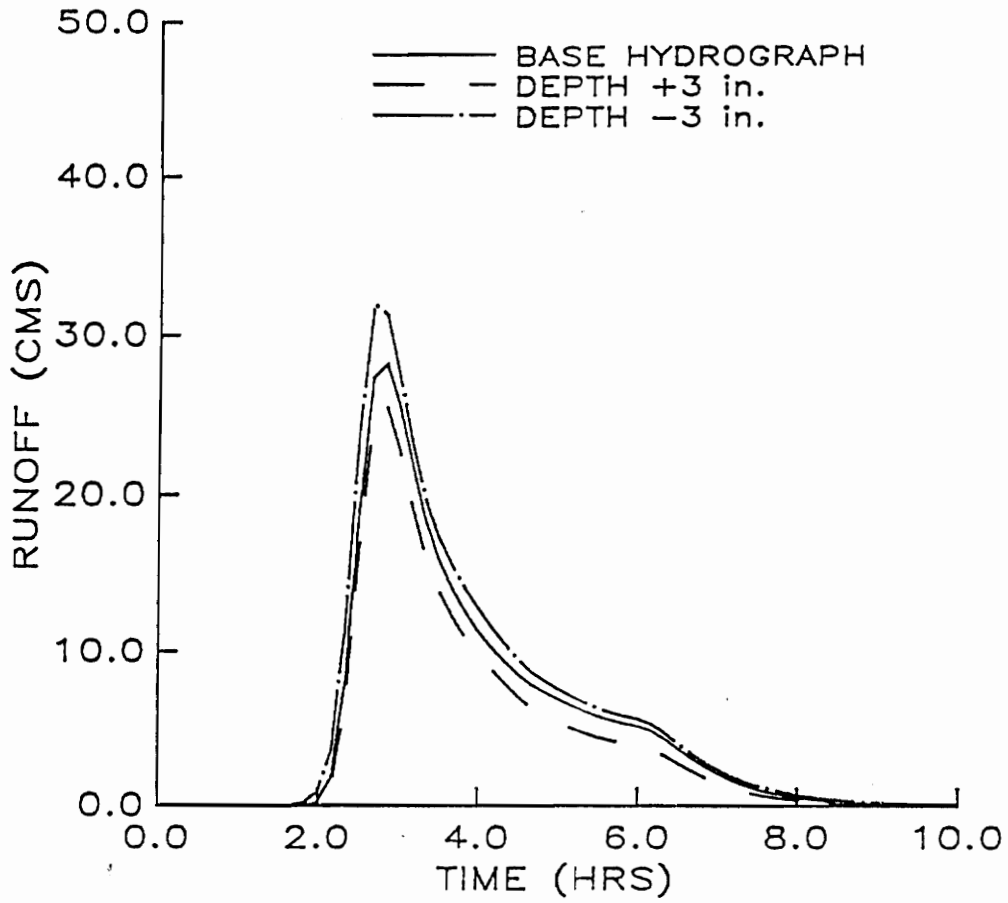

Figure F-30. The effect of depth of soil profile on simulated discharge hydrographs from the Right Fork Sandlick Creek watershed.

11.7 APPENDIX G: BRUSH CREEK SIMULATION RESULTS

Table G-1. Brush Creek simulation results from 17-years of the historical record.

Event Date	Peak Flow (CMS) Observed	Simulated	Relative Error (%)	Volume (mm) Observed	Simulated	Relative Error (%)
1959						
5/27	0.97	0.52	- 46.33	2.235	0.914	- 59.09
5/30*	7.30	14.61	100.18	8.941	13.005	45.45
6/ 2*	1.70	1.49	- 12.50	4.674	1.981	- 57.61
6/23	0.39	0.46	17.03	0.711	0.686	- 3.57
7/21	0.60	0.32	- 45.67	1.041	0.559	- 46.34
7/22*	21.71	29.98	38.08	10.922	23.114	111.63
7/27	0.35	0.22	- 36.75	0.635	0.330	- 48.00
8/ 4	0.38	0.16	- 58.07	1.473	0.279	- 81.03
8/30	1.09	1.05	- 3.79	1.803	1.524	- 15.49
9/ 6*	2.21	2.01	- 8.86	3.073	2.210	- 28.10
10/ 8	0.39	0.00	-100.00	0.584	0.000	-100.00
10/10*	9.98	13.63	36.56	12.370	16.332	32.03
10/13	0.40	0.12	- 69.05	0.356	0.279	- 21.43
10/23	0.79	0.59	- 25.08	0.533	0.940	76.19
1960						
5/ 8	0.76	0.00	-100.00	2.235	0.000	-100.00
5/28	0.65	0.84	28.66	1.016	1.143	12.50
6/24	0.72	0.35	- 51.09	1.245	0.533	- 57.14
7/ 1	0.59	0.00	-100.00	1.422	0.000	-100.00
8/14*	3.86	8.05	108.30	5.842	8.585	46.96
8/31*	1.35	4.24	215.09	2.032	3.988	96.25
9/ 1	0.55	0.05	- 91.39	0.914	0.102	- 88.89
9/17*	1.14	0.63	- 44.27	4.115	0.914	- 77.78
10/20	0.35	0.00	-100.00	1.372	0.000	-100.00
1961						
5/ 7	0.31	0.00	-100.00	0.965	0.000	-100.00
5/10*	0.71	0.00	-100.00	4.547	0.000	-100.00
5/11	0.97	0.02	- 97.51	1.702	0.076	- 95.52
6/21	0.44	0.00	-100.00	0.610	0.000	-100.00
8/22*	3.27	8.07	147.12	6.350	7.137	12.40
8/31*	1.78	1.78	- 0.10	2.489	1.905	- 23.47
10/20	0.62	0.04	- 94.06	2.184	0.102	- 95.35
1962						
5/28	0.37	0.00	-100.00	0.838	0.000	-100.00
7/ 3	0.76	0.65	- 14.26	1.753	0.889	- 49.28
7/30*	0.84	0.98	15.53	4.928	2.261	- 54.12
1963						
5/17	0.27	0.15	- 42.77	0.610	0.356	- 41.67
9/29	0.40	0.00	-100.00	1.575	0.000	-100.00

Table G-1 (continued)

Event Date	Peak Flow (CMS) Observed	Simulated	Relative Error (%)	Volume (mm) Observed	Simulated	Relative Error (%)
1964						
6/18	0.42	0.76	79.32	0.965	1.041	7.89
6/22	0.25	0.27	7.55	0.406	0.432	6.25
7/12	0.24	0.00	-100.00	0.813	0.000	-100.00
7/19	0.30	0.00	-100.00	1.118	0.000	-100.00
8/30*	1.02	0.07	- 93.30	4.115	0.279	- 93.21
10/16	0.45	0.00	-100.00	1.905	0.000	-100.00
1965						
5/27	0.49	0.46	- 5.37	1.041	0.686	- 34.15
6/12	0.34	0.28	- 17.45	0.660	0.483	- 26.92
6/23	0.43	0.00	-100.00	0.737	0.000	-100.00
7/ 4*	1.60	1.65	3.18	2.667	1.956	- 26.67
7/ 7	0.24	0.20	- 20.16	0.483	0.356	- 26.32
7/10*	2.52	5.95	136.10	4.013	5.690	41.77
7/11*	1.22	1.34	10.10	2.540	1.753	- 31.00
8/25	0.79	0.27	- 65.60	2.108	0.457	- 78.31
9/20	0.65	0.05	- 92.44	1.168	0.076	- 93.48
10/ 7	0.44	0.00	-100.00	1.626	0.000	-100.00
1966						
5/ 2	0.45	0.00	-100.00	2.108	0.000	-100.00
5/27	0.43	0.19	- 56.10	1.118	0.305	- 72.73
7/30	0.54	0.03	- 94.88	1.727	0.076	- 95.59
8/10	0.27	0.00	-100.00	0.533	0.000	-100.00
9/14	0.28	0.00	-100.00	1.041	0.000	-100.00
10/18*	0.99	0.00	-100.00	6.223	0.000	-100.00
1967						
7/18	0.42	0.45	6.72	0.660	0.711	7.69
7/20	0.41	0.50	20.99	0.787	0.660	- 16.13
8/24	0.48	0.00	-100.00	1.880	0.000	-100.00
8/31	0.24	0.17	- 27.54	0.483	0.356	- 26.32
10/25	0.36	0.00	-100.00	1.168	0.000	-100.00
1968						
5/26	0.27	0.00	-100.00	1.473	0.000	-100.00
6/ 8	0.26	0.13	- 49.22	0.559	0.279	- 50.00
7/ 2	0.19	0.22	13.54	0.406	0.356	- 12.50
7/13	0.20	0.13	- 37.62	0.711	0.229	- 67.86
7/25	0.28	0.82	186.32	0.559	1.067	90.91
7/26	0.22	0.00	-100.00	0.584	0.000	-100.00
8/ 2	0.17	0.22	27.91	0.356	0.356	0.00
8/ 4	0.35	0.31	- 11.78	0.686	0.457	- 33.33
10/18*	1.85	2.35	27.52	10.668	5.359	- 49.76

Table G-1 (continued)

Event Date	Peak Flow (CMS) Observed	Simulated	Relative Error (%)	Volume (mm) Observed	Simulated	Relative Error (%)
1969						
6/13	0.31	0.16	- 46.75	0.381	0.330	- 13.33
6/15	0.29	0.01	- 97.18	0.686	0.025	- 96.30
6/15*	1.12	1.16	3.10	2.108	1.422	- 32.53
7/ 6	0.43	0.38	- 12.45	0.914	0.610	- 33.33
8/16	0.52	0.22	- 56.98	1.295	0.483	- 62.75
8/19	0.73	0.35	- 51.98	2.388	0.635	- 73.40
1970						
6/ 5	0.77	0.66	- 15.11	1.676	0.914	- 45.45
7/24*	2.20	1.49	- 32.31	3.302	1.727	- 47.69
8/10	0.36	0.00	-100.00	2.083	0.000	-100.00
1971						
5/ 6	0.33	0.00	-100.00	0.991	0.000	-100.00
5/12	0.50	0.00	-100.00	1.626	0.000	-100.00
5/20*	3.11	4.27	37.38	6.553	4.623	- 29.46
6/16	0.50	0.00	-100.00	0.965	0.000	-100.00
6/23*	2.29	1.92	- 16.04	3.937	2.261	- 42.58
7/29*	2.65	13.37	405.01	3.073	9.931	223.14
9/11	0.36	0.36	1.66	0.762	0.584	- 23.33
9/20	0.50	0.20	- 60.70	1.270	0.381	- 70.00
10/25*	1.88	0.70	- 62.60	5.182	1.092	- 78.92
1972						
5/ 3	0.59	0.02	- 96.91	2.210	0.051	- 97.70
5/ 3	0.64	0.00	-100.00	1.524	0.000	-100.00
5/15	0.70	0.00	-100.00	1.219	0.000	-100.00
6/20*	7.65	3.93	- 48.60	59.919	25.349	- 57.69
7/ 4*	1.49	0.00	-100.00	12.522	0.000	-100.00
9/29	0.41	0.13	- 68.76	1.702	0.229	- 86.57
1973						
5/27*	9.20	10.65	15.86	11.430	10.439	- 8.67
6/21	0.32	0.00	-100.00	0.457	0.076	- 83.33
6/27	1.14	4.16	264.35	2.108	5.258	149.40
7/ 1	0.42	0.00	-100.00	0.889	0.000	-100.00
8/ 7	0.66	0.09	- 86.88	1.092	0.152	- 86.05
8/14	0.56	0.70	24.90	1.041	1.016	- 2.44
9/14	0.47	0.09	- 80.33	1.041	0.254	- 75.61
10/ 2	0.97	0.41	- 57.47	2.591	0.889	- 65.69
10/28	0.31	0.00	-100.00	1.397	0.000	-100.00

Table G-1 (continued)

Event Date	Peak Flow (CMS) Observed	Simulated	Relative Error (%)	Volume (mm) Observed	Simulated	Relative Error (%)
1974						
5/12*	1.62	2.39	47.18	2.692	2.769	2.83
5/18	0.35	0.63	80.34	0.483	0.813	68.42
7/25	0.37	1.12	203.68	0.686	1.219	77.78
8/16*	1.26	1.38	9.44	1.880	1.626	- 13.51
9/ 6*	0.86	0.00	-100.00	4.496	0.000	-100.00
9/10*	2.26	1.75	- 22.65	6.299	3.404	- 45.97
9/12	0.49	0.20	- 59.07	1.118	0.330	- 70.45

VITA

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