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Tennessee Valley Authority

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User's Guide to TVA-HYSIM

A Hydrologic Program for Quantifying Land-Use Change Effects

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USER'S GUIDE TO TVA-HYSIM
A HYDROLOGIC PROGRAM FOR QUANTIFYING LAND-USE CHANGE EFFECTS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollution impacts on our environment and even on our health often require that new and increasingly efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report is a user's guide for a computer package designed to quantify the hydrologic effects of land-use change. These programs have been developed to permit their use at an interactive computer terminal, and to streamline the output to the types of information used in land-use planning applications. This program package and user's guide should be of interest to planners and consulting engineers in such applications as determining the probable hydrologic consequences of surface coal mining on the hydrologic balance as required under Public Law 95-87. For further information contact the Oil Shale and Energy Mining Branch of the Energy Pollution Control Division.

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ABSTRACT

TVA-HYSIM is a computer package containing complex hydrologic models specifically designed for ease of application in land-use planning studies. TVA-HYSIM contains models capable of continuous hydrologic simulation, as well as a rainfall generator and an erosion component.

This user's guide outlines the information required to operate the programs and how this information is obtained, shows examples of input and output, and provides examples of job controls needed to operate the program. Model components are described in sufficient detail so that changes to the algorithms may be made if so desired.

TVA-HYSIM is not adapted to handling dynamic land-use conditions, but rather is designed to be used as a planning tool so that the end effects of the land-use change can be evaluated before the change occurs. Thus in a typical land-use change evaluation the model package would first be used to simulate hydrology under present land-use conditions and then used to simulate the post land-use change hydrology. Some strategies for using TVA-HYSIM to determine the effects of land-use change on the hydrologic balance are offered.

This user's guide is submitted by the Tennessee Valley Authority, Division of Water Resources, in a partial fulfillment of the terms under Interagency Agreement No. D9 E721-DS with the U.S. Environmental Protection Agency. Work was completed as of February 1, 1980.

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LIST OF ABBREVIATIONS AND SYMBOLS

Because of the use of FORTRAN nomenclature, the difference between abbreviations and symbols becomes difficult to define. Therefore, all abbreviations and symbols are listed alphabetically. The location or equation in which these variables, parameters, or coefficients are first encountered are indicated.

Symbol	
AA	Used in unit hydrograph definition (eq. V-46)
ACCIA	Daily rate of dust and dirt accumulation (Section II.B.11)
AHORD	Soil A horizon depth parameter (Section V.C.6)
ARF	Accumulated storm rainfall (eq. V-38)
AWC	Available water holding capacity of soil (Section III.A.3)
AW	Parameter in Continuous Daily Streamflow Model (eq. V-17)
B	Parameter in Continuous Daily Streamflow Model (eq. V-17)
BB	Used in unit hydrograph definition (eq. V-46)
BFQ	Baseflow discharge (eq. V-74)
BGWR	Beginning value for groundwater reservoir (eq. V-37)
BHORP	Soil B horizon permeability parameter (Section V.C.6)
B NPE	Duration of a burst of precipitation excess (Section II.D)
B PE	Burst precipitation excess (Section II.D)
B RF	Burst rainfall (Section II.D)
B ROI	Burst runoff intensity (Section II.D)
BSMI	Beginning soil moisture reservoir value (eq. V-36)
C	Cover term in Universal Soil Loss Equation (Section II.B.10)

CC	Used in unit hydrograph definition (eq. V-46)
CFS	Cubic feet per second (Section II.A)
CN	SCS curve number based on soils and land-use (Section II.D)
CN-PE	Curve number used in determining precipitation excess distribution (Section II.D)
CO	Cutoff used to define storm rainfall burst (eq. V-42)
CONC	Concentration (eq. V-74)
CSLOPE	Channel slope (eq. III-1)
D	Ratio of median sediment grain size to one micron (Section II.D)
DA	Drainage area in square miles (eq. III-4)
DD	Drainage density (eq. III.2)
ΔE	Increment of elevation along main channel (eq. III-1)
DK	Constant in evapotranspiration equation (eq. V-23)
ΔL	Increment of distance along main channel (eq. III-1)
DLF	Deep loss measure (Section II.B.8)
DS	Parameter in Continuous Daily Streamflow Model (eq. V-17)
DT	Convolution interval (Section II.B.12)
DUR	Storm duration (eq. V-39)
FOR	Percent forest/100, plus one (eq. V-30)
GI	Growth index, used in evapotranspiration adjustment (eq. V-23)
GRO	Ground water runoff (eq. V-26)
GROK	Ground water recession coefficient (eq. V-26)
GROKW	Winter GROK coefficient (Section V.C.11)
GROKS	Summer GROK coefficient (Section V.C.11)
GWDOR	Ground water dormant season recharge (Section V.C.5)
GWK	Parameter in Continuous Daily Streamflow model (eq. V-19)
GWL	Ground water loss due to bypass seepage (eq. V-20)

GWR	Ground water reservoir volume (eq. V-17)
GWV	Ground water volume to be allocated (eq. V-19)
H	Maximum difference in watershed elevation (eq. III-4)
HTFLUX	A measure used to increase evaporation of intercepted moisture (Section II.B.13)
I	Interception (eqs. V-13)
IN	Runoff in watershed inches (eq. IV-1)
ITPS	Factor used to delay peak sediment concentration (Section II.D)
IUSG	Instantaneous unit sediment graph (eq. V-72)
IUSGI	Impervious area unit sediment graph (eq. V-73)
JD	Julian day (eq. V-5)
K	Soil erodability term in Universal Soil Loss Equation (Section II.B.10)
L	Main channel length (eq. III-7)
LAT	Latitude (eq. III-9)
LC_n	Length in miles across the watershed of the contour representing 25, 50, or 75 percent of the watershed height (eq. III-4)
LENGTH	Watershed length term (eq. III-5)
LI	Length of grid lines used in calculating DD (eq. III-2)
LOSS	Long-term average annual evapotranspiration (eq. V-23)
LS	Length-slope term in Universal Soil Loss Equation (Section II.B.10)
LT	Literature values (Table 2)
LULL	Interval between bursts during storm rainfall (eq. V-43)
M	Constant in dust and dirt washoff equation (eq. V-68)
MAXRF	Maximum rainfall threshold for defining storms (Section II.B.15)
MINRF	Minimum rainfall threshold for defining storms (Section II.B.15)
MINRO	Minimum runoff threshold for defining storms (Section II.B.15)

N	Number of grid intersections (eq. III-2)
P	Conservation practice term in Universal Soil Loss Equation (Section II.B.10)
PCM	A measure of percent mined (Table 5)
PD	Transitional probability for dry (eq. V-3)
PD/D	Transitional probability of dry given dry (eq. V-3)
PD/W	Transitonal probability of dry given wet (eq. V-2)
PE	Precipitation excess (Figure 3)
PE_i	Precipitation excess from impervious areas (eq. V-16)
PE_p	Precipitation excess from pervious areas (eq. V-18)
PEIN	Normalized precipitation excess intensity (eq. V-47)
PET	Long-term monthly potential evapotranspiration (eq. V-23)
PERM	Soil permeability (Table 5)
PHI	Constant loss term used in determining PE (Section II.D)
PKARST	Parameter affecting storm runoff in karst terrain (Section II.B.8)
PR	Transitional probability (generic) (eq. V-1)
PPM	Suspended sediment concentration in parts per million (Section II.A)
PPM1	Suspended sediment concentration at one cfs/mi^2 (eq. V-74)
PW/W	Transitional probability of wet given wet (eq. V-2)
QP	Storm hydrograph peak discharge (eq. V-71)
R	Dust and dirt daily removal rate (Section II.B.11)
ra	Coefficient in transitional probability equation (eq. V-1)
rb	Coefficient in transitional probability equation (eq. V-1)
RF	Rainfall, used to refer to monthly or storm rainfall (eq. III-9)
RF	Mean monthly rainfall (eq. III-10)
RFD	Daily rainfall (eq. V-4)

RF5	Five-minute rainfall (eq. V-10)
RFH	Hourly rainfall (eq. V-7)
RF_i	Available moisture after interception and precipitation excess are removed (eq. V-19)
RF_r	Daily rainfall less interception (eq. V-16)
RF2	Rainfall for storm greater than one inch (eq. V-12)
RI	Retention index (eq. V-17)
RO	Storm runoff (precipitation excess) (eq. III-9)
S	Maximum potential retention (eq. V-38)
SB	Coefficient in time lag-PEIN equation (eq. V-48)
SC	Coefficient in time lag-UP equation (eq. V-50)
SD	Standard deviation (eq. III-11)
SE	Coefficient in time lag-UP equation (eq. V-50)
SEDDAY	Accumulated dust and dirt (eq. V-66)
SF	Coefficient in time lag-T2 equation (eq. V-51)
SG	Coefficient in time lag-T2 equation (eq. V-51)
SHAPE	Watershed shape (Table 5)
SI	Seasonal index (eq. V-17)
SINU	Sinuosity (eq. V-39)
SLOPE	Watershed slope in percent (eq. III-4)
SMR	Soil moisture reservoir (eq. V-17)
SRO	Storm runoff (eq. V-25)
SROK	Storm runoff routing constant (eq. V-25)
SURES	Storm runoff reservoir (eq. V-25)
$S\mu$	Coefficient in time lag-PEIN equation (eq. V-48)
T1	Time to initial unit hydrograph peak (Figure 7)
T2	Time to inflection point on unit hydrograph (Figure 7)

T3	Time base of unit hydrograph (Figure 7)
t1	Average duration of one-inch storm (eq. V-11)
t2	Average duration of storm larger than one-inch (eq. V-12)
TC	Time of concentration (eq. III-7)
TDSRO	Parameter indicating runoff that occurs on day of rain (eq. V-25)
T50	Time to half the area under unit hydrograph (Figure 7)
TL	Time lag (Section II.D)
TLP	Transmission loss parameter (eq. V-21)
TONS	Suspended sediment load in tons (eq. V-71)
UGMOD	Coefficients which can be used to modify the TL-PEIN relation (Section IV.D.2)
UP	Peak of the unit hydrograph (Figure 7)
UR	Inflection point on unit hydrograph (Figure 7)
USLE	Universal Soil Loss Equation (Section III.A.6)
USLEP	Product of 95 and terms in the USLE equation (Section II.D)
USLEXP	Exponent in Modified USLE equation (Section II.D))
WASH	Dust and dirt washed off during storm (eq. V-68)
WB	Term relating QP, the maximum PE_j and the time to peak (eq. V-72)
Y	Long term annual runoff/rainfall (eq. V-27)
YP	Random number from uniform probability distribution (eq. V-4)
μ	micron

SECTION I

INTRODUCTION

A. OVERVIEW

The Tennessee Valley Authority Hydrologic Simulation Model (TVA-HYSIM) is a computer package containing complex models specifically designed for ease of application in land-use planning studies. TVA-HYSIM contains models capable of continuous hydrologic simulation as well as a rainfall generator and an erosion component. This package is formulated to provide the level of output normally required for land-use planning studies and yet be very simple to operate (no learning period). The approach is to use an "interactive" input technique, wherein the computer prompts the user for the information.

An earlier package has many additional options including programs for determining optimized model parameters by adjusting the models to observed data. (This more complex model version is also available from the authors.) Because of the many options, however, a learning period is required before this earlier program can be used with ease.

This user's guide briefly describes the models in the program package TVA-HYSIM, outlines the information required to operate the programs and how this information is determined, and shows examples of the input/output. Also, some strategies for using the models are offered. A later section describes the model components in sufficient depth so that changes to the program may be made by the user, if necessary. And finally, examples of the job controls needed to operate the computer package are provided.

English units have been used deliberately throughout this report. Because model algorithms, particularly the regionalized parameter prediction equations, were developed based on measures in English units, it would be virtually impossible to incorporate metric units into the report or into the computer program. A table of English to metric conversions is included as an Appendix for convenience.

The information provided in this user's guide may appear to be excessive for a model designed for ease of application. Certainly not all of this information is needed to operate the model package. The extended documentation included in this guide goes well beyond the information needed to simply operate the model. This additional information is provided to simplify other aspects of model application including: job controls, determining basin characteristics, and modifying model components, if necessary.

B. MODEL DESCRIPTION

TVA-HYSIM provides users a relatively easily applied tool for quantifying the effects of land-use change on the hydrologic balance, yet the model package is capable of handling the complex geologic-hydrologic system. Briefly, TVA-HYSIM consists of several linked components. A rainfall generator drives the package and supplies rainfall to a continuous daily streamflow model. Hourly or shorter duration rainfall is supplied by the rainfall generator to the storm hydrograph model for those storms selected for simulation. Runoff volumes are calculated in the daily streamflow model. Storm suspended sediment loads and concentrations may also be simulated in conjunction with the storm hydrographs.

TVA-HYSIM contains "regionalized" model components. Regionalizing a model involves adjusting the model to data at locations where adequate data are available to obtain optimized values for each model parameter. In a second step, each optimized parameter is related to some combination of basin characteristics in the upstream watershed and/or climatological measures. Once these relationships are developed, the model may be applied at ungaged locations since the model parameters can be predicted from basin characteristics and appropriate climatological measures.

The advantage of regionalization is obvious--the model may be applied at locations where gaged data are unavailable. A regionalized model cannot, however, be applied blindly to all situations. For instance: (1) the model must be used with caution at locations outside of or under conditions differing from those used in regionalizing the model; (2) judgment must be exercised to ensure that reasonable results are obtained since validation data are unavailable and; (3) if measures of basin characteristics are mis-scaled because a different computation technique is used, because an error was made in measurement, or because a bad estimate of a characteristic is made in a case where needed information (such as a soils map) is lacking, simulation results may be unrepresentative but the effect probably will not be obvious. It is hoped that this user's guide will contain enough information about TVA-HYSIM so that these caveats do not become problems.

The basic set of models from which TVA-HYSIM was formulated has been under development for about 15 years. This development began with a project in the rural Upper Bear Creek watershed located in northwest Alabama (TVA, 1973a). Urban capabilities and algorithms to handle the effects of carbonate rock terrain on hydrology were developed at a project located in Knoxville, Tennessee (Betson, 1976). The model has recently been adapted to handle surface mining in an ongoing project (Betson, 1979b, Bales, 1979, Barr, 1979). Section V in this report describes in some detail the newer features of the model components not documented elsewhere. (An EPA Report to be issued in late 1981 will document model development, calibration, and validation in greater detail.)

TVA-HYSIM may be used for a variety of land-use evaluations. There are provisions for differentiating among hardwood and conifer forest types, several agricultural cover classes, and unvegetated conditions. Impervious

areas (urban conditions) can be considered as can the effects of surface mining. The model has provisions for handling the effects of the underdrainage that influences storm runoff in areas of soluble carbonate rock (Betson, 1977). And finally, suspended sediment loads can be considered as washoff of dust and dirt from impervious surfaces and as erosion from pervious areas.

C. REGION OF APPLICABILITY

The regionalized relationships incorporated in TVA-HYSIM were derived using hydrologic data collected in the Tennessee Valley and surrounding area. This region includes six physiographic provinces: Blue Ridge, Valley and Ridge, Cumberland Plateau, Highland Rim, Central Basin, and Mississippi Embayment (Fenneman, 1938). These provinces include a considerable range of physical watershed, soil, topographic and meteorological conditions. The model has been calibrated using data from watersheds in this region receiving an average of from 38 to 77 inches of rainfall per year.

The region where this model has been calibrated is roughly bounded between latitudes 34°N and 37°N and between longitudes 82°W and 89°W. To the extent that conditions are similar to those within this region, the model will apply elsewhere. Its applicability, however, should be verified. In more northern climates where snow and snow melt runoff are significant considerations, changes to model components will become necessary to adequately model the snow-snow melt phenomenon continuously. Approaches are suggested in Section IV. The model is not adapted to arid-climate hydrology. A list of watersheds used in calibrating the models, which was part of the regionalization process, is included in Section III of this report to provide an idea of the range of conditions that was included.

SECTION II

PROGRAM INPUT/OUTPUT DESCRIPTION

A. GENERAL DESCRIPTION

The input information required to operate TVA-HYSIM is input to the program interactively. Experience has shown that the typical input formatting which utilizes poorly defined FORTRAN "type" variables requires a learning period before the procedure can be used with confidence, and even then this approach is error-prone. The interactive free-form mode used in TVA-HYSIM was designed to be used at a time-sharing terminal so that the user simply responds to data prompts, or requests, made by the computer. This system is very simple to use since the computer essentially defines the format for the user. The same data input sequence is also used for optional batch runs that may be made with TVA-HYSIM although, of course, there is no direct interaction between computer and user per se.

Figure 1 shows the interactive input required to make a three-year simulation of continuous daily streamflow and selected large storms. The watershed used for this simulation, Cane Branch near Parkers Lake, Kentucky, was the mined watershed (10.5%) in the strip mine effects study reported by Musser et al, (1970). (Although there are actually no impervious areas in the watershed, a two percent impervious area was added to the land cover so that all input questions and all possible options could be shown in this example.) The set-up shown in Figure 1 resulted in the three-year sequence of simulation of hydrologic information for which the selected information is summarized in Figure 2. Shown in Figure 2 are simulations for user selected large storms in each year which include the rainfall and runoff in inches, peak discharge in cubic feet per second (cfs), suspended sediment load in tons, and average and maximum suspended sediment concentration in parts per million (ppm). The annual simulated rainfall, runoff, and minimum one-day discharge are shown for each year, as is the total sediment load for those storms simulated. At the end of the output the average annual rainfall, runoff (in inches), and suspended sediment load (in tons) for the entire simulation period are shown.

Although most of the questions shown in Figure 1 are straightforward, each will be explained in sequence, and the information or characteristics requested will be defined. Section III explains in more detail how these characteristics are measured and where the necessary information is obtained.

This example run was set up so that all possible questions would appear. In most runs, however, not all of the questions will necessarily

FIGURE 1

Interactive Input

Input Data Values As Called For In Each Line With A Comma Or Blank Between Each Value.

1. What is the name & location of the watershed?
   Cane Branch Nr. Parkers Lake, KY.

2. Do you want a batch printout stored? (Yes or No)
   Yes

3. Is sediment to be simulated? (Yes or No)
   Yes

4. What is the drainage area & land cover percentages:
   Hardwood, conifer, pasture, small grain, row crop, impervious, unvegetated? (8 Values)
   ?
   0.67 71 14 2.5 0 0 2 10.5

5. Are special directly connected impervious areas to be considered? (Yes or No)
   Yes

6. What is the percent? (1 Value)
   ?
   1

7. What are watershed characteristics values: Slope, shape, drainage density, curve no., sinuosity, % mined, soil perm., available water holding capacity? (8 Values)
   ?
   194 2.04 11.4 50 0.14 10.5 2.98 5.28

8. What are the values for bypass seepage (DLF) & karst areas (PKARST)? (2 Values)
   ?
   0 0

9. What is the average sediment concentration at 1 CFS/SM in PPM? (1 Value)
   ?
   10

10. What are the USLE factors: Soil-erodibility (K), slope length & gradient (LS), cropping management (C), & erosion control practice (P)? (4 Values)
    ?
    0.3 5.0 0.0126 1.0

11. What are the sediment associated coefficients: Grain size ratio (D), daily impervious area removal rate (R), & daily accumulation rate (ACCIA)? (3 Values)
    ?
    1 0.08 1.0

12. What is the convolution time interval? (Hours & minutes with a period between) (1 Value)
    ?
    1.0

FIGURE 1.(CONTINUED)

13. What are the long-term or expected mean rainfall, and runoff or average latitude, & htflux? (4 Values)
?
47.2 0 36.9 3.0

14. Number of years to be simulated and beginning year (2 Values)
?
3 01

15. What lower limits are to be used in defining a storm to be simulated? (MINRF & MINRO, & MAXRF) (3 Values)
?
1.5 0.2 2.5

16. What are the 12 values for the mean of the cube roots observed monthly rainfall in water year sequence? (12 Values)
?
1.315 1.49 1.54 1.57 1.545 1.70 1.57 1.59 1.61 1.62 1.45 1.46

17. What are the 12 values for the standard deviation of observed monthly rainfall in water year sequence? (12 Values)
?
0.38 0.27 0.28 0.28 0.28 0.28 0.27 0.25 0.26 0.30 0.30 0.31

18. What are the 12 values for the mean monthly potential evapo-transpiration in water year sequence? (12 Values)
?
2.72 1.44 0.88 0.95 1.44 2.89 4.24 5.34 5.86 5.97 5.29 4.22

IHN002I STOP 99

19. Are you ready to run the program? (Yes or No)
Yes

FIGURE 2

Interactive Output Using TVA-HYSIM

Cane Branch Nr. Parkers Lake, KY.

Storm Data	RF(IN)	RO(IN)	MAX Q(CFS)	SS(TONS)	AVG PPM	MAX PPM
1/ 8/ 1	2.11	0.7478	18.92	102.70	2829.	8328.
2/ 1/ 1	1.85	0.6950	14.28	82.04	2431.	3602.
6/ 4/ 1	3.19	0.5226	19.36	83.19	3279.	5486.

Annual RF = 48.77 IN. & annual RO = 16.001 IN for year 19 1

Minimum one-day flow for 19 1 -- 0.0 CFS

$ The total sediment for the above storms is 267.93 tons

Storm Data	RF(IN)	RO(IN)	MAX Q(CFS)	SS(TONS)	AVG PPM	MAX PPM
12/23/ 1	1.72	0.3396	6.50	34.47	2091.	5073.
1/24/ 2	2.71	1.3697	32.72	194.34	2922.	3816.
2/24/ 2	1.53	0.7424	94.86	253.33	7029.	11749.
3/19/ 2	1.64	0.8720	19.08	109.70	2591.	3889.
5/30/ 2	4.95	1.9841	92.66	434.71	4513.	7956.

Annual RF = 48.49 IN. & annual RO = 22.031 IN for year 19 2

Minimum one-day flow for 19 2 -- 0.01 CFS

$ The total sediment for the above storms is 1026.55 tons

Storm Data	RF(IN)	RO(IN)	MAX Q(CFS)	SS(TONS)	AVG PPM	MAX PPM
1/ 5/ 3	1.55	0.5164	9.34	53.24	2123.	4418.
1/23/ 3	1.77	0.9329	29.22	146.46	3233.	4765.
7/ 4/ 3	3.24	0.1531	5.29	17.81	2397.	5842.
7/15/ 3	2.80	0.3740	16.10	60.16	3314.	5780.

Annual RF = 49.81 IN. & annual RO = 17.664 IN for year 19 3

Minimum one-day flow for 19 3 -- 0.00 CFS

$ The total sediment for the above storms is 277.68 tons

The following are the simulated averages for 3 years

RF = 49.02 RO = 18.59 SED = 524.05

appear. Some questions are contingent on the response to a previous question or a measure previously entered.

The first item at the top of Figure 1 involves initiating the CLIST (see Section VI) which begins the program. HYSIM is the name of the CLIST.

B. INTERACTIVE INPUT INFORMATION BY QUESTIONS

1. What is the name and location of the watershed? A descriptor not to exceed 80 characters.

2. Do you want a batch printout stored? (Yes or no). A "yes" causes detailed storm by storm simulated hydrographs and continuous daily streamflow model simulation information to be stored (at increased run-time) for subsequent printout. The storm hydrograph information may be obtained at the end of the interactive printout (see last paragraph this sub-section). Information from the continuous daily streamflow model and/or the storm hydrograph model may be obtained in either a separate job step when the program is run from a terminal or using the optional batch run (see Section II.C).

3. Is sediment to be simulated? (Yes or no) If "no", questions 9, 10, and 11 will be deleted.

4. What is the drainage area and land cover percentages: hardwood, conifer, pasture, small grain, row crop, impervious, and unvegetated? (8 values) The drainage area contributing to streamflow (surface and/or ground water) is in square miles and the land cover values are in percent (100% must be accounted for).

5. Are special directly connected impervious areas to be considered? (Yes or no) This question is contingent on entering a non-zero value for impervious areas in question 4. A "yes" results in question 6.

6. What is the percent? (1 value) Special directly connected areas are impervious areas that drain directly into a stream. This feature should not be used when the impervious area is much greater than about 17 percent.

7. What are the watershed characteristics for slope, shape, drainage density, curve no., sinuousity, % mined, soil perm., available water holding capacity? (8 values) These are watershed characteristics typically obtained from topographic and soils maps.

   a) Slope A weighted measure of main-channel slope in feet per mile.

b) Shape Dimensionless measure defined as the squared length of the main channel in one-mile chords (with fractional value included) divided by the drainage area.

c) Drainage Density As measured on a 1/24,000 scale topographic map (7.5 minute quadrangle map) in miles/mi^2.

d) Curve No. The Soil Conservation Service curve number averaged across the watershed (SCS 1972, 1975).

e) Sinuosity The ratio of the length of the main channel to the channel length measured in one-mile chords, minus one.

f) % Mined A measure of the percent of the watershed that is mined, where this mining has a substantial affect on the timing of the storm hydrograph. See Section III for information on the range of values used in deriving the regionized relationships.

g. Soil Perm. Soil permeability averaged across the watershed in inches per hour.

h. Available Water Holding Capacity As determined from published soils information and averaged across the watershed in inches.

8. What are the values for bypass seepage (DLF) and karst areas (PKARST)? (2 values) These are measures typically used only in soluble carbonate rock areas where drainage within the rock system begins to dominate the streamflow. See Section III for hints on how these measures may be estimated.

a. Bypass Seepage (DLF) This is a ratio index of the amount of potential ground water runoff expected to bypass the location on a stream where simulations are being made (DLF=1.0, no ground water runoff occurs; DLF=0, no potential ground water runoff is lost to deep seepage).

b. Karst Areas (PKARST) This is a ratio index of the amount of potential storm runoff from pervious areas expected to enter the soil carbonate rock system, except during very large storms when the capacity of the soil to hold this additional moisture may be exceeded. (PKARST=1.0, storm runoff occurs only during very large storms; PKARST=0, all potential storm runoff occurs).

9. What is the average sediment concentration at 1 cfs/sm in PPM? (1 value) This is an estimate of the suspended sediment concentration in parts per million that would occur at a discharge of one cubic foot per second per square mile and is used with baseflow in the model to provide a base concentration for sediment simulations when storm hydrographs are printed. Any reasonable value will suffice as the value does not appreciably affect the

sediment load predictions (i.e., 10 ppm). This question appears only when question 3 is answered "yes".

10. What are the USLE factors: soil erodibility (K), slope length and gradient (LS), cropping management (C), and erosion control practice (P)? (4 values) These are measures in the Universal Soil Loss Equation averaged across the watershed. This question appears only when the answer to question 3 is "yes". See Section III.A.6 for a detailed description of these parameters.

11. What are the sediment associated coefficients: grain size ratio, daily impervious area removal rate (R), and daily accumulation rate (ACCIA)? (3 values) These terms are associated with the suspended sediment simulations. This question appears only when the answer to question 3 is "yes." See Sections III.A.6 and V.E for details on how these terms are determined.

    a. Grain Size Ratio This is the ratio of the expected median suspended sediment grain size to one micron.

    b. Daily Impervious Area Removal Rate (R) This is a measure of the fraction of dust and dirt that accumulates on impervious surfaces during days of no rain, which is then removed due to the effects of wind and traffic.

    c. Accumulation Rate (ACCIA) ACCIA is the daily accumulation rate of dust and dirt on impervious surfaces in pounds per acre. Normally this and the companion removal rate R are used only for urban situations where the impervious areas are more extensive. Values of zero may be used where the percent of impervious area is relatively small.

12. What is the convolution time interval? (Hours and minutes with a period between) (1 value) Convolution is the process of multiplying a distribution of precipitation excess by a unit hydrograph to obtain streamflow. The convolution interval should be about 1/4 of the time to peak of the hydrograph. See Haan and Barfield (1978) or any hydrology text for a discussion of the unit hydrograph. The convolution interval, DT, must be a five-minute increment evenly divisible into an hour (i.e., 5, 10, 15, 20, and 30 minutes) or an integer multiple of an hour. DT is expressed in hours and minutes with a decimal between (i.e., for 20 minutes DT = 0.20). DT is converted to hours and fractions of an hour internally in the program.

13. What are the long-term or expected mean rainfall, runoff, or average latitude, and HTFLUX? (4 values).

    a. Mean Rainfall The estimated long-term average annual watershed rainfall in inches.

b. Mean Runoff The estimated expected annual runoff in inches. Where the latitude relationship applies (see next measure) a value of zero may be used. At other locations, the mean annual runoff is either estimated from records from nearby applicable streamgages or by subracting estimated long-term evapo-transpirative losses from average rainfall.

c. Average Latitude The average latitude in degrees for the watershed is used to estimate long-term average annual evapo-transpiration in inches (loss) in the model with a relationship (loss=65.5 - latitude) generally applicable at locations noted in Section I.C. At locations where this relationship is not applicable, a value of zero should be used for this measure and the expected long-term runoff estimated.

d. HTFLUX This is a ratio measure to allow intercepted rainfall to evaporate at a rate faster than the normal rate of transpiration (see Betson, 1979a). A recommended value of 3.0 will allow intercepted water to evaporate at three times the rate of transpiration. (This feature is more important in forested areas.)

14. Number of years to be simulated and beginning year (2 values) The choices are arbitrary. For simulations that involve flood flow frequency analyses, 25 years are usually run.

15. What lower limits are to be used in defining a storm to be simulated? (MINRF and MINRO and MAXRF) (3 values) These are controls which will, if desired, limit the number of storm hydrographs that will be simulated. Any one day or two day rainfall (with corresponding runoff) greater than these values will cause a storm hydrograph to be simulated. In long-term simulations, the goal is to set lower limits so that only the three to four storm hydrographs with the largest peaks are simulated per year. This decreases run time and associated costs as well as limiting the output to the desired information.

a. Minimum Rainfall (MINRF) Each storm with rainfall equal to or exceeding MINRF and simulated runoff equal to or greater than MINRO will have a storm hydrograph simulated.

b. Minimum Runoff (MINRO) This minimum value of storm runoff is used to screen low runoff storms when the purpose of the run is peak flow analysis.

c. Maximum Rainfall (MAXRF) All storms with rainfall equal to or exceeding this threshold will have a storm hydrograph simulated regardless of the storm runoff volume.

16. What are the 12 values for the mean of the cube roots of observed monthly rainfall in water year sequence? (12 values) The cube root of monthly rainfall at a representative raingage is summed by

months for a recommended 25-year record and the monthly average determined. (October is the first month in the water year.)

17. What are the 12 values for the standard deviation of observed monthly rainfall in water year sequence? (12 values) The standard deviations of the array of cube root of monthly rainfall values determined for question 16 are supplied here.

18. What are the 12 values for mean monthly potential evapotranspiration in water year sequence? (12 values) Mean evaporation values from a published land pan or as computed using standard equations that are based on meterological data are supplied here.

19. Are you ready to run the program? (yes or no) A "yes" begins the program. A "no" will cause an exit from the TVA-HYSIM program. This question allows the user to exit and begin again if input errors are detected.

If the answer to question 2 was "yes," another question will be asked following printout of the storm summaries (see Figure 2) as to whether a listing of the storm hydrographs is desired. A "yes" to this question will begin the sequential printing of all storm hydrographs.

C. OPTIONAL OUTPUT

TVA-HYSIM has several output options. The interactive terminal output which contains much of the essential information that is simulated is shown in Figure 2. If the response to question 2 was "yes," much more of the simulated information is stored. The next sub-section describes the detailed storm hydrograph printout that may be obtained at the terminal. These hydrographs are stored on a disk file and may also be printed with a user-supplied utility program that will print a normal file. Similarly, water year simulations of daily rainfall and streamflow are stored on the disk file but this information may be obtained only with a utility program. Section VI explains how this is accomplished in more detail.

A batch run of the program is another option. (Batch runs are made by reading data into the computer by cards and receiving output at a line printer, as opposed to an interactive run in which data is keyed directly into the computer via a teletype terminal.) The data set-up for batch runs is similar to that used in the interactive runs; but, of course, all of the printout may be obtained in a single step. Section VI provides an example of a job control set-up for a batch run.

D. EXAMPLE STORM HYDROGRAPH OUTPUT

Figure 2 shows an example output containing simulated storm values for the short-form printout option. Figure 3 shows an example storm hydrograph simulation that may be obtained using either the interactive approach

TENNESSEE VALLEY AUTHORITY ---- SIMULATED STORM HYDROGRAPH MODEL - VERSION DATE: OCT. 1979 11/05/80

CANE BRANCH NEAR PARKERS LAKE, KY STORM OF 1/ 8/ 1

SIMULATED RANDOM NUMBER IS 35265

WATERSHED CHARACTERISTICS VALUES:

D. A.	C SLOPE	SHAPE	DD	SINU	% FOREST	% MINED	CURVE #	PERM	AWC	% URBAN	PKARST
0.67	194.00	2.04	11.40	0.140	85.00	10.50	50.00	2.98	5.28	2.00	0.0

INPUT RAINFALL ****TOTAL RF = 2.11****

0.050	0.120	0.040	0.030	0.080	0.220	0.030	0.090	0.050	0.080	0.060	0.340
0.020	0.150	0.030	0.030	0.150	0.090	0.090	0.080	0.210	0.080	0.0	0.0

RAINFALL EXCESS ****TOTAL PE= 0.7478****

0.0	0.001	0.000	0.000	0.001	0.049	0.000	0.021	0.001	0.017	0.005	0.216
0.000	0.083	0.000	0.000	0.086	0.034	0.034	0.026	0.145	0.026	0.0	0.0

HOURLY PARAMETERS & CHARACTERISTICS:

T1	T2	T3	UP	UR	TL	B KOI	B RF	B PE	B NPE
3.0000	7.9187	20.4490	0.1507	0.0462	4.7069	0.1439	1.4200	0.3968	9.0000

TIME UNITS PARAMETERS & OTHER DATA:

T1	T2	T3	UP	UR	PHI	CN - PE	DT
3	8	20	0.1507	0.0467	0.0518	96.4970	1.0000

HOURLY PARAMETERS & CHARACTERISTICS:

T1	T2	T3	UP	UR	TL	B KOI	B RF	B PE	B NPE
6.0000	16.2890	38.0304	0.0728	0.0254	10.0495	0.0914	0.7000	0.3511	6.0000

TIME UNITS PARAMETERS & OTHER DATA:

T1	T2	T3	UP	UR	PHI	CN - PE	DT
6	16	38	0.0728	0.0261	0.0518	96.4970	1.0000

USLE	USLEXP	ITPS	D-RATIO	R	ACCIA IMPERVIOUS & PERVIOUS SED (TONS)		
1.7955	0.5600	1	1.0000	0.0800	1.0000	0.0156	57.0484

TENNESSEE VALLEY AUTHORITY ---- SIMULATED STORM HYDROGRAPH MODEL - VERSION DATE: OCT. 1979 11/05/80

CANE BRANCH NEAR PARKERS LAKE, KY STORM OF 1/ 8/ 1

GRAPH RUNOFF FULL SCALE= 1.89D+01 RAINFALL FULL SCALE= 10.0

TIME	OBSERVED	PREDICTED	ERROR		RAIN	SED-TONS	SED-PPM
1	0.0	0.16368D+00	0.0	*P | | | | | | | | | R*	0.0	0.9105D-04	5.
2	0.0	0.18981D+00	0.0	*OP | | | | | | | | |R *	0.09	0.47290-03	22.
3	0.0	0.22607D+00	0.0	*UP | | | | | | | | | R *	0.04	0.86790-03	34.

FIGURE 3. SIMULATED STORM HYDROGRAPH

4	0.0	0.26991D+00	0.0	0.03	0.1230D-02	41.
5	0.0	0.30236D+00	0.0	0.08	0.1397D-02	41.
6	0.0	0.13942D+01	0.0	0.22	0.2347D+00	1496.
7	0.0	0.24830D+01	0.0	0.03	0.3467D+00	1241.
8	0.0	0.40046D+01	0.0	0.09	0.4276D+00	949.
9	0.0	0.40205D+01	0.0	0.05	0.3094D+00	684.
10	0.0	0.44054D+01	0.0	0.08	0.2518D+00	508.
11	0.0	0.42571D+01	0.0	0.06	0.1813D+00	379.
12	0.0	0.87811D+01	0.0	0.34	0.4571D+01	4627.
13	0.0	0.12850D+02	0.0	0.02	0.6650D+01	4600.
14	0.0	0.18924D+02	0.0	0.15	0.8006D+01	3760.
15	0.0	0.18380D+02	0.0	0.03	0.5663D+01	2738.
16	0.0	0.17992D+02	0.0	0.03	0.3998D+01	1975.
17	0.0	0.15502D+02	0.0	0.15	0.2635D+01	1511.
18	0.0	0.13305D+02	0.0	0.09	0.1790D+01	1196.
19	0.0	0.11316D+02	0.0	0.09	0.1290D+01	1013.
20	0.0	0.11039D+02	0.0	0.08	0.1135D+01	914.
21	0.0	0.11524D+02	0.0	0.21	0.1590D+01	1227.
22	0.0	0.12756D+02	0.0	0.08	0.1955D+01	1362.
23	0.0	0.13368D+02	0.0	0.0	0.2086D+01	1387.
24	0.0	0.13736D+02	0.0	0.0	0.2131D+01	1379.
25	0.0	0.13855D+02	0.0	0.0	0.2110D+01	1354.
26	0.0	0.13872D+02	0.0	0.0	0.2047D+01	1312.
27	0.0	0.12837D+02	0.0	0.0	0.1648D+01	1141.
28	0.0	0.11647D+02	0.0	0.0	0.1311D+01	1000.
29	0.0	0.10458D+02	0.0	0.0	0.1037D+01	882.
30	0.0	0.92985D+01	0.0	0.0	0.8156D+00	780.
31	0.0	0.81474D+01	0.0	0.0	0.6362D+00	694.
32	0.0	0.73595D+01	0.0	0.0	0.4923D+00	595.
33	0.0	0.67015D+01	0.0	0.0	0.3815D+00	506.
34	0.0	0.62350D+01	0.0	0.0	0.2931D+00	418.
35	0.0	0.58207D+01	0.0	0.0	0.2228D+00	340.
36	0.0	0.54454D+01	0.0	0.0	0.1671D+00	273.
37	0.0	0.52259D+01	0.0	0.0	0.1370D+00	233.
38	0.0	0.50458D+01	0.0	0.0	0.1126D+00	198.
39	0.0	0.48657D+01	0.0	0.0	0.9241D-01	169.
40	0.0	0.46856D+01	0.0	0.0	0.7572D-01	144.
41	0.0	0.45055D+01	0.0	0.0	0.6195D-01	122.
42	0.0	0.43254D+01	0.0	0.0	0.5061D-01	104.
43	0.0	0.41453D+01	0.0	0.0	0.4129D-01	89.
44	0.0	0.39652D+01	0.0	0.0	0.3365D-01	75.
45	0.0	0.37851D+01	0.0	0.0	0.2740D-01	64.
46	0.0	0.36050D+01	0.0	0.0	0.2229D-01	55.
47	0.0	0.34249D+01	0.0	0.0	0.1814D-01	47.
48	0.0	0.32448D+01	0.0	0.0	0.1478D-01	40.
49	0.0	0.30647D+01	0.0	0.0	0.1205D-01	35.
50	0.0	0.28846D+01	0.0	0.0	0.9866D-02	30.
51	0.0	0.27045D+01	0.0	0.0	0.8114D-02	27.
52	0.0	0.25244D+01	0.0	0.0	0.6719D-02	24.
53	0.0	0.23443D+01	0.0	0.0	0.5615D-02	21.
54	0.0	0.21642D+01	0.0	0.0	0.4748D-02	20.
55	0.0	0.20282D+01	0.0	0.0	0.4137D-02	18.
56	0.0	0.19097D+01	0.0	0.0	0.3674D-02	17.
57	0.0	0.18088D+01	0.0	0.0	0.3330D-02	16.
58	0.0	0.17210D+01	0.0	0.0	0.3076D-02	16.
59	0.0	0.17075D+01	0.0	0.0	0.3068D-02	16.
60	0.0	0.17075D+01	0.0	0.0	0.3068D-02	16.
61	0.0	0.17075D+01	0.0	0.0	0.3068D-02	16.

TOTAL NET SEDIMENT (LESS BACKGROUND) 0.5706D+02

FIGURE 3. (CONTINUED)

or a batch run. Shown on each storm hydrograph simulated are the simulated storm date along with the random number used to generate the storm rainfall (see Section V.B). The word "simulated" at the left margin just under the title will always appear to remind the user that the storm rainfall and runoff values have been simulated rather than observed. A list of the input watershed characteristics that are used in the storm hydrograph component is provided. Next, the total storm rainfall and its distribution (in convolution time intervals-DT) are tabulated followed by a tabulation of the precipitation excess and its distribution.

For each rainfall burst (see Section V.D.2 for burst definition), predicted hourly parameters of the unit hydrograph are shown. On the same line characteristics of the storm burst are given and include: time lag (TL), weighted precipitation excess intensity (B ROI), rainfall (B RF), precipitation excess (B PE), and precipitation excess duration (B NPE). (See Section V.D. for further definitions.) Occasionally, as in this example, the sum of the burst rainfall volumes does not equal the total rainfall. This is due to internal round-off in the computer.

The next line presents the unit hydrograph parameters in integer DT units along with the loss term PHI, the SCS curve number used in determining the precipitation excess distribution, and DT. This curve number, CN-PE, is based on a relationship among storm rainfall, runoff, and PHI (see eq. V-38) and differs from the watershed average curve number, CN, that was input. DT is printed out in hours and fractions of an hour, as opposed to the way it is read in.

If the sediment simulation option is exercised, the storm hydrograph output will contain information relevant to this option including: a computed product of constants in the Universal Soil Loss Equation multiplied by 95, USLEP; the exponent on the runoff energy term in the modified Universal Soil Loss Equation (0.56), USLEXP; a term to delay the peak sediment concentration, ITPS; the grain size ratio, D; the impervious area washoff term, R; the dust and dirt accumulation rate, ACCIA; and the simulated storm sediment load from impervious and pervious areas (in tons).

The last segment of the storm hydrograph output is a print-plot which has a column for observed flows, predicted flows, and the difference between the observed and predicted flows, all in cfs per DT unit. (This is a general print-plot routine used in other programs--in TVA-HYSIM the observed and the error columns will always be zeros.) These predicted runoff values (usually beginning and ending with baseflow) are plotted at a scale shown at the top of the print-plot such that the maximum predicted value is full-scale. Also shown on the right margin of the print-plot are the rainfall (less interception), the incremental suspended sediment load in tons and the suspended sediment concentration. The total sediment load is printed at the bottom of the print-plot.

SECTION III

BASIN CHARACTERISTICS

A. DETERMINATION OF BASIN CHARACTERISTICS

Because TVA-HYSIM contains regionalized models, the basin characteristics must be determined in the same manner as were those characteristics that were used in developing the regionalized relationships. This section describes how each of the characteristics is measured.

1. Land Cover Measures

These measures, listed in question 4, Section II, can best be obtained by direct observation or from aerial photographs. For larger watersheds, the overall percent forest may be estimated from current topographic maps which depict forest areas, and an estimate of the remaining agricultural cover distribution estimated from county information in a current USDA Census of Agriculture (assuming the distribution in the watershed corresponds with that in the county).

2. Topographic Characteristics

These characteristics are determined using a 7-1/2 minute quadrangle map, 1/24,000 scale.

a. Drainage Area If the drainage area is not published, the topographic divide of the watershed is depicted on the map and the area obtained using a planimeter or by counting intersections within the divide on a grid overlay. Known non-contributing areas such as sinkholes should not be included. (See sub-section A.4.a of this section.)

b. Channel Slope is a weighted measure calculated from the point of simulation to the watershed divide along the main channel. Channel slope is calculated in feet per mile. The number of miles between each contour crossing of the main channel upstream of the simulation point is tabulated (ΔL). The associated difference in elevation (ΔE) is then tabulated in feet (ΔE should usually be constant). The weighted channel slope can then be calculated as

$$CSLOPE = (\Sigma\Delta L/\Sigma(\Delta L/\sqrt{\Delta E/\Delta L}))^2 \qquad \text{III-1}$$

c. Sinuosity This is an index measure of the sinuosity of the main channel. The measure is defined as the ratio of the actual length of the main channel to the main channel length as measured in one-mile chords (with fractional value included), minus 1.0.

d. Drainage Density A grid intersection method is used to compute drainage density. The grid size in map scale miles should be approximately equal to the square root of (drainage area in square miles/75). This should give about 100 grid intersection points, regardless of the drainage area size. First, all channels and/or courses that might carry water are delineated on a 1:24,000 scale contour map and extended as indicated by contour crenulations ("V" shaped cusps). Next, the total number (ΣN) of intersections of the channel system with the grids are tallied. Then the total length (ΣLI) of all grid lines within the watershed (in miles) is determined. Drainage density is calculated as

$$DD=1.571\ \Sigma N/\Sigma LI \qquad \text{III-2}$$

e. Shape This is a dimensionless measure of the shape of the basin. It is defined as the squared length of the main channel measured in one-mile chords (with the fractional value included) divided by the drainage area in square miles.

3. Soil Associated Characteristics

Soils information is essential for operating TVA-HYSIM. An SCS county soil survey is available for many counties. Where unavailable, a soils association map is often available. Usually, the local Soil Conservation Service county representative can provide the necessary soils information. The calculation of these characteristics begins with a determination of the percent of the watershed in each soil type. This information is best obtained from soil maps using a grid-intersection counting method. Information on the hydraulic properties of the various soil types are contained in the more recent County Soil Survey reports, or may be obtained from standard soils series descriptions which can usually be obtained from a county SCS representative (also, see Section IV.B).

a. Soil Permeability Permeability in inches per hour is usually expressed in the soils series descriptions as a range of values. A separate range of values may be given for each depth horizon. The average of the range of permeability values for each depth horizon is used. These permeabilities are weighted by the incremental horizon depth to determine an average permeability value for each soil type. Only the depths of each soil type provided in the descriptions, usually to about six feet maximum, are used. Where hard-pans or other confining layers occur, only values above this horizon are considered. A watershed average value is determined by weighting the permeability of each soil by the portion of the watershed it occupies.

b. Available Water Holding Capacity (AWC) Water holding capacity (usually expressed in inch/inch) is typically given in the soil series descriptions as a range for each of a number of soil horizons. The average value of the range is multiplied by the incremental depth it represents and these amounts summed to determine an AWC for each soil. A weighted watershed average value is then computed.

c. Curve Number (CN) This is the SCS curve number (SCS 1972, 1975) which combines the percent of the watershed in A, B, C, D, hydrologic classes of soils with land cover. See the SCS references or Haan and Barfield (1978) for procedures for computing CN. Care must be taken to ensure that the soil series description corresponds with the assigned hydrologic class (see Section IV.B). In practice, the land cover occupying each soil type is seldom known. Therefore, an assumption can be made that forest occupies the poorer soils (class D) while row crops occupy the better soils (class A or B). Each land cover is allocated to a logical hydrologic soil group and the corresponding CN for that cover-hydrologic group is determined from the tables. A watershed average CN is then determined.

4. Carbonate Rock Associated Measures

These measures apply in areas underlain by carbonate rock. A geologic map must be available in those areas where carbonate rock is suspected in order to determine rock type. Determination of the following measures requires some knowledge of geohydrology.

a. Modifications to Drainage Area In soluble carbonate rock areas, the geologic divide may not correspond with the topographic divide. Springs may bring in water from areas outside the topographic divide and water may be lost from within the topographic divide through sinkholes. To the extent possible, adjustments to the drainage area should be made where there is supporting evidence such as sinkholes.

b. Bypass Seepage (DLF) In the absence of any hydrologic data this measure is difficult to estimate. It can be approximated as the fraction of the watershed area underlain by very soluble carbonate rock. This measure primarily affects the yield of potential ground water runoff (see Section V.C.7).

c. Karst Areas (PKARST) This measure controls the yield of potential storm runoff. Values are assigned to each rock type underlying the watershed as follows: very soluble carbonate rock, PKARST=1.0; moderately soluble carbonate rocks, PKARST=0.5; all other rocks PKARST=0.0. Judgment values between these numbers can be used. An average value for the watershed is determined based upon the percent of the watershed each rock type occupies (see Section V.C.9).

5. Other Land-Use Measures

a. Percent Mined The measure applies only to a surface mined area that has a significant effect on the storm hydrograph. For example, if the land is returned back-to-contour and revegetated, the value used here would be zero. It is important that the value used for this measure not exceed the range of values used during regionalization (0-24 percent). (See the last sub-section in this section.)

b. Directly Connected Impervious Areas In the algorithms used in the daily flow model, an impervious area amounting to less than 17 percent of the watershed area does not affect the volume of storm runoff (see Section V.C.2.a). The assumption is that when the impervious area is less than 17 percent, the runoff from these impervious surfaces drains into adjacent pervious areas. However, occasionally there are impervious surfaces, such as roads paralleling a stream, that drain directly into the stream. These areas should be considered even though the total impervious area is less than 17 percent. If a value is provided for the directly connected measure, that value will be used as the impervious area contributing to storm runoff, regardless of the impervious area measure used for land cover.

6. Sediment Associated Measures

There are provisions for simulating suspended sediment from both impervious areas (dust and dirt) and pervious areas (erosion) within a watershed. The model formulations are from published sources so that estimates of the input measures can be made without field measurements.

a. USLE Terms These are the terms in the modified Universal Soil Loss Equation (Williams, 1975) determined for the pervious portions of a watershed. The Modified Universal Soil Loss Equation (without the runoff energy term) is expressed by:

$$USLEP=95\ LSKCP \qquad \text{III-3}$$

Terms required as model input include:
LS is the length slope term for the watershed as determined using the method of Williams and Berndt (1976),
K is the soil erodability factor for each soil averaged across the watershed,
C is the cover term averaged for the watershed, and
P is the conservation practice term,

The length-slope term, LS, for a watershed is determined in the following manner.

$$SLOPE = \frac{25H(LC_{25}+LC_{50}+LC_{75})}{5280\ DA} \qquad \text{III-4}$$

where: SLOPE = slope in percent,
H = maximum difference in watershed elevation in feet,
LC_n = length in miles across the watershed of the contour representing 25, 50, or 75 percent of H, and
DA = drainage area in square miles.

The length term, LENGTH, is calculated as

$$LENGTH = .264/DD \qquad \text{III-5}$$

where LENGTH = length in feet and
DD = drainage density.

The length-slope term then becomes

$$LS = \left(\frac{LENGTH}{72.6}\right)^{0.5} (0.065+0.0454SLOPE+0.0065(SLOPE)^2) \qquad \text{III-6}$$

The text by Haan and Barfield (1978) summarizes methods for determining the other terms.

b. Grain Size Ratio (D) If a grain size distribution is available, the ratio of the median grain size to one micron is used. Otherwise, in the absence of additional information assume a value of one.

c. Daily Impervious Area Removal Rate (R) The removal rate R is the fraction of accumulated dust and dirt removed daily by wind, traffic, and sweeping. A value of 0.08 is recommended if sediment from impervious areas is to be simulated.

e. Accumulation Rate (ACCIA) This is the daily accumulation rate for dust and dirt on impervious surfaces in pounds per acre. (See Donigan and Crawford, 1976, and Metcalf and Eddy, 1971, for values for several cities.) Values typically range from 1 to 10 lb/ac or more. Since the yield of dust and dirt from impervious surfaces is usually low relative to the sediment from pervious surfaces, the R and ACCIA terms can be assumed to be zero if the impervious portion of a watershed is small (<10-15 percent).

7. Convolution Interval (DT)

Although selection of a convolution interval (DT) is not critical, the use of a DT that is too small can significantly add to the computer run time, while one that is too long will generally result in poor simulations and may cause computer diagnostics. The text by Haan and Barfield (1978, p81ff) presents a number of equations for predicting unit hydrograph time parameters.

In general, the following relationship adapted from Kirpich (1940) may be used to give an initial estimate of the time of concentration, which is the time of travel from the hydraulically most distant point in the basin to the watershed outlet.

$$TC=2.6\ L^{0.77}(L/H)^{0.385} \qquad \text{III-7}$$

where: TC is the time of concentration in hours,
L is the main channel length in miles,
H is the difference in elevation between the basin outlet and the hydraulically most distant point in the watershed, in feet.

Using TC as an estimate of the time to peak and recognizing that there should be at least three DT units prior to the peak, DT may be estimated in hours as

$$DT=TC/3 \qquad \text{III-8}$$

DT would then be rounded to 5, 10, 15, 20, or 30 minutes, or an integer multiple of one hour. DT is converted to hours or fractions of an hour internally in the program. In locations where significant mining or urbanization has occured, or will occur, it may be necessary to reduce DT somewhat. Conversely, where there is an extensive forest cover and/or permeable soils, the DT estimated by these equations will be too short. Following an initial simulation, the adequacy of the estimated DT may be determined from a printout of storm hydrographs as shown in Figure 3 and adjustments may be made if necessary. If, for instance, the time to peak is consistently less than three DT units, DT should be shortened.

8. Storm Selection Threshold Measures

The threshold measures allow the user to control the number of storm hydrographs which are simulated per year of continuous simulation. These measures should be selected so that 3 to 4 storm hydrographs per year are simulated when flow frequencies are to be determined. When the model is used to simulate continuous storm hydrographs (for example, if a year of sediment loads are simulated) these limits would be set much lower.

a. Minimum rainfall (MINRF) The value for a larger storm that typically falls during the winter (high runoff) season should be selected.

b. Minimum Runoff (MINRO) This threshold is used to eliminate storms that occur during the summer when runoff is so low as to preclude a high peak discharge.

c. Maximum Rainfall (MAXRF) This threshold forces hydrographs for all of the storms equal to or larger than this threshold value to be simulated regardless of the associated runoff. This option can be important when urban areas are involved.

To simulate three to four storms per year in an area where annual rainfall averages between 45 and 55 inches, a first trial set of values might be MINRF=1.5, MINRO=0.2, and MAXRF=2.5 inches.

9. Meterological Measures

Although the required meterological inputs are seemingly rather gross measures, the simulations are quite sensitive to these values being representative. The long-term average rainfall and runoff (or loss) estimates are used in the regionalized relationships for predicting parameters in the continuous daily streamflow model and thus affect the allocation of all precipitation among streamflow, soil moisture recharge, and evapotranspiration. The measure of long-term monthly evaporation, on the other hand, need only have a reasonable distribution among the 12 months as a volumetric correction is made within the model so that the annual total corresponds with the read-in loss determined from latitude (see Section II.B.13.c) or from rainfall minus runoff. In contrast, the statistical measures of rainfall are critical since generated precipitation drives the entire system.

a. Long-term Average Rainfall This information can best be obtained from published NOAA-National Weather Service records or comparable sources that determine long-term normal or mean rainfall for reporting stations. The raingage selected should be nearby and representative. Records from stations less than 25 years old should be adjusted to a long-term mean at a longer-record station. The station selected to give the long-term mean should also be used in determining the monthly statistics. The long-term mean annual rainfall need not correspond exactly with that at the long-term station, however, if a better estimate can be made from another source (for example, if there is a long-term rainfall isohyetal map available which indicates a different value). Data should be compared from several stations in the area to ensure that a representative value is being used.

b. Long-term Average Runoff (or Latitude) Only one of these two measures is needed. Within the region of applicability (Section I) latitude should normally be used unless there is evidence to indicate that the long-term runoff computed using this method will be in error. Rearranging terms in the equation presented in Section II.B.13.c, results in the following equation for predicting long-term runoff (RO) from long-term rainfall (RF) and latitude (LAT).

$$RO=RF-65.5+LAT \qquad \text{III-9}$$

When a value for LAT is entered, RO should be entered as zero. At locations outside the region of model applicability the long-term runoff should be entered (this can be determined from RF minus an expected loss). In this case a zero should be entered for average latitude.

c. HTFLUX This measure is a ratio of the rate of evaporation of intercepted rainfall to the normal rate of transpiration. A value of 3.0 should be used in the absence of better data. This allows intercepted water to evaporate at three times the rate of transpiration. The HTFLUX measure becomes more important on forested watersheds.

d. Mean of the Cube Root of Monthly Rainfall This information must be obtained from representative long-term raingage records (at least some 25 years in duration). The monthly and annual simulated rainfall averages will be very nearly the same as those of the station used, so this station must be representative. If, however, very unusual rainfall patterns occurred during a month or two, some adjustment to these data may be justified. For example, if the average for a particular month differed considerably from the published normal, because of unusual rainfall during a year or two, some adjustment should be made. These adjustments should seldom be necessary for very long-term stations.

These values are determined by taking the cube root of all monthly rainfall values and then determining a mean for each month. As an option, the mean of the cube root of monthly rainfall may be estimated from published station monthly mean or normal data with the following equation:

$$\sqrt[3]{RF} \cong 0.935(RF)^{0.3436} \qquad \text{III-10}$$

where RF is the long-term mean monthly rainfall for a given month. This equation is valid for monthly rainfall within the range of about 2.5 inches to 9 inches. This monthly information is input in water year sequence; i.e., October is the first month.

e. Standard Deviation of Cube Root of Monthly Rainfall (SD) The monthly rainfall simulations are quite sensitive to the values used for these standard deviations. These data must be obtained from a representative nearby long-term raingage record. In order to understand how these numbers combine to simulate rainfall, a simple computation can be made. In a 20-year simulation, on the average, there will be one monthly rainfall simulated outside the range determined by the following equation:

$$RF \quad \text{monthly} \quad = \quad (\sqrt[3]{RF} \pm 2SD)^3 \qquad \text{III-11}$$

Thus for a typical October with a long-term mean of the cube root of monthly rainfall ($\sqrt[3]{RF}$) equal to 1.3 and assuming an SD of .29 (lowest observed), at least one month of October rainfall will be outside the range of 6.7-0.4 inches for a 20-year simulation period. If, on the other hand, the maximum observed SD is used, the range becomes 10.4-.07 inches. This points up the need for care when selecting a representative long-term gage.

The computed standard deviations should be smoothed somewhat as the calculated values are quite sensitive to unusual monthly rainfall values, even in a 25-year record. This smoothing should result in a fairly consistent pattern from month to month. Figure 4 shows an average pattern and the extreme values obtained analyzing data from 34 raingage locations across the Tennessee Valley area and into Kentucky where rainfall averaged from 39 to 59 inches annually.

Actual calculation of the standard deviation of the cube root of monthly rainfall involves the following:

1. Determine the cube root of the rainfall for a given month for each year in the period of record and compute the mean value (beginning with October).

2. Determine the standard deviation of these cube root values for the given month.

3. Repeat for other 11 months

4. Smooth standard deviation values as necessary

B. THE WATERSHEDS USED TO DEVELOP THE REGIONALIZED RELATIONSHIPS

Table 1 lists the watersheds for which hydrologic data were used to obtain optimum values for the parameters of the continuous daily streamflow model and the storm hydrograph model. These optimized values were used subsequently to develop the regionalized relationships. Shown in the table are the gage type, the latitude and longitude of the watershed, the physiographic province involved, the percent impervious or mined, percent forest, the annual rainfall and the model with which the data were used.

C. RANGE OF VALUES USED IN DEVELOPING REGIONALIZED RELATIONSHIPS

Listed in Table 2 are those measures used in the regionalized relationships to predict model parameters. Some of these measures are used in standardized formulations (such as terms in the Universal Soil Loss Equation) and consequently are not regionalized measures, per se. Acceptable values may be obtained from the literature for these measures, therefore, these terms are noted with an "LT". Where upper and lower bounds for the measures are given, it is important that computed measures stay within these limits or the regionalized relationships may not apply. Section IV will provide some clues on how to handle situations where measures exceed these limits.

The characteristics listed in Table 2 generally follow the sequence in which they were presented in the Section II description of the interactive input information. A relative measure of the importance of keeping measures within the stated bounds is also shown in Table 2. The

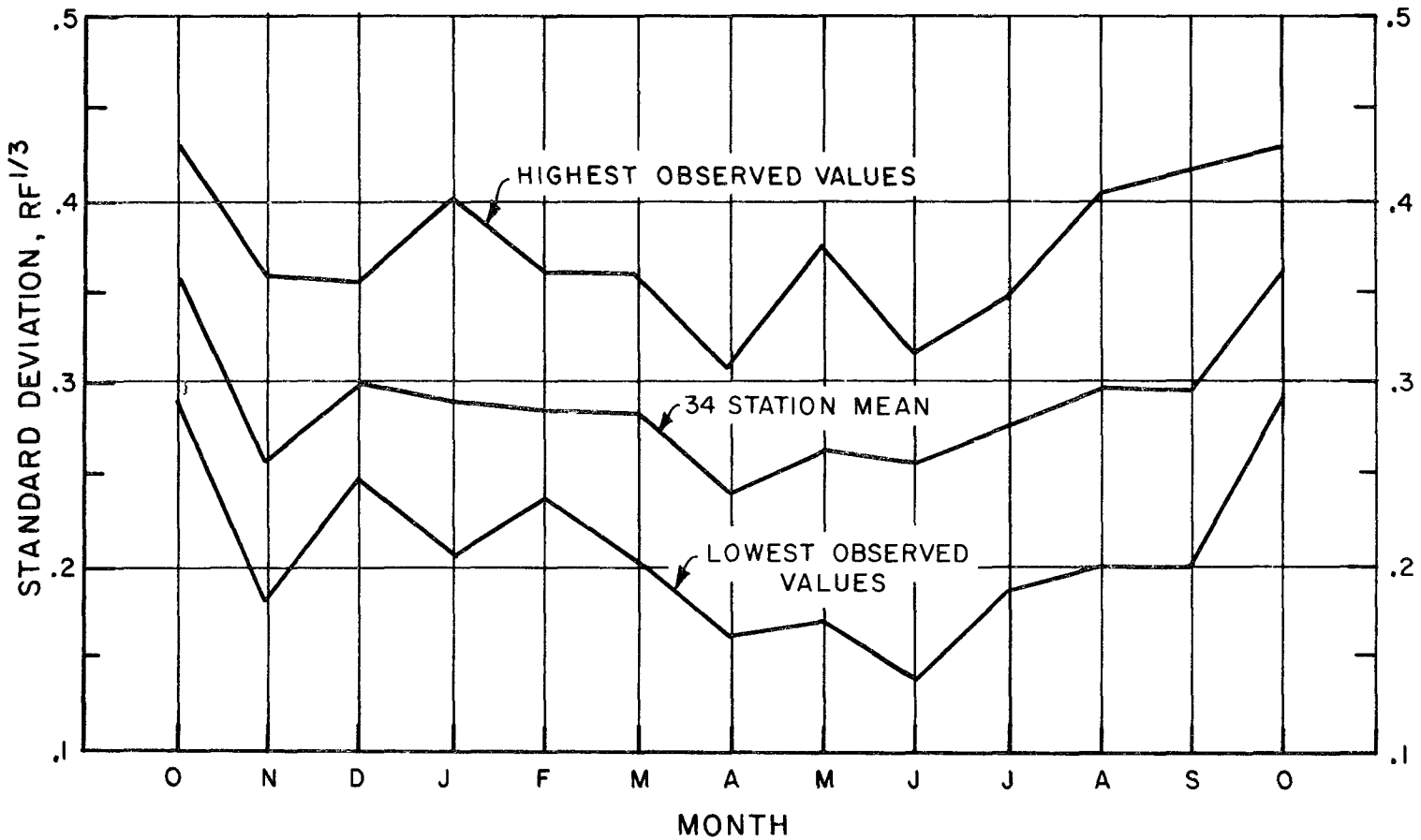

Figure 4 : Range of Values-Standard Deviation Cube Root Monthly Rainfall

TABLE 1

CALIBRATION WATERSHEDS FOR MODEL TVA-HYSIM

Watershed	Gage Type	Lat. (deg.)	Long. (deg.)	Drainage Area (mi^2)	Physio-graphic Province (1)	Percent Urban or Mined (2)	Percent Forest	Annual Rainfall Inches	Used In (3)
Upper Bear Cr. AL (SA-1)	TVA	34.3	87.7	2.0	HR	0	22	55	C
Upper Bear Cr. AL (SA-2)	TVA	34.3	87.7	7.18	HR	0	42	56	C/S
Upper Bear Cr. AL (SC-1)	TVA	34.3	87.6	0.87	HR	0	25	55	C/S
Upper Bear Cr. AL (SC-2)	TVA	34.3	87.6	1.92	HR	0	29	54	C
Upper Bear Cr. AL (SC-3)	TVA	34.3	87.6	11.4	HR	0	41	54	C
East Fork Upper Bear AL (XF-2)	TVA	34.4	87.5	0.2	HR	0	100	54	C/S
Upper Bear Cr. AL (SF-1)	TVA	34.4	87.5	2.48	HR	0	100	56	C/S
Upper Bear Cr. AL (SF-2)	TVA	34.4	87.5	13.9	HR	0	85	58	C/S
Upper Bear Cr. AL (S-1)	TVA	34.3	87.6	26.8	HR	0	77	56	C
Upper Bear Cr. AL (S-2)	TVA	34.3	87.7	36.2	HR	0	62	56	C/S

(continued)

TABLE 1 (continued)

Watershed	Gage Type	Lat. (deg.)	Long. (deg.)	Drainage Area (mi^2)	Physio-graphic Province (1)	Percent Urban or Mined (2)	Percent Forest	Annual Rainfall Inches	Used In (3)
West Fork Upper Bear (XF-1) AL	TVA	34.4	87.5	0.2	HR	0	100	54	S
Horse Creek Savannah, TN	TVA	35.2	88.2	104.0	HR	2.5U	80	50	C
Calfkiller River Sparta, TN	USGS	35.9	85.5	175.0	HR	0	75	56	C
Spring Cr. Lebanon, TN	USGS	36.2	86.2	35.3	NB	2.4U	31	52	C
Cane Creek Shady Hill, TN	TVA/ USGS	35.6	88.3	16.8	MA	0	23	49	S
Browns Creek Nashville, TN	USGS	36.1	86.8	11.8	NB	33U	24	46	C/S
Caney Fork Clifty, TN	USGS	35.7	85.6	114.0	CP	12.0U	74	53	C
Emory River Wartburg, TN	USGS	36.1	84.6	83.2	CP	0	53	53	C
Bitter Creek Camp Austin, TN	USGS	36.0	84.5	5.53	CP	6.5U	4.0M 86.0	55	S
Raccoon Creek Old Windsap, TN	USGS	35.8	85.1	1.52	CP	3.2U	89.4	50	S

(continued)

TABLE 1 (continued)

Watershed	Gage Type	Lat. (deg.)	Long. (deg.)	Drainage Area (mi^2)	Physio-graphic Province (1)	Percent Urban or Mined (2)	Percent Forest	Annual Rainfall Inches	Used In (3)
Self Creek Big Lick, TN	USGS	35.8	85.0	3.80	CP	3.0U	79.6	50	S
Forked Creek Oakdale, TN	USGS	36.0	84.5	2.44	CP	2.0U	1.7M 94.3	46	S
Byrd Creek Crossville, TN	USGS	35.9	85.1	1.10	CP	4.0U	71.8	54	S
Helton Branch Greenwood, KY	USGS	36.9	84.5	0.85	CP	0	91.0	48	C/S
Lowe Branch Norma, TN	UT*/ USGS	36.3	84.4	0.92	CP	0	100	54	S
Anderson Branch Norma, TN	UT*/ USGS	36.4	84.4	0.81	CP	1.0M	99.0	47	S
Green Branch Norma, TN	UT*/ USGS	36.3	84.4	1.4	CP	24.0M	76.0	47	S
Bills Branch Norma, TN	UT*/ USGS	36.3	84.4	0.65	CP	10.4M	90.2	47	S
Cane Branch Parkers Lake, KY	USGS	36.9	84.5	0.67	CP	10.5M	88.0	47	C/S
Sewee Creek Decatur, TN	USGS	35.6	84.7	117.0	VR	0	46	52	C/S

(continued)

TABLE 1 (continued)

Watershed	Gage Type	Lat. (deg.)	Long. (deg.)	Drainage Area (mi^2)	Physio-graphic Province (1)	Percent Urban or Mined (2)	Percent Forest	Annual Rainfall Inches	Used In (3)
White Creek Sharps Chapel, TN	TVA	36.3	83.9	2.68	VR	0	100	47	C/S
Brush Creek Johnson City, TN	TVA	36.3	82.3	6.78	VR	2.0U	26	41	C
Buffalo Creek Norris, TN	USGS	36.2	84.1	9.92	VR	2.0U	32	54	C
Bullrun Creek - Halls Cross Roads, TN	USGS	36.1	84.0	68.5	VR	1.0U	53	48	C
L. Chestuee Creek Wilson Station, TN	TVA	35.1	84.6	8.24	VR	0	49	53	S
Chestuee Creek Englewood, TN	TVA	35.1	84.6	14.8	VR	0	18	52	S
Fourth Creek Knoxville, TN	TVA	35.9	84.1	0.82	VR	45U	24	46	S
Third Creek Knoxville, TN	TVA	36.0	84.0	1.6	VR	28U	26	46	C/S
First Creek Knoxville, TN	TVA	36.0	84.1	0.5	VR	16U	45	46	S
Plantation Hills Knoxville, TN	TVA	36.0	84.0	0.24	VR	23U	37	46	S

(continued)

TABLE 1 (continued)

Watershed	Gage Type	Lat. (deg.)	Long. (deg.)	Drainage Area (mi^2)	Physio-graphic Province (1)	Percent Urban or Mined (2)	Percent Forest	Annual Rainfall Inches	Used In (3)
Parker Branch Leicester, NC	TVA	35.7	82.5	1.51	BR	0	15	38	C/S
N. Fk. Citico Creek Tellico Plains, TN	USGS	35.4	84.1	7.04	BR	0	100	77	C/S
Crab Creek Penrose, NC	USGS	35.1	82.5	10.9	BR	0	83	72	S
Boylston Branch Horseshoe, NC	USGS	35.3	82.7	14.8	BR	0	64	57	S
S. F. Mills R. Pink Beds, NC	USGS	35.4	82.7	9.99	BR	0	100	69	C/S
Allen Creek Hazelwood, NC	USGS	35.4	83.0	14.4	BR	0	99	57	S
N. Indian Creek Unicoi, TN	USGS	36.2	82.3	15.9	BR	0	79	53	S
Noland Creek Bryson City, NC	USGS	35.5	83.5	13.8	BR	0	100	68	S

(1) Fenneman (1938) HR = Highland Rim; MA = Mississippi Aluvium; NB = Nashville Basin; CP = Cumberland Plateau; VR = Valley & Ridge; BR = Blue Ridge

(2) Listed are percent urban (U) or mined (M)

(3) C = continuous daily streamflow model
C/S = both models
S = storm hydrograph model
*University of Tennessee

critical index ranges from 1 for measures that must be kept nearly within the range used in regionalization, to 3 for measures where this range is relatively unimportant.

TABLE 2

BASIN CHARACTERISTIC RANGE USED IN REGIONALIZED RELATIONSHIPS

Characteristic	Lower Value	Upper Value	Critical Index[a]
Drainage area (sq. miles)	0.2	175	2
% Hardwood	0	100	3
% Conifer	0	100	3
% Pasture	0	100	3
% Small grain	0	100	3
% Row crop	0	100	3
% Impervious	0	45	2
% Unvegetated	0	86	3
% Directly connected impervious areas	0	5	3
Slope (ft/mi)	10.9	1170	1
Shape	1.2	7.3	1
Drainage density (mi/sq.mi.)	9.4	17	1
Curve number	35	82	1
Sinuosity	0.015	0.56	1
% mined	0	24	1
Soil permeability (in/hr)	1.2	8.1	1
AWC (inches)	2.6	11.7	1
Bypass seepage	0	1.0	1
PKARST	0	1.0	1
Sediment conc. at 1 csm*	10	10	3
K Univ. Soil Loss Equation term.	LT	LT	-
LS " " " "	LT	LT	-
C " " " "	LT	LT	-
P " " " "	LT	LT	-
Grain size ratio	1	2	2
Daily imp. area removal rate	LT	LT	-
Daily D&D accumulation rate	LT	LT	-
Convolution time DT (hours)	0.083	2	1
Mean rainfall (inches)	38	77	2
Mean runoff (inches)	10	50	2
Latitude (degrees)	34.3	36.9	2
HTFLUX*	3	3	2

*default or standard value used
LT=literature values
a-1=measures should be kept within stated bounds
2=measures should be kept near stated bounds
3=measures should be reasonable

SECTION IV

USER STRATEGIES

A. THE TYPES OF SIMULATIONS THAT MAY BE OBTAINED

Figure 2 shows the basic output that is obtained from the interactive version of TVA-HYSIM. The basic output consists of storm rainfall, runoff, and peak discharge, and if the sediment option is exercised, the suspended sediment load, and average and maximum sediment concentration for each storm simulated. The annual rainfall, runoff, minimum one-day flow, and sediment load is given for each year simulated and the average annual rainfall, runoff, and sediment load are shown at the end of the simulation. The units for rainfall and runoff are watershed-inches (equivalent depth over the contributing drainage area). Sediment loads are in tons. Peak discharge and minimum flow are in cubic feet per second.

If a flood frequency is to be evaluated, the storm threshold controls (Section II.B.15) should be set so that on the average three to four storms per year are simulated. If these thresholds are set too low many storms will be simulated, the computer cost will be high, and nothing will be gained from the simulation of additional storms; but if the thresholds are too high, no storms may be simulated during one or more years. The thresholds should be set with the MINRF corresponding to a storm size that typically occurs several times during a high runoff season. MAXRF should be set at a reasonable high storm or daily, rainfall value. The threshold MINRO can be set to any reasonable value that will eliminate those storms with high rainfall that occur during the low runoff season but do not produce significant peak flows.

Water yield can be determined from the average annual rainfall and runoff shown at the end of the printout (Figure 2). If only water yield is to be analyzed, the rainfall-runoff threshold values should be set high so that no storm hydrographs are simulated.

Minimum one-day flows are determined for each year during the course of the simulations and are shown on the interactive printout. If minimum flow simulations for other durations are needed, they may be obtained by answering "yes" to question 2 (Section II) which causes a detailed printout to be stored. When running the program from a time-sharing terminal, the detailed printout of the continuous mean daily discharge simulations and the storm hydrograph simulations will be stored on a disk file. This information may be obtained in a second job step using a user-supplied utility program that will print a normal file to a line printer.

When the program is run from cards (batch), the job controls can be used to obtain the equivalent interactive printout along with the continuous daily streamflow model and storm hydrograph model simulations. Section VI has an example job control set-up showing how this batch run might be accomplished. When this printout is obtained, the continuous daily streamflow information will contain identification information and parameter values. Following this, there will be two tables (matrices) for each year simulated. The first table is the simulated daily rainfall for the water year; the second table is the simulated daily runoff. These simulated runoff values are in watershed-inches printed in scientific notation. The minimum simulated flows for any desired duration can be determined from this latter table and converted to conventional units with the following equation:

$$CFS=DA \cdot IN/0.0372 \qquad \text{IV-1}$$

where: CFS is cubic feet per second (per day),
IN is the average daily flow in watershed-inches, and
DA is the drainage area in mi^2.

Suspended sediment simulations are tied to the storm hydrograph simulations. Obviously, as more storms are simulated per year, the total annual sediment load that is computed will increase (although typically most of the sediment will be associated with the larger storms). Therefore, if annual sediment loads are the consideration, the rainfall-runoff thresholds should be set very low so that most storms are simulated. If this is done, however, only a few years should be simulated to keep the computer run-time reasonable.

TVA-HYSIM is not adapted to handling dynamic land-use conditions. For example, there are no provisions for handling the changing land-use that occurs in urban areas or the during-mining phase of surface mining. This model package is designed to be used as a planning tool so that the end effects of the land-use change can be evaluated before the change occurs. Thus, in a typical land-use change evaluation the model package would be used first to simulate hydrology under present land-use conditions (or any other baseline condition) and then used to simulate the post land-use change hydrology. Used in this manner, the model package could, for example, be used to determine many of the probable hydrologic consequences of surface mining as required under PL95-87 (30CFR 780.21C).*

B. ARE THE BASIN CHARACTERISTICS "CORRECT"?

There are a number of basin and climatological measures needed to operate TVA-HYSIM. Section III described at some length how these characteristics are to be measured to help assure that they are determined in the same way that they were for the regionalized relationships. Nevertheless, problems in determining these characteristics will occur. Probably, the most serious problems will center around the soils-associated measures (Section III.A.3).

*Surface Coal Mining and Reclamation Operations-Permanent Regulatory Program, March 1979.

The various soil measures are essential to operating TVA-HYSIM. This model cannot be used where soils information is unavailable. Soil-association maps can be used with caution at locations where detailed SCS soils survey maps, or equivalent, are unavailable. However, even where detailed county soil surveys are available, there are limits to the applicability of certain of the measures at a given site. (1) The hydrologic measures (available water holding capacity and permeability) published in newer County Soil Survey reports or in established series descriptions are typically based upon measurements made at a particular location. How applicable these measures may be at another site many miles away with the same soil series is unknown. The use of range averages for these measures as a computational device does not circumvent the fact that at a particular site the actual values could be at either side of the range, or beyond it. (2) The calculation of curve number, CN, is highly dependent upon the hydrologic soil group classification which is based upon minimum infiltration rates (SCS, 1975). Because of changes in soil classifications, the published hydrologic information for a particular soil may not adequately reflect the characteristics of that soil in a particular county. Therefore, it is important that published descriptions in the County Soil Survey describe an infiltration rate corresponding with the hydrologic soil group. (For instance, the relatively low CN used in the example in Section II, Figure 1, results from an adjustment to account for high infiltration capacities.) If they do not agree, adjust the hydrologic soil group. (3) Where hard-pans, plow-pans or fragipans exist which significantly inhibit the downward movement of water, the soil moisture associated measures should be determined only down to the impeding horizon. (4) Although some soils are deep with bedrock at depths of 10 feet or more, the soil associated measures are computed only as deep as the typical profile measures are given (usually about six feet maximum).

Most of any problems encountered in simulating sediment will be associated with determining the cover term "C" provided the approach of Williams and Berndt (1976) is used to compute the length-slope term. The simulation of suspended sediment loads is highly sensitive to the value used for the cover term. Yet, for many cover conditions published values for "C" may vary by a factor of from two to ten. The simulated loads will vary proportionately. This means that, to a large degree, the reasonability of the pervious area sediment simulations will depend upon the estimate used for the cover term. In watersheds with mixed land-use, these estimates are most critical for disturbed areas and agricultural lands.

And finally, as pointed out in Section III.A.9.e, even when as much as 25 years of monthly rainfall data are used to determine the standard deviation of the cube root of monthly rainfall, some adjustment to these calculated standard deviation values may be necessary. If the standard deviations (SD) are too large, inordinately large and small monthly rainfall values will be simulated occasionally. If the SD values are too small the simulated monthly values will vary little from the mean monthly values. If unusual monthly rainfall amounts have occurred in the observed data, the computed standard deviations will probably be too large or too small. A somewhat smoothed seasonal distribution of the standard deviations should be used and be patterned after the average relationship shown in Figure 4.

C. *VALIDATION/VERIFICATION*

In the absence of data for validation, simulation results using a hydrologic model cannot be accepted with complete confidence. Even at locations where a regionalized model is presumed to apply, verification of the results is necessary. There are too many possible sources of error that range from mistakes in measuring characteristics, to poorly estimated measures, to using unrepresentative published measures, to simply making mistakes in entering information into the computer. At locations beyond the region of applicability for the models, validation becomes a necessity.

Perhaps the safest approach to validating the model package is to simulate at a watershed where rainfall, streamflow and, with luck, suspended sediment data are being, or have been, collected. The range and means of the simulated annual rainfall, runoff and sediment loads can be compared with the observed data. Similarly, the optional printout can be obtained and monthly and daily rainfall extremes can be compared with observed data for reasonability. The simulated large-storm peak discharges can be compared with the published data. Through this process, and by changing some of the "soft" or estimated measures described in the previous section, the user can begin to develop confidence in the model and an appreciation of the "art" involved in determining some of these measures.

Where appropriate validation data are simply unavailable, then the results should still be verified for reasonability. The following steps should help assure that the results are at least reasonable.

1. Be sure that the simulated average annual rainfall, runoff, and sediment load, shown at the bottom of Figure 2, are reasonable. The average annual rainfall, for longer simulations, should correspond well with the read-in value in question 13, Section II. The mean runoff should also be fairly close to the read-in runoff or rainfall minus the computed loss as obtained from values supplied for that question. The average annual sediment load and peak concentrations should correspond with values measured on similar streams in the vicinity or be within the range of values obtained from applicable published sources such as Dawdy (1967).

2. If large-storm hydrographs are simulated for a number of years, the flood frequency relationship should be checked against predictions obtained from published sources such as the statewide flood frequency reports of the U.S. Geological Survey. While complete agreement should not be expected, the two approaches should predict 100-year floods, for example, that are reasonably similar. Site factors, such as land-use, that might not be accounted for in the published relationships should be considered when making the comparisons.

3. The large-storm simulated rainfall and runoff values obtained from the interactive printout (Figure 2) should be reasonable. If too many unusually large storm rainfall values are found, the daily transitional probabilities (Section V.B) may have to be adjusted

or the standard deviation of the monthly rainfall cube roots may have to be reduced somewhat. The optional simulated daily rainfall printout (see Section IV.A, paragraph on minimum flows) is helpful in these evaluations.

4. Storm hydrograph simulations (obtained when the answer to question 2, Section II, is "yes") should be checked to be sure the hourly (or shorter) rainfall distributions are intuitively reasonable. Considering the total rainfall involved and the season, the durations should be reasonable and not too "bursty". If a number of storms appear to have unreasonable intensities, adjustments may be needed in the hourly transitional probabilities.

5. From the storm hydrograph simulation (Figure 3) check to be sure the value used for DT (question 12, Section II) is less than the shortest computed unit hydrograph time to peak (T1). Also, check the computed time-lag values (TL) to be sure they are reasonable. Time-lag can be estimated from standard procedures (for example: See Haan and Barfield, 1978). The computed time-lag shown on the printout should be reasonable considering the watershed characteristics in general and the burst runoff intensity (B ROI). Unreasonable time-lag values could indicate an error in measuring one or more of the unit-hydrograph associated watershed characteristics, that one or more characteristics are beyond the range of values shown in Table 2, or that the model is being used beyond the applicable "region".

D. WHAT IF THE REGIONALIZED RELATIONSHIPS ARE NOT APPLICABLE?

There are probably three reasons why changes to the model might be necessary: snow is a dominant consideration in the hydrology of the area; a land-use that was not considered in the regionalization is encountered; the model package is being used in an area where the regionalized relationships are inapplicable. Each will be considered and approaches suggested for handling the problem.

1. Where snow melt is an occasional occurrence, the effect on the hydrology can be ignored. This model has no explicit provisions for handling snow melt, as such. In areas where snow melt is important and cannot be ignored, the transitional probabilities (Section V.B) should be adjusted to reflect the snow melt pattern (PW/W probably increased during months of snow melt to provide more apparent days of "rain".) If a snow pack typically develops during certain winter months, the average monthly rainfall pattern used should reflect the snow melt regime rather than the water equivalent of the snow buildup (with appropriate adjustments in the standard deviation of the monthly cube root of rainfall). In areas where snow packs dominate the hydrology, the previous adjustments may not work well and major changes to the rainfall generator may be necessary.

2. If a land-use is encountered that has not been considered in the regionalized relationships (for example, a mountaintop removal-head of hollow fill surface mining operation) and the regionalized relationships do not work well, modifications to the unit hydrograph regionalized relationships may be needed. The regionalized relationships for predicting the unit hydrograph model parameters can be modified rather simply in the model. Arriving at what modifications are necessary, however, is somewhat complicated and requires analysis of storm hydrograph data. Section V.D.4 describes the regionalized relationships used to predict the unit hydrograph parameters and notes that there is a vector of modification constants defaulted to 1.0 in a data definition statement in subroutine SCHAR1. The various equations for predicting coefficients in the time-lag precipitation intensity equation can be modified by redefining this modification variable named UGMOD. The recommended method for determining values for the vector of UGMOD modification variables involves adjusting the unit hydrograph model to observed storm hydrograph data using an analytical storm hydrograph model (obtainable from the authors). When this is done for a range of storms, the runoff intensity for each storm is plotted versus the time lag determined from the analysis program and the value obtained using the existing regionalized relationships. The regionalized relationship is then modified with an appropriate UGMOD variable so that the slope of the relationship best fits the time-lag values obtained from analysis. This is a rather complex process and should be attempted only after the analysis of a large number of storms.

3. When validation testing with observed data indicates that the regionalized relationships may not be applicable, there is a recommended hierachy for considering modifications (the component models are described in Section V). First, be sure that the stochastic rainfall generator is simulating reasonable monthly volumes since the monthly simulations are easiest to compare with observed data. Then check the daily rainfall volumes, their seasonal distribution, and the hourly rainfall volumes for storm periods for reasonability. The rainfall generator is the most easily modified component and is critical to simulations with all other components.

   Second, compare the annual and monthly streamflow simulations from the continuous daily streamflow model with available data and check the values for reasonability. Simulations with this model are sensitive to the estimates of long-term mean precipitation and runoff (question 13 Section II) and the measure of soil available water holding capacity. If these measures are incorrect, the simulations will be affected. Also, if the runoff loss terms (DLF and PKARST question 8, Section II) are incorrect, the simulations will be affected. The continuous daily streamflow model has been adjusted to data from watersheds where the average annual runoff ranged from about 10 inches to about 50 inches. The model cannot handle arid-climate hydrology, however, because of some of the

basic formulations (see Section V.C.3). If all of these precautions are considered and there is still a need to modify the regionalized relationships, an analytic version of the model (obtained from the authors) must be adjusted to daily rainfall-runoff data to obtain optimized parameter values for a number of watersheds. Appropriate changes can then be made to the regionalized relationships (Table 4, Section V).

Finally, check the storm hydrograph model simulations. Be sure the basin characteristics are measured well and that none are outside of the ranges shown in Table 2. If a critical measure is outside this range, verify the measure. Try a computer run with the measure set on one of the tabular limits. If all of the measures appear to be correct and consistent with the methods of measuring them described in Section III, and the hydrographs appear to have consistent error, then modifications to the model may be made as described in the previous paragraph.

The authors will be interested in any major modifications that are made to TVA-HYSIM and the results obtained.

E. DIAGNOSTICS

Diagnostics, either from the operating system or from programmed messages indicating invalid conditions, may occur during the course of the simulations. It is impractical to attempt to describe them. Generally, however, because of the straightforward information input procedures used in this program, diagnostics usually indicate input data or procedure errors.

SECTION V

DESCRIPTION OF TVA-HYSIM COMPONENTS

A. INTRODUCTION

TVA-HYSIM consists essentially of four linked components. Figure 5 shows a schematic of the model package. It is driven by a stochastic rainfall generator that simulates a daily rainfall distribution for the continuous daily streamflow model. Storm runoff (one or two day) amounts identified in the continuous daily streamflow model, along with the corresponding storm rainfall, are passed to the storm hydrograph model. Here, an hourly (or shorter period) storm rainfall distribution is computed by the rainfall generator. This distribution is used as the basis for computing a storm hydrograph. When an urban sediment option is exercised, the continuous daily streamflow model also determines the washoff of dust and dirt from impervious surfaces for storm periods and transfers this information to the suspended sediment model component. Suspended sediment loads from pervious and impervious areas are distributed in the suspended sediment model using precipitation excess from the storm hydrograph model component.

The output block on Figure 5 termed TVA-HYSIM indicates the output that is illustrated in Figure 2. The optional storm hydrograph output shown in Figure 5 is illustrated in Figure 3. There are no provisions in TVA-HYSIM for obtaining at a time sharing terminal the daily runoff option shown on Figure 5 which consists of lengthy tables of annual daily rainfall and runoff. These latter simulations may be obtained in a separate job step or when the program is run batch as explained in Sections II and VI.

This section describes each of the four model components. These descriptions are presented in sufficient detail so that if changes in component model algorithms become necessary for other regions or conditions, these changes may be more easily made.

In the interest of keeping this user's guide easy to follow by avoiding duplication, certain of the variables and coefficients are renamed and therefore do not correspond with their counterparts in the FORTRAN listings. The changes are slight and should not create problems in identifying the algorithms in the listing. A number of subroutines are mentioned in this section to identify the location of algorithms. These subroutines are described in the next section in Table 6.

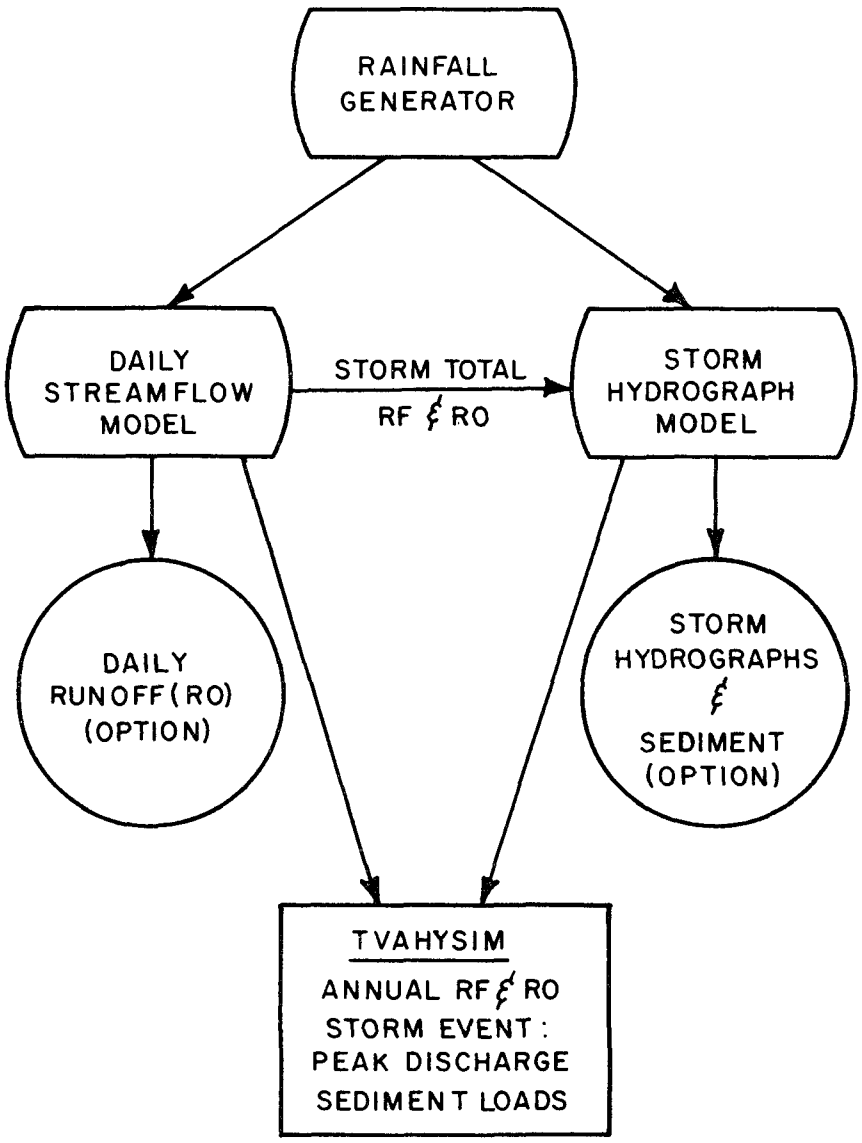

Figure 5 : Schematic of Watershed Model

B. STOCHASTIC RAINFALL GENERATOR COMPONENT

This rainfall generator uses a disaggregation approach. The advantage of this approach (as opposed to the more conventional serially dependent Markovian approach) lies in the ease with which the seasonal characteristics and statistics of the rainfall are preserved. The rainfall generator disaggregates generated monthly rainfall into: (1) a distribution of daily rainfall using transitional probabilities; (2) the daily rainfall into an hourly rainfall distribution; and (3) if shorter duration rainfall is needed, the hourly rainfall into five-minute amounts which are then added together to produce amounts for durations evenly divisible into an hour (5, 10, 15, 20 or 30 minutes).

Observed monthly rainfall is normalized using a cube root transform. Random numbers from a uniform probability distribution (subroutine URAND) are operated upon in subroutine GAUSS to generate values that preserve the mean of the cube root of monthly rainfall and standard deviation values that are read-in. These generated values are converted to monthly rainfall in subroutine RFSIM. Next, the monthly rainfall is disaggregated into daily rainfall using transitional probabilities of the following form:

$$PR = e^{-raRF^{rb}} \qquad \text{V-1}$$

where: PR is a transitional probability,
RF is the monthly (or daily or hourly) rainfall, and
ra, rb are coefficients.

The coefficients for two of the transitional probabilities are defined in the program; the probability that a day will be dry given that the previous day was dry (PD/D); and the probability of wet given wet (PW/W). The following identities may be used to determine the remaining transitional probabilities:

$$PD/W = 1 - PW/W \qquad \text{V-2}$$

$$PD = 1/[((1-PD/D)/PD/W) + 1] \qquad \text{V-3}$$

Table 3 includes transitional probabilities used in subroutine RFSIM to determine a rain or no rain event for each day.

TABLE 3

DAILY RAINFALL TRANSITIONAL PROBABILITY COEFFICIENTS

		Month			
Probability	Coefficient	Oct.	Nov.	Dec.-Aug.	Sept.
PW/W	ra	1.0	1.4	1.36	1.4
	rb	-0.06	-0.30	-0.38	-0.30
PD/D	ra	0.1	0.14	0.18	0.14
	rb	0.60	0.40	0.31	0.40

Rainfall is allocated to days of rainfall using the following Weibull distribution to convert values from a normalized probability distribution function (subroutine URAND) into rainfall:

$$RFD = (19.0 \log(1/YP)^{1.176} + 0.1)/100 \qquad \text{V-4}$$

where: RFD is the daily rainfall (unadjusted) in inches, and
YP is a random number from a uniform probability distribution.

An adjustment is next made to each day of rainfall by adding together the unadjusted RFD's and multiplying each by the ratio of this total to the predicted monthly rainfall previously determined. This adjustment forces the distribution to total to the predicted monthly value.

Similarly, daily rainfall totals are disaggregated into hourly amounts whenever storm rainfall simulations are made. Subroutine HOURF uses a Fourier function to allow the probability of wet given wet (PW/W) to vary across the year. The formulation for the transitional probabilities are:

$$PW/W = \exp[-(.15-.03\sin[(2\pi \cdot JD/365)-0.8])RFD^{-.3}] \qquad \text{V-5}$$

$$PD/D = \exp[-0.041\ RFD^{\frac{1}{2}}] \qquad \text{V-6}$$

where: JD is the Julian day beginning with Oct. 1 = 1, and
RFD is the daily rainfall.

Seasonal phasing in equation V-5 is in radians and the -0.8 term causes the highest PW/W (winter) to occur about February 15.

Rainfall is allocated to hours of rainfall using random numbers drawn from a uniform probability distribution and transformed with the following Weibull distribution function:

$$RFH = ((10\log(1/YP))^{0.8} + 1.0)/100 \qquad \text{V-7}$$

where: RFH is hourly rainfall in inches.

An adjustment is next made to each value of hourly rainfall to assure that it adds to the correct total predicted for the storm.

A final subroutine FIVMIN determines five-minute rainfall amounts each hour there is rainfall (when DT is less than an hour) for use in the storm hydrograph model. The two transitional probabilities used are:

$$PW/W = \exp[-0.026RFH^{-0.65}] \qquad \text{V-8}$$

$$PD/D = \exp[-3.0RFH^{0.5}] \qquad \text{V-9}$$

and the Weibull distribution is:

$$RF5 = (2.0 \log(1/YP) + 1.0)/100 \qquad \text{V-10}$$

where: RF5 is a five minute rainfall amount.

When the pre-set transitional probabilities and Weibull distributions are used, the only information needed to operate this model component are the means of the cube root of monthly rainfall and the corresponding standard deviations. This is typically obtained from about 25-years or more of monthly raingage data. Section III.A.9 explains in detail how these data are obtained.

At locations where the pre-set probabilities (Table 3) do not apply, the probabilities must be adjusted by changing data definition statements in the appropriate subroutines. The basis for such adjustments must be observed data. The basic transitional probability relationship, equation V-1, may be used to help in revising the coefficients. For example, if storm durations are too long or too short, estimate an expected duration for a 1 inch rainfall such that about half the storms are longer and half are shorter. The "ra" coefficient in the basic equation will equal:

$$ra = -\ln(0.5)/t1 \qquad \text{V-11}$$

where: ra is a coefficient in the transitional probability equation, and
t1 is the average duration of a one-inch storm in hours.

The ra term can be calculated for both summer and winter and then used with the Fourier relationship in equation V-5, or a single-season relationship may be used.

Similarly, the average duration for a larger storm is estimated and the "rb" term estimated from the following:

$$rb = \frac{\ln(t1/t2)}{\ln RF2} \qquad \text{V-12}$$

where: t2 is the average duration for a storm other than one-inch (for example, a large storm) in hours, and
RF2 is the corresponding rainfall for the storm other than one inch, in inches.

This approach may be used to estimate coefficients for either the PW/W or PD/D transitional probabilities using observed data, in this case hourly rainfall abstracts. Usually the hourly transitional probabilities are most critical. Revisions to the Weibull distributions are less straightforward and if necessary can best be done by summarizing a relatively long-term period of observed rainfall (daily, hourly, or five-minute) and comparing with corresponding simulated values.

C. CONTINUOUS DAILY STREAMFLOW MODEL COMPONENT

This model component performs the basic moisture accounting for TVA-HYSIM. A daily time unit is used because of the ready availability of daily rainfall and streamflow data for calibration and validation and because this is about the longest time scale at which continuous moisture accounting can be performed and the individual processes considered. The model is fairly well documented (TVA, 1972; Betson, 1976). Figure 6 shows a schematic of the model. This component model has features for handling urban conditions (including the washoff of dust and dirt as described in the subsequent section on sediment), the effects of under-drainage in soluble carbonate rock terrain on streamflow, and a variety of land covers. Although the information is not needed to operate TVA-HYSIM, model algorithms are documented in this section so that should problems in operating the model be encountered, or should it become desirable to modify this model component in other regions, the formulations and the subroutines in which the algorithms occur can be more easily identified. The format of this documentation loosely follows the schematic in Figure 6.

1. Interception Storage. This is the first of the model compartments and is deterministic. Forest and non-forest interception is handled separately. For forested areas the following interception equations for 20-year old loblolly pine and hardwoods are based upon the work of Swank et al (1972) and Helvey and Patric (1965), respectively:

Loblolly pine (20-years old)	$I = 0.02 + 0.12RF$	V-13
Hardwood (growing season)	$I = 0.04 + 0.06RF$	V-14
Hardwood (dormant season)	$I = 0.02 + 0.024RF$	V-15

where: I is the interception in inches, and
RF is the storm rainfall in inches.

For non-forested areas an interception capacity of 0.05 inch per day is used. During winter periods when rainfall is sustained over many days and evapotranspiration is low this interception compartment could become unrealistically large. Therefore, there is a limit on the amount of intercepted water that can be held during the dormant season and is as follows: pine (0.3 inch), hardwood (0.08 inch), non-forest (0.05 inch). During the growing seasons these limits are each increased by 0.12 inch.

Evaporation of intercepted rainfall occurs at a faster rate than the computed evapotranspiration rate (described subsequently in Section V.C.10). As described by Betson (1979, p. 58 ff), this additional evaporation is necessary to account for the higher losses experienced in forests, most noticeably in pine forests. The literature indicates that evaporation of intercepted water occurs at a rate some three times the transpiration rate (Stewart 1977; Singh and Szeicz, 1979). The variable HTFLUX (read in question 13, Section II) is the ratio at which the evaporation of intercepted water occurs in relation to the computed transpiration rate. The interception calculations are all made in subroutine MODEL.

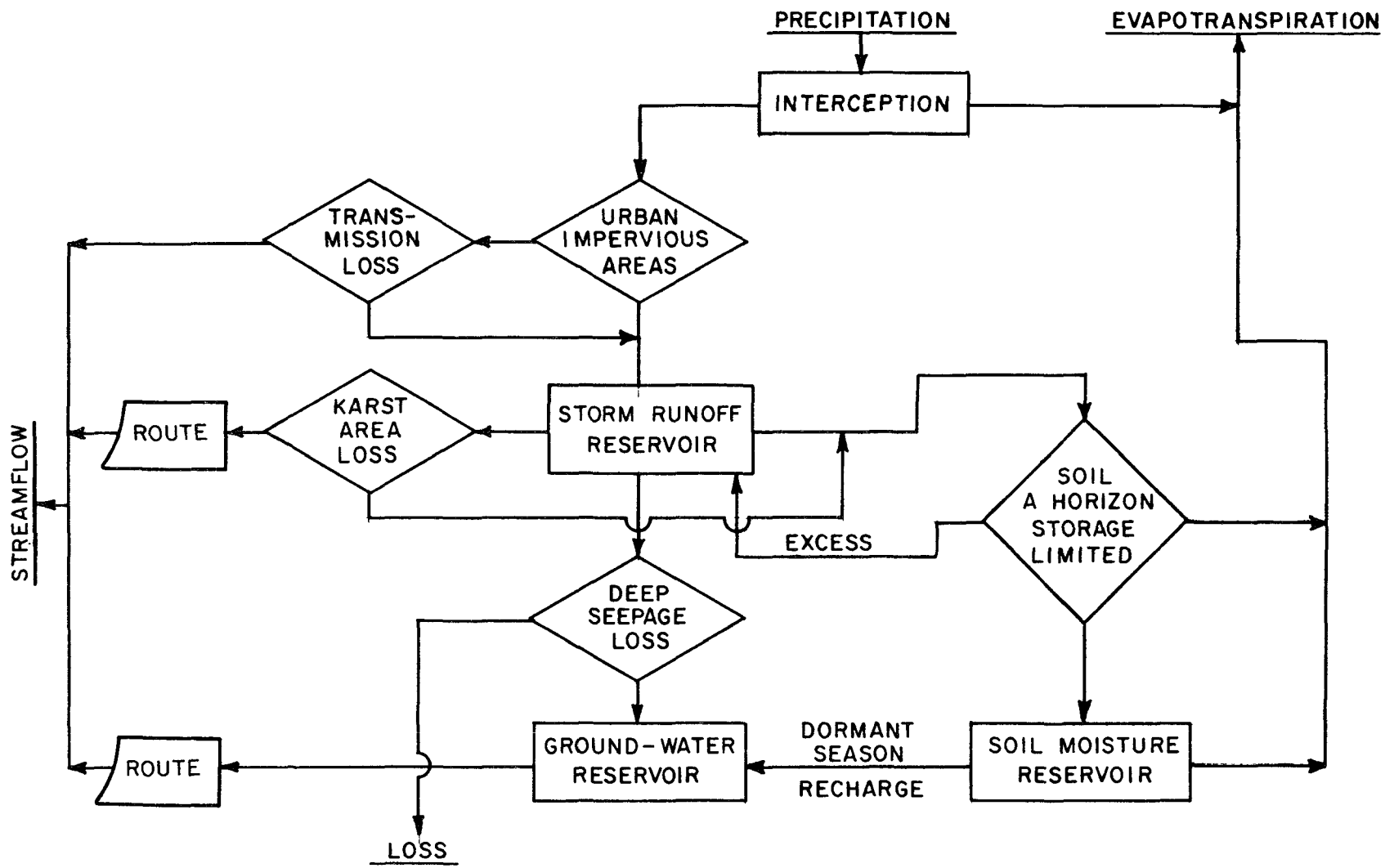

Figure 6 : Continuous Daily Streamflow Model Schematic

2. Storm Runoff Volumes (a) Impervious Areas. An algorithm developed by Miller and Veissman (1972) is used for predicting daily storm runoff (precipitation excess) from urban areas. The algorithm, in subroutine MODEL, determines daily precipitation excess based upon the portion of a watershed which is in excess of 17 percent impervious:

$$PE_i = 1.165\ RF_r \quad (IMPERVIOUS - 17)/100 \qquad \text{V-16}$$

$$\text{and } (IMPERVIOUS - 17) \geqq 0$$

where: PE_i is precipitation excess in inches from impervious surfaces,
RF_r is daily rainfall less interception in inches, and
IMPERVIOUS is the percent of the watershed with impervious surfaces.

The algorithm is based upon the observation (by Miller and Viessman, 1972) that when less than 17 percent of a watershed is impervious the water tends to drain onto pervious surfaces and the "urban effect" is insignificant. This 17 percent minimum does not apply if there are areas directly connected to a stream through sewers or culverts. Thus, if a value is entered in response to interactive question 6 (Section II) that value will be used to compute impervious area precipitation excess. Question 5 should be answered "yes"; however, only when the total impervious area is less than about 17 percent and there are directly connected areas.

3. Storm Runoff Volumes (b) Pervious Areas. The algorithm in subroutine MODEL for determining daily precipitation excess from pervious areas is an adaptation of a rational model presented by Betson et al (1969). The algorithm is based upon the assumption that the yield of precipitation excess is proportional to the amount of moisture stored in the system.

$$RI = AW + (DS - AW)\ SI)\ e^{-B(SMR + GWR)} \qquad \text{V-17}$$

$$PE_p = (RF_r^{\ 2} + RI^2)^{0.5} - RI \qquad \text{V-18}$$

where: RI is a retention index in inches,
AW is a model parameter associated with winter storms,
DS is a model parameter associated with summer storms,
B is a model parameter associated with runoff volumes in 1.0/inches,
SI is a phenologic index that equals one in summer and zero in winter, with interpolated values for spring and fall,
SMR is the moisture in inches stored in the soil moisture reservoir in inches,
GWR is potential runoff stored in the ground water reservoir in inches, and
PE_p is the pervious area precipitation excess in inches.

The phenologic index SI is used in several of the model compartments to allow seasonal variation. It is determined in subroutine SEASON and the beginning of each season is defined as: Fall = 15 (October 15); Winter = 92; Spring = 183; Summer = 212. Should it become necessary to alter this phasing, a change must be made in program DATSET (which controls the interactive input). The season is defined in a write statement (FORMAT 190) just prior to the question which asks for the mean of the cube root of monthly rainfall.

4. Ground Water Runoff Volumes. After interception and precipitation excess have been removed the residual storm rainfall becomes a potential for ground water runoff. These computations are made in subroutine MODEL. The portion of the residual storm rainfall that will become ground water is proportional to the yield of daily precipitation excess from pervious areas:

$$GWV = (PE_p/RF_r)GWK \cdot RF_i \qquad \text{V-19}$$

$$\text{and } GWV \leqq RF_i$$

where: GWV is a volume to be added to the ground water reservoir (GWR) in inches,
RF_r is the daily rainfall less interception,
GWK is a model parameter, and
RF_i is the available moisture after interception and precipitation excess have been removed.

5. Dormant Season Recharge. For watersheds with high soil water holding capacities, such as in clay and loam soils, a recharge to the ground water reservoir can occur as vegetation becomes dormant in the fall. During the fall period, moisture held in the soil under tension by the vegetation is released as the vegetation becomes dormant. This moisture is added to the ground water. These accretions are taken from the soil moisture reservoir in subroutine MODEL (when sufficient moisture is available) at a daily rate according to the parameter GWDOR, in inches, and added to the ground water reservoir. This feature has effects only minimum flow simulations when using TVA-HYSIM.

6. Soil A Horizon Moisture Storage Capacity. Soils that have shallow A horizons and/or have low permeability rates in the B horizon will experience relatively large volumes of precipitation excess once the storage capacity of the upper soil horizon is exceeded. This heavy runoff will occur even though the total moisture stored in the system may be low, which according to equations V-17 and V-18 should produce low volumes of precipitation excess. Therefore, two parameters, the A horizon depth (AHORD), and the B horizon permeability (BHORP) are defined which provide a limit above which all excess moisture to be allocated to the soil moisture reservoir becomes precipitation excess. The sum of the two parameters is this limit with recovery storage capacity in AHORD occurring at a daily rate of BHORP. Both parameters are preset to 1.5 inches in subroutine CHAR for TVA-HYSIM.

7. Potential Runoff Volume Losses (a) Bypass Seepage. Losses of potential runoff can occur for a variety of reasons. In areas with deep alluvial soils, much of the ground water and some of the potential surface water runoff may occur beneath the surface. In areas underlain by soluble carbonate rocks this bypass drainage can become significant and must be accounted for to keep the simulations reasonable.

Bypass losses are the losses of potential ground water runoff that bypass the site where simulations are being made, for whatever reason. These losses are often significant in carbonate rock terrain. These bypass or deep losses are removed in subroutine MODEL directly from the potential ground water runoff, in proportion to a parameter (DLF in question 8, Section II) and are not considered further in the simulations:

$$GWL = GWV \cdot DLF \qquad \text{V-20}$$

where: GWL is a deep, or bypass loss, in inches,
GWV is the ground water volume computed in equation V-19, and
DLF is value read-in in question 8 (Section II).

When DLF equals zero, no losses occur (GWL = 0) and when DLF equals one no ground water runoff occurs. In the absence of any site information or data, DLF is difficult to determine and probably should be set to zero. In carbonate rock areas it has been set equal to the fraction of the watershed underlain by very soluble carbonate rocks.

8. Potential Runoff Volume Losses (b) Transmission Losses. Transmission losses occur when potential precipitation excess originating from impervious areas does not reach the simulation site. These losses are most pronounced during smaller storms when precipitation excess originating from driveways, roofs, etc., infiltrates into lawns, pervious surfaces or dry tributary channels. These losses decrease as the storm size increases until at some value of precipitation, all of the potential precipitation excess will reach the simulation site. The impervious area precipitation excess, as calculated in eq. V-16, is adjusted for transmission losses using the following algorithm:

$$PE_i = (PE_i/TLP)\ PE_i = PE_i^2/TLP \qquad \text{V-21}$$

$$\text{and } (PE_i/TLP) \leq 1.0$$

where: PE_i is impervious area precipitation excess in inches, and
TLP is a transmission loss parameter preset to 1.0 inch.

This adjustment occurs in subroutine MODEL where the parameter is redimensioned to remove the effect of the size of impervious area. The value for parameter TLP is preset to 1.0 inch in program DATSET for applications with TVA-HYSIM. Transmission losses are not lost from the system but become part of the residual rainfall used in the pervious area storm runoff volume calculations.

9. Potential Runoff Volume Losses (c) Pervious Area Runoff Losses. In carbonate rock areas, in particular, the potential precipitation excess that should be realized from pervious areas based on the physical watershed characteristics and antecedent moisture conditions, often does not materialize. This potential runoff may be all or partially lost into sinkholes through pervious channel seeps or through rapid percolation into near-surface channels in the soluble carbonate rock. It is important to recognize this phenomenon, where it exists, since it can affect all of the simulations. Where these pervious area losses occur, not only must storm precipitation excess be reduced, but this loss must be cascaded along with the remaining residual rainfall into subsequent compartments, or reservoirs, since it must be accounted for in the moisture budgeting. The algorithm used to modify PE_p (as calculated in eq. V-18) to account for losses due to soluble carbonate rock systems is:

$$PE_p = PE_p \ (1\text{-}PKARST) \qquad \text{V-22}$$

where: PE_p is the pervious area precipitation excess from equation V-18 in inches, and
PKARST is a read-in value from question 8 (Section II).

PKARST is defined so that a zero value results in no loss while a value of one results in no precipitation excess (unless the A horizon limit described in Section V.C.6 is exceeded). Values for PKARST are estimated based upon the fraction of the watershed area underlain by soluble carbonate rock as described in Section III.A.4. These adjustments are made in subroutine MODEL.

10. Evapotranspiration. Monthly values of evapotranspiration are used in the model. Adjustments are made to the mean monthly evapotranspiration index read-in in question 18 (Section II) based on seasonal growth index (GI) relationships. The total evapotranspiration thus computed is then forced to total either the long-term loss predicted from the latitude (question 13, Section II) or optionally from long-term mean rainfall minus expected runoff. The algorithm used is:

$$LOSS = DK \sum_{j=1}^{12} (PET_j \cdot GI_j) \qquad \text{V-23}$$

where: LOSS is the long-term annual evapotranspiration in inches,
DK is a factor used to equate the accumulated products of PET·GI to the expected long-term loss,
PET is long-term monthly potential evapotranspiration as measured, for example, by a land pan, in inches, and
GI is a crop growth index - a ratio of monthly evapotranspiration to potential evapotranspiration.

This algorithm forces the measure of potential evapotranspiration used to have a monthly distribution based upon cover present in the watershed, and for the annual total to be equal to the expected long-term annual loss. The monthly growth index values (Holtan and Lopez, 1973) are con-

tained in data definition statements in subroutine ETYEAR where the monthly values of evapotranspiration are calculated. Computed daily evapotranspiration first depletes the intercepted rainfall (see Section V.C.1) and then the soil moisture reservoir.

An adjustment to the expected long-term annual evaporation (LOSS) is made when unvegetated areas are present. This adjustment is patterned after a relationship devised by Douglass and Swank (1972) which related an increase in runoff to the reduction in forest stand:

$$LOSS = LOSS + 1.39 - 0.13\ (UNVEGETATED) \qquad \text{V-24}$$

$$\text{and:} \quad UNVEGETATED \geqq 10.7 \text{ percent}$$

where: UNVEGETATED is the percent of the watershed unvegetated.

11. Runoff Routing. Although not relevant to the operation of TVA-HYSIM in which storm precipitation computed by the continuous streamflow model is routed in the storm hydrograph model, the continuous daily streamflow model also routes runoff on a daily basis. Daily streamflow simulations can, therefore, be obtained as explained in Section IV.A.

Precipitation excess originating from impervious areas (PE_i) is assumed to become streamflow on the day of the rain. Precipitation excess originating from pervious surfaces (PE_p) is routed on a daily basis as follows:

$$SRO_j = TDSRO \cdot (PE_p)_j + SURES_j \cdot (1\text{-}SROK) \qquad \text{V-25}$$

where: SRO is routed precipitation excess in inches,
TDSRO is a parameter indicating that portion of the PE_p that becomes runoff on the day of the rain,
SURES is the storm runoff reservoir in inches, and
SROK is a storm runoff recession parameter.

On a day of rainfall, that portion of the precipitation excess that does not become runoff (1-TDSRO) is allocated to the reservoir SURES, where it runs off on subsequent days. No distinction is made between surface runoff and interflow.

Ground water runoff (GRO) is routed daily from the ground water reservoir (GWR) using a recession constant (GROK):

$$GRO = GWR\ (1\text{-}GROK) \qquad \text{V-26}$$

There are provisions in the model for separate summer and winter ground water recession constants, GROKS and GROKW, respectively. All routing is done in subroutine MODEL.

12. Regionalized Model Parameter Prediction Equations Table 1 lists the watersheds involved in developing regionalized relationships for the continuous daily streamflow model (total of 28 watersheds). An analytic version

of the model was first adjusted to three or four years of continuous daily rainfall and streamflow data using an optimization technique (TVA, 1972). Next, relationships between the optimized model parameters and watershed characteristics were developed. These relationships are shown in Table 4. (All necessary coefficients for deterministic algorithms were presented earlier and certain of the model quasi-parameters that must be estimated were described.)

Three additional parameters have values internally set in the program: AHORD (1.5 inches), BHORP (1.5 inches) and TLP (1.0 inch) as explained in previous sections.

The model parameters are predicted in subroutine CHAR using these regionalized relationships. The last two equations in Table 4 are used to predict initial values for the soil moisture reservoir (BSMI) and the ground water reservoir (BGWR), respectively. The model begins calculations on July 1 with a three-month lead-in used to further adjust these reservoirs before simulations begin on October 1.

D. STORM HYDROGRAPH MODEL COMPONENT

Storm rainfall and runoff are determined in the continuous daily streamflow model. Storm periods (one or two days) above threshold criteria (question 15, Section II) are identified in subroutine MODEL and the basic storm hydrograph model component, subroutine STORM, is called. Here, the total storm rainfall and precipitation excess determined by the continuous daily streamflow model is distributed into shorter time intervals, the unit hydrograph parameters are predicted, the storm precipitation excess and unit hydrograph are convoluted, and the storm sediment computations are made. The description of this component is organized roughly in the sequence in which these computations are performed. (The sediment-associated calculations are described in sub-section E.)

1. Precipitation Excess Distribution For each storm identified in the continuous daily streamflow model for storm hydrograph simulation, the total rainfall is distributed into hourly (subroutine HOURF) or shorter time periods (subroutine FIVMIN) depending on the convolution interval, DT, read in question 12 (Section II). A precipitation excess distribution is computed using this rainfall distribution and a modification of the Soil Conservation Service (SCS 1972, 1975) method using a constant loss parameter PHI. This SCS distribution technique reduces to:

$$SRO_j = (ARF_j - 0.2S)^2/(ARF_j + 0.8S) \qquad \text{V-38}$$

where: SRO_j is the accumulated storm precipitation excess at time j in inches,
ARF_j is the accumulated storm rainfall in inches, and
S is the maximum potential retention which is related to a SCS curve number, CN-PE, which is defined as: CN-PE = 1000/(10+S).

TABLE 4

TVA CONTINUOUS DAILY STREAMFLOW MODEL
REGIONALIZED PARAMETER PREDICTION EQUATIONS

Parameter	Prediction Equation	Equation No.
AW	$AW = 9000 \cdot Y^{5.68} \leqq 200$	V-27
DS	$DS = 3400 \cdot Y^{3.92} \leqq 200$	V-28
B	$B = 8.2 \cdot Y^{3.3}$ V-29	
GWK	$GWK = 0.28 \cdot AWC \cdot (FOR)$	V-30
GWDOR	$GWDOR = 0.00003\ AWC^{2.6}$	V-31
TDSRO	$TDSRO = 0.75 - 0.31\ (\log DA) - 0.069\ (\log DA)^2$ and $TDSRO \leqq 1.0$	V-32
SROK	$SROK = e^{-1.61/DA^{0.2}} \leqq 1.0$	V-33
GROKS	$GROKS = 1 - 4.70\ AWC^{-2.485} \leqq 1.0$	V-34
GROKW	$GROKW = 1 - 0.78\ AWC^{-1.48} \leqq 1.0$	V-35
	- - - - -	
--	$BSMI = 1.04\ AWC - 0.0343\ AWC^2$	V-36
--	$BGWR = 0.0023\ AWC^{2.9}$	V-37

where: Y is long-term annual yield (runoff/rainfall) (question 13, Section II),

AWC is the available water holding capacity of the soil in inches (question 7, Section II),

FOR is a measure of the portion of watershed area covered by forest [(hardwood + conifer)/100] + 1.0 (question 4, Section II), and

DA is the drainage area in mi^2 (question 4, Section II).

The SCS technique is then modified to increase losses during lulls in multi-burst storms with a constant loss variable PHI. This variable is subtracted from each RF_j value prior to accumulation to obtain a new ARF. PHI is allowed to vary from storm to storm and is calculated in subroutine SCHAR1 using the following equation:

$$PHI = 0.0567 - 0.0003\ FOR - 0.0971\ SINU - 0.015\ PE + 0.0332\ PKARST + 0.0314\ (ARF - PE) + 0.024\ (ARF/DUR) \qquad \text{V-39}$$

where: FOR is the fraction of the watershed covered by forest plus one,
SINU is the sinuousity measure read-in in question 7 (Section II),
PE is the storm precipitation excess,
PKARST is the measure read-in in question 8 (Section II), and
DUR is the storm duration in hours.

The revised ARF calculation is made as follows:

$$ARF_j = \sum_{j=1}^{n} RF_j - PHI \qquad \text{V-40}$$

subject to $PHI \leqq RF_j$

The distribution of precipitation excess over time is determined from equation V-38 by differencing:

$$PE_j = SRO_j - SRO_{j-1} \qquad \text{V-41}$$

2. Storm Burst Definition The unit hydrograph, far from being a fixed characteristic as visualized by Sherman (1932), is highly variable from storm to storm and from burst to burst within storms, particularly for smaller watersheds. As will be described in the next two sub-sections, the unit hydrograph function used in the storm hydrograph component of this model varies according to the precipitation excess distribution. When storm rainfall is intermittent, as is common in the summer, a point is reached (depending upon the size of the watershed involved) where these intermittent precipitation excess distributions must be subdivided into bursts which can be individually characterized more meaningfully for the unit hydrograph relationships. Two definitions are needed, a lower cutoff and a defined lull. The lower cutoff is needed to cover the situation where rainfall is sustained but low for a period such that an insignificant amount of sustained precipitation excess is calculated. The cutoff is a limit of precipitation excess (for each convolution interval DT) below which a lull may be defined:

$$CO = 0.01\ SRO \cdot DT \qquad \text{V-42}$$

subject to $CO \leqq 0.01$ inch.

A lull is the minimum duration during which PE_j must be below the computed CO in order for a burst to be designated. Bursts are calculated in subroutine STORM where a lull is defined in convolution interval units, as

$$LULL = (2.5/DT)\ DA^{0.2} \qquad \text{V-43}$$

where: DA is the drainage area in mi^2.

There are no constraints on the number of bursts that may be identified during a storm.

3. The Unit Hydrograph TVA-HYSIM uses a unit hydrograph to distribute the precipitation excess across the storm hydrograph. This unit hydrograph is represented with the double-triangle function depicted in Figure 7. The rationale for this functional representation was presented by TVA (1973b) and Betson (1976). In essence, it was developed from the concept of partial-watershed area contributions to storm runoff.

The symbols used in Figure 7 are:

UP is the peak ordinate of the initial response triangle, generally the unit hydrograph peak, in inches per hour,

T1 is the time of the initial peak UP in hours,

UR is the ordinate of the recession inflection point (infrequently the maximum peak) in inches per hour,

T2 is the time to the recession inflection point in hours,

T3 is the time base of the unit hydrograph in hours, and

TL is time-lag defined as the time from the occurrence of ½ DT unit to the centroid of the unit hydrograph.

The five parameters UP, UR, T1, T2, and T3 completely describe the double-triangle unit hydrograph.

4. Regionalized Unit Hydrograph Prediction Relationships A time-lag concept is used as the basis for predicting the unit hydrograph parameters. The definition of time-lag employed shown on Figure 7 is that developed by Overton (1970) which is essentially the time between the occurrence of 50 percent of the precipitation excess volume and 50 percent of the storm hydrograph volume.

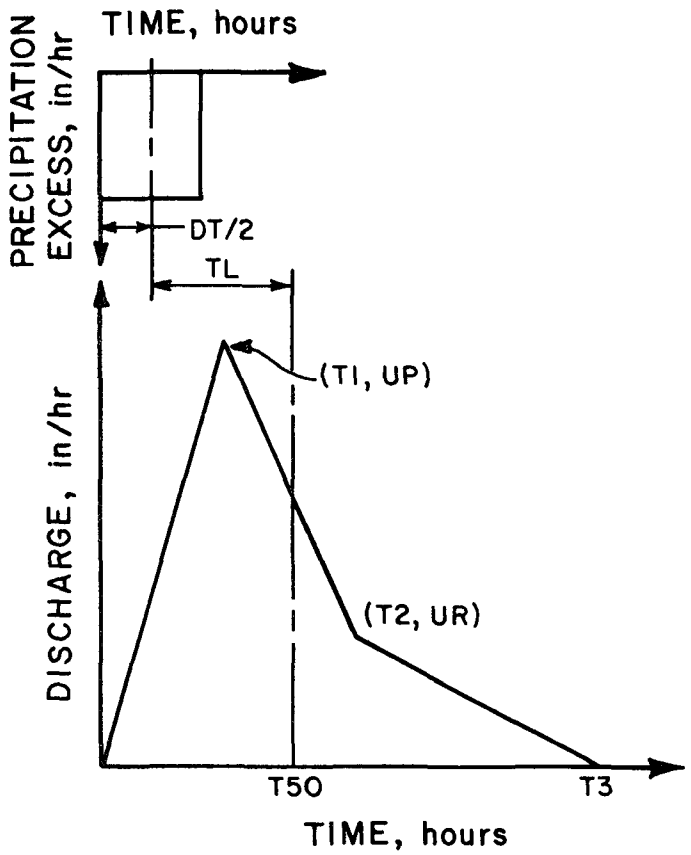

Figure 7: Double Triangle Unit Hydrograph and Lag Time Definition

In unit hydrograph terms, if 50 percent of the unit area occurs before T1 (see Figure 7), the time to 50 percent of the unit area T50 is:

$$T50 = (T1/UP)^{\frac{1}{2}} \qquad \text{V-44}$$

If T50 is greater than T2 the relationship is:

$$T50 = T3 - [(T3-T2)/UR]^{\frac{1}{2}} \qquad \text{V-45}$$

And, if T50 lies between T1 and T2, as in the usual case, the relationship is

$$T50 = [UP-(UP^2-[1-AA]\cdot[BB/CC])^{\frac{1}{2}}]\cdot[CC/BB] + T1 \qquad \text{V-46}$$

where: $AA = UP\cdot T1$,
$BB = UP-UR$, and
$CC = T2-T1$

Using an adaptation of the method proposed by Troxler (1978), Bales (1979) developed a measure of the intensity of the burst precipitation excess distribution as:

$$PEIN = [\sum_{j=1}^{n} (PE_j^{\,2})/\Sigma PE]/(\Sigma PE/RF)$$

$$= \sum_{j=1}^{n} (PE_j)^2 \cdot RF/(\Sigma PE)^2 \qquad \text{V-47}$$

where: PEIN is a normalized precipitation excess intensity in inches per hour,
PE_j is the precipitation excess at time j,
ΣPE is the total storm precipitation excess, and
RF is the total storm rainfall.

This measure of precipitation excess intensity, normalized by dividing by the yield, provides a measure of intensity that considers antecedent conditions (yield).

Based on work by Overton (1967, 1968, and 1971), the normalized precipitation excess intensity is used in the prediction of a lag-time unique to each watershed for each storm. The equations are of the form

$$TC = S\mu\ (PEIN)^{SB} \qquad \text{V-48}$$

and $$TL = TC/1.6 \qquad \text{V-49}$$

where: TL is time lag in hours,
TC is time of concentration in hours, and
Sμ and SB are coefficients to be predicted.

The predicted time-lag for the storm is next used in subroutine SCHAR1 in relationships to predict the parameters UP and T2. The relationship for UP is:

$$UP = SC \cdot TL^{SE} \qquad \text{V-50}$$

where: UP is the initial unit hydrograph peak in inches/hour, and
SC, SE are coefficients to be predicted.

Similarly, the relationship for T2 is:

$$T2 = SF \cdot TL^{SG} \qquad \text{V-51}$$

where: T2 is the time to recession inflection, in hours, and
SF, SG are coefficients to be predicted.

Based upon the fact that geomorphic thresholds govern channel formation (Schumm, 1973), separate equations are used to predict the coefficients in Equations V-48, V-50 and V-51 for small basins and for large basins. Table 5 shows the equations used to predict these coefficients for basins less than or equal to two square miles along with the equations used for larger basins.

The basin characteristics in Table 5 are defined as follows:

DA = drainage area (question 4),

CN = SCS curve number (question 7),

PCM = an internally defined measure of percent mined (question 7) defined as: (% mined/100) + 1.0,

PERM = soil permeability, inches per hour (question 7),

CSLOPE = channel slope, feet per mile (question 7),

DD = drainage density, mi/mi^2 (question 7),

AWC = available water holding capacity, inches (question 7),

SHAPE = watershed shape (question 7),

FOR = an internally defined measure based upon information in question 4:

FOR = [(HARDWOOD + CONIFER)/100] + 1.0, and

SINU = a measure of sinuosity (question 7).

TABLE 5

REGIONALIZED EQUATIONS FOR PREDICTING COEFFICIENTS IN EQUATIONS FOR TL, UP, AND T2

Coefficient*	Constant	Exponent on Basin Characteristic										Equation No.
		DA	CN	PCM	PERM	CSLOPE	DD	AWC	SHAPE	FOR	SINU	
				DA less than or equal to two square miles								
Sμ	330.9	0.047	-1.389	-2.018	1.270							V-52
SB	-.00461	-.240		3.116		0.358	1.634	-.724				V-53
SC	0.290		0.115	0.361	-.082		0.179					V-54
SE	-1.215	0.073	-.109					0.132				V-55
SF	2.989	0.092		-1.039	0.415	-.154						V-56
SG	1.802				0.140		-.395		0.195	0.049		V-57
				DA greater than two square miles								
Sμ	147.5	0.072	-.581			-.158			0.150	0.935	0.438	V-58
SB	-8.79×10^{-6}		2.483		-.057	0.072			-.521			V-59
SC	0.708	-.030				0.032		-.020	-.085			V-60
SE	-1.655		-.135		0.078			0.088			0.149	V-61
SF	3.742					-.228		0.334	0.158		0.300	V-62
SG	40.62		-.711			-.100	-.224					V-63

*These coefficients are used in Equations 48, 50 and 51

For example: Sμ for DA>2.0 mi^2 (eq. 58)

$$S\mu=147.5DA^{0.072}CN^{-.581}CSLOPE^{-.158}SHAPE^{0.150}FOR^{0.935}SINU^{0.438}$$

The equations for the four coefficients used to predict time-lag (V-52 and V-53, V-58 and V-59) are shown in subroutine SCHAR1 with a variable UGMOD(I), which is set to 1.0 in each case, in a data definition statement. As explained in Section IV.D.2, this variable may be used to modify the regionalized relationships, if necessary.

The equation for T3 is as follows for all drainage areas:

$$T3 = 6.026TL^{0.818}DA^{0.113} \qquad \text{V-64}$$

To complete the solution of the double-triangle unit hydrograph T1 and UR are determined solving relationships derived from the geometry of the double triangle. Depending upon the value of T50 relative to T1 and T2, equation V-44, V-45, or V-46 is used to either solve for T1 directly (equation V-44) or UR directly (equation V-45) or T1 in terms of UR (equation V-46). The following equation, which forces the unit hydrograph to have an area of 1.0, is then used to solve for the remaining measure:

$$UR = [2-(UP \cdot T2)]/(T3-T1) \qquad \text{V-65}$$

All of the above calculations are performed in subroutine SCHAR1.

Because of the way these regionalized relationships are formulated, modifications for other locations (regions) and other land-use conditions can be made rather easily should these regionalized relationships prove to be inadequate. Probably all that would need to be revised are the equations used to predict the coefficients in the time-lag equation V-48 (equations V-52, V-53, V-58, V-59). This can be done by changing appropriate values for the variable UGMOD. These changes can be developed for a particular land-use condition by analyzing several storm hydrographs to develop a relationship between TL and PEIN. Revisions to the regionalized relationships to handle a variety of land-uses is, of course, more involved.

Convolution of the predicted unit hydrograph with the precipitation excess distribution to compute a storm hydrograph is accomplished in subroutine STORM. The storm hydrograph is added to base flow computed from the ground water predicted in the continuous daily streamflow model. Interpolations between the daily values of predicted ground water are made so that simulated storm hydrograph, as portrayed in the print-plot shown in Figure 3, do not usually begin or end at zero flow.

E. SUSPENDED SEDIMENT MODEL

TVA-HYSIM has provisions for simulating the washoff of dust and dirt accumulated on impervious surfaces and the sediment eroded from pervious areas. Standard formulations are used; thus there are no model parameters, as such, in this model component.

1. Impervious Area Dust and Dirt. Dust and dirt accumulations on impervious surfaces are accounted for in the continuous daily streamflow

model component according to an algorithm presented by Donigan and Crawford (1976).

$$SEDDAY_t = SEDDAY_{t-1} \cdot (1-R) + ACCIA \qquad \text{V-66}$$

where: SEDDAY is the dust and dirt on impervious surfaces at time t in pounds/acre,
R is the fraction removed daily due to traffic, wind, or sweeping, and
ACCIA is the dust and dirt accumulation rate, lb/ac/day.

This equation is used to accumulate dust and dirt every day there is no rain. The accumulation reaches a limit of:

$$SEDDAY_t = ACCIA/R \qquad \text{V-67}$$

which occurs in 1/R days. The limit is based upon the assumption that the accumulated rate will diminish as the amount builds up simply due to the effects of wind and traffic.

On days when rainfall occurs a portion of the accumulated dust and dirt will wash off. The algorithm that is used was devised by Metcalf and Eddy (1971, p. 178) for the EPA SWM model, wherein the pounds of pollutant (WASH) washed off during time interval, dt, is proportional to the pounds on the impervious surfaces (SEDDAY) at the beginning of the period.

$$\frac{-d(WASH)}{dt} = \frac{-d(SEDDAY)}{dt} = M \cdot SEDDAY \qquad \text{V-68}$$

which integrates to:

$$WASH = SEDDAY\ (1-e^{Mt}) \qquad \text{V-69}$$

The relationship used in TVA-HYSIM is similar to that used in the SWM model in that it is assumed that one-half inch of runoff (depth on the impervious surfaces) in one day will wash away 90 percent of the dust and dirt accumulated on impervious surfaces. This leads to the algorithm for daily washoff during days of rain. (Time, by definition, in this case is one since the time unit is one-day.)

$$SEDDAY - WASH = SEDDAY\ (1-e^{-4.6 \cdot PE_i \cdot t}) \qquad \text{V-70}$$

This accounting is performed in subroutine MODEL. The washoff load is transferred to subroutine SEDMEN where it is routed across a storm hydrograph.

2. Pervious Area Storm Sediment. The approach used to simulate suspended sediment loads from pervious areas is the modified Universal Soil Loss Equation devised by Williams (1975).

$$TONS = 95\ (53.33DA \cdot PE_p \cdot QP)^{.56}\ LSKCP \qquad \text{V-71}$$

where: TONS is the storm suspended sediment load in tons,
DA is the drainage area in mi^2 (the product 53.33DA converts PE_p in inches to acre-feet),
PE_p is the pervious area precipitation excess volume in watershed inches,
QP is the storm hydrograph peak discharge in cfs,
LS is a length-slope factor,
K is a soil erodibility factor,
C is a crop management factor, and
P is an erosion control practice factor.

Equation V-71 is used to calculate the suspended sediment load from pervious areas for the storm. These calculations are performed in subroutine SEDMEN. The latter four terms in equation V-71 are read-in with question 10 (Section II). The LS term is usually defined only for small fields. When determined for the entire watershed the approach proposed by Williams and Berndt (1976) should be used.

3. Sediment Routing Separate approaches are used for routing the dust and dirt washed off impervious surfaces and the pervious area sediment load. The washed off dust and dirt is distributed across the impervious area precipitation excess vector PE_i using equation V-70, which has the effect of allocating much of the washoff early in the storm (the well-known first-flush effect), yet in proportion to the magnitude of the precipitation excess occurring in each time interval. Routing of the impervious-area washoff load across the storm hydrograph is accomplished in subroutine SEDMEN using an adaptation of Williams' (1978) instantaneous unit sediment graph (IUSG):

$$IUSG = (DT/ITPS)\ e^{-WB \cdot DT \cdot \sqrt{D}} \qquad \text{V-72}$$

where: DT is time in DT units, question 12 (Section II),
ITPS is a factor used to delay the peak of the IUSG (defaulted to 1.0 in TVA-HYSIM),
WB is an internal variable determined from a relationship among the maximum precipitation excess value, the peak discharge, and the time to peak, and
D is a ratio of mean suspended sediment grain size to one-micron, μ, question 11 (Section II).

The adaptation of equation V-72 for impervious areas involves the assumption that 90 percent of the washoff will occur by the time T3, the base of the storm unit hydrograph. This assumption redefines WB and yields the following algorithm for an impervious area unit sediment graph (IUSGI).

$$IUSGI = (DT/ITPS)e^{-2.303DT \cdot \sqrt{D}/T3} \qquad \text{V-73}$$

This impervious area unit sediment graph is multiplied by the storm runoff unit hydrograph and the product forced to unity. The resultant impervious area unit sediment graph is then convoluted with the computed incremental dust and dirt loads to determine a distribution of dust and dirt washoff across the storm hydrograph.

The pervious area IUSG, determined using equation V-72, is multiplied by the storm runoff unit hydrograph (and the product forced to unity) to provide a pervious area unit sediment graph. This pervious area unit sediment graph is then convoluted with the incremental pervious area precipitation excess values squared. The sum of these convoluted values is then divided by the sediment load computed using equation V-71 to determine a ratio which when multiplied by the distribution will provide a correct total. A rational development for this technique is presented by Williams (1978).

Baseflow sediment is also determined. Using the average concentration read-in in question 9 (Section II) corresponding with a discharge of one cubic foot per second per square mile (PPM1), loads are computed for ground water simulated by the continuous daily streamflow model. The algorithm used in subroutine STORM to compute baseflow sediment concentrations is:

$$CONC = PPM1\ (BFQ/DA)^{1.5} \qquad \text{V-74}$$

where: CONC is the suspended sediment concentration associated with baseflow in mg/l,
PPM1 is a read in concentration for one cfs/mi^2, question 9, (Section II),
BFQ is the simulated baseflow (ground water) discharge in cfs, and
DA is the drainage area in mi^2.

The suspended sediment loads determined for each DT interval (baseflow plus impervious area washoff plus pervious area loads) are shown to the right of the storm hydrograph print-plot (see Figure 3). The corresponding concentrations are also shown. The interactive output shown in Figure 2 tabulates the total pervious and impervious area sediment load. (The baseflow load during storm periods is negligible.) The average storm concentration and the maximum simulated concentration are also shown for each storm.

SECTION VI

COMPUTER REQUIREMENTS

A. GENERAL COMPUTER REQUIREMENTS

Because program TVA-HYSIM is interactive, because the input data process is simplified, and because the interactions among model components necessitates use of storage files, a number of input/output devices are required. The job control statements needed for every computer system on which the program TVA-HYSIM might be used are impossible to anticipate. However, to assist users, the job control statements used to operate the model on the TVA system are provided. These statements are provided as a guide for use in adapting TVA-HYSIM to other systems. This section also describes the general computer requirements for the model.

As noted in the introduction, TVA-HYSIM is a version of a complex model that has a number of options unavailable in TVA-HYSIM. These options were omitted because they have limited application in land-use planning studies and they do make the model more complicated to use. In the descriptions of some of the material in this chapter, a few of these unavailable options are encountered.

The TVA-HYSIM is composed of two programs which are written in FORTRAN IV. The programs are compiled on the TVA system using IBM G1 or H Extended compilers. They are being run on TVA Amdahl 470/V6-II computer with a MVS JES3 IBM batch system and IBM OS/VS2 TSO interactive system. Figures 8 and 9 are flowcharts showing how the programs fit together for interactive and batch runs, respectively.

The first program (DATSET) drives the interactive feature. DATSET requests the input data and creates the formatted data file for input to the second program (RUNOFF). Program DATSET accepts list-directed read statements (free formatted) which the G1 and H extended compilers will handle. On TVA's computer system DATSET uses 50K bytes of storage and ¼ CPU second. The program variables are in single precision. This program uses the following data set reference numbers which specify the input/output devices:

5 - Reads input from terminal or cards,
6 - Outputs to terminal or printer,
10 - Outputs to RUNOFF input data file.

The second program (RUNOFF) is a complex program which performs all of the hydrological simulations. RUNOFF receives input data in formatted form from the data file created by the program DATSET. On TVA's

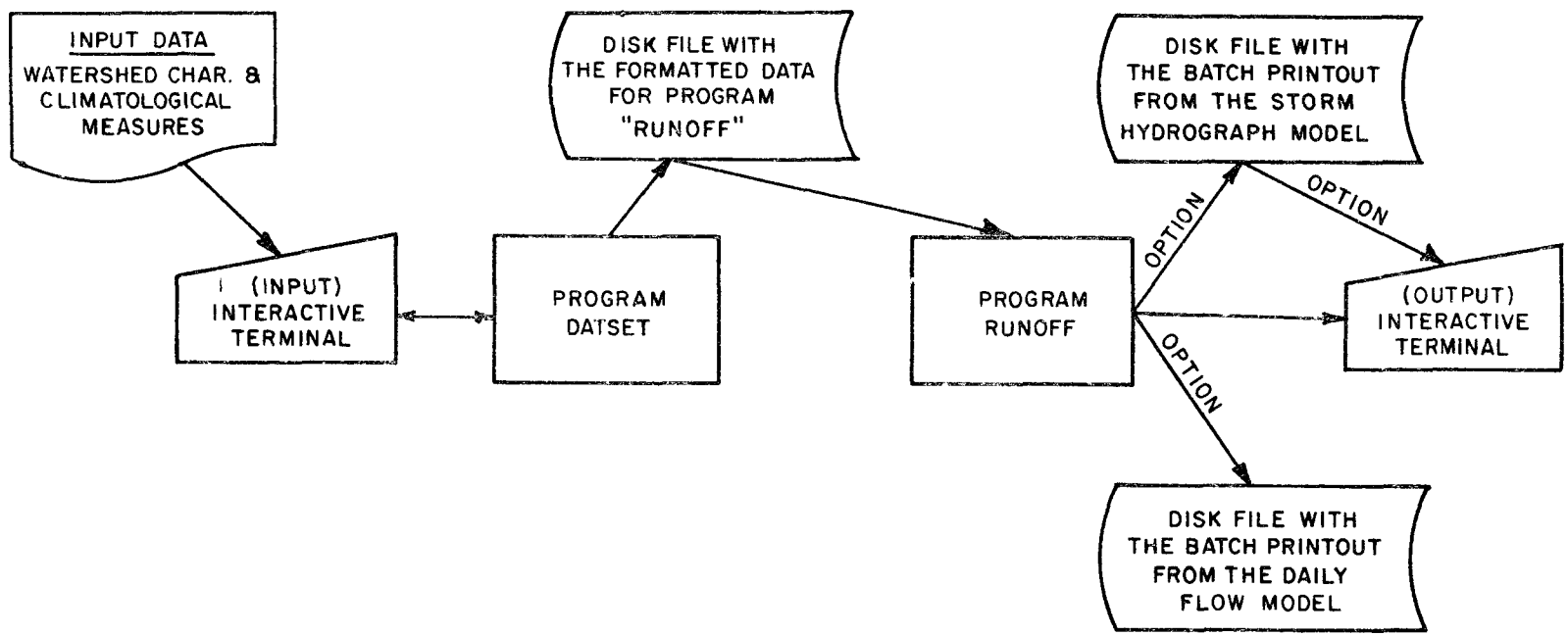

Figure 8: Interactive Procedure Flowchart

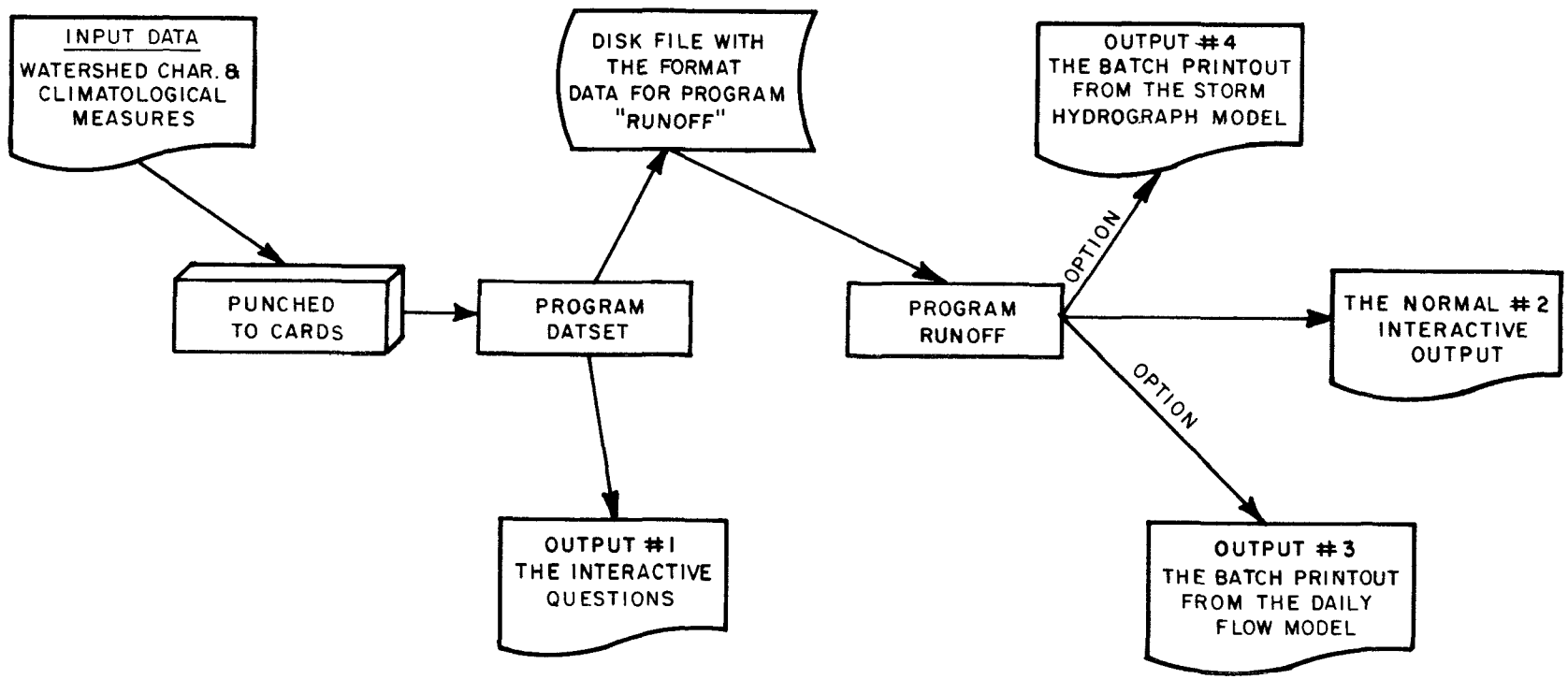

Figure 9 : Batch Procedure Flowchart

computer system, RUNOFF uses 230K bytes of storage and about 1½ CPU second for each year simulated (3 to 4 storms per year). The variables in this program are in double precision. Table 6 gives a description of all subroutines in program RUNOFF. Table 7 describes each function used. These functions must be provided by the user or be included in the computer system software.

Program RUNOFF uses the following data set reference numbers for specifying input/output devices:

1 - Outputs the storm hydrograph model results to printer or disk file.
2 - A temporary working file to store the storm hydrograph input data. This file is fixed length, 80 bytes per record. About 16K bytes are needed for this file.
3 - Outputs the daily flow model results to the printer or disk file.
4 - Outputs the observed and simulated discharge from the daily and storm models to a tape for plotter use later (option not available in TVA-HYSIM).
5 - Reads input data from the RUNOFF input data file or from cards.
6 - Outputs interactive output to the terminal or printer, also error messages are written to this data set reference number.
7 - Punches simulated daily streamflow values to cards for use with other programs, (option not available in TVA-HYSIM).
8 - A temporary working file. This file consists of fixed length, 24 bytes per record. About 48 bytes are needed.

B. RUNOFF INPUT DATA FILE

On the TVA system, an on-line disk is used to store the RUNOFF input data file created by DATSET. This file is a partitioned data set with input data for a single watershed being a member of the file. A sequential file can be used on disk or tape. The file has the following attributes: (1) record format (RECFM) of Fixed length and Blocked (FB), (2) record length (LRECL) of 90 bytes, and (3) block size (BLKSIZE) of about a ¼ of a track on a 3330 disk.

C. TSO COMMANDS FOR INTERACTIVE RUNS

This section describes the TSO command procedure (CLIST) used to run the interactive form of HYSIM. Figure 10 is the CLIST used in TVA to run HYSIM. Due to the various types of interactive systems not all can be described. The TVA CLIST can be used, however, as a guide to set up the CLIST for another computer system. The following describes lines of the CLIST that may be need more explanation.

CLIST Line #	Description
20	This suppresses TSO informational mes-

TABLE 6

PROGRAM RUNOFF SUBROUTINES AND DESCRIPTIONS

Subroutine	Description
Main	Driver for the subroutines. In addition, it reads in operational controls for a variety of options not available in TVA-HYSIM.
MODEL	Main subroutine which operates the continuous daily streamflow model (DFM).*
CHAR	Calculates daily flow model parameters from basin characteristics (DFM).
SEASON	Calculates the daily season variable for the four seasons (DFM).
ETYEAR	Calculates daily evapotranspiration from land cover and GI curves (DFM).
PRINT	Prints optional daily rainfall and simulated flow by months (DFM).
QUDAT	Simulates daily water quality information (option not available in TVA-HYSIM).
RFSIM	Generates daily rainfall (DRFG) from the mean of the cube roots of observed monthly rainfall and the standard deviation of this distribution.
GAUSS	Generates a normally distributed variable from the mean and standard deviation of cube root of monthly rainfall (DRFG).
URAND	Generates random numbers with a uniform probability distribution (DRFG, HRFG, FRFG).
SMODEL	Drives the storm hydrograph model (SHM) when used by itself (option not available in TVA-HYSIM).

*Denotes the model component where subroutine is used--see end of table.

TABLE 6 (continued)

STORMD	Reads observed storm hydrograph data from cards and stores on data set reference number 2 (option not available in TVA-HYSIM). Portions of this subroutine are used in TVA-HYSIM for procedural operations (SHM).
SCHAR1	Reads storm hydrograph watershed characteristics from data reference number 2, calculates storm hydrograph parameters from basin and storm characteristics (SHM).
STORM	Main component of storm hydrograph model (SHM).
RUNOFF	Determines precipitation excess distribution (SHM).
HOURF	Generates hourly rainfall (HRFG).
FIVMIN	Generates five-minute rainfall (FRFG).
INTERP	Interpolates hourly rainfall for shorter time periods (SHM) (option not available in TVA-HYSIM).
STATS	Calculates statistics indicating agreement between simulations and observed data when provided (option not available in TVA-HYSIM) (DFM, SHM).
PLOT	Provides a print-plot of a year of daily flow (not available in TVA-HYSIM) or a storm hydrograph (DFM, SHM).
SEDMEN	Calculates storm suspended sediment loads (SSM).
DATE	A dummy subroutine to replace a TVA system subroutine which obtains the date from an internal computer clock.
MOV	A subroutine to initialize arrays to zero. This replaces a software subroutine on the TVA system.

TABLE 6 (continued)

CORE	A TVA system subroutine to modify the format of variable data. This replaces a software subroutine on the TVA system.

-- -- -- -- --

DFM = Continuous daily streamflow model
DRFG = Rainfall generator, daily
HRFG = Rainfall generator, hourly
FRFG = Rainfall generator, five-minute
SHM = Storm hydrograph model
SSM = Suspended sediment model

TABLE 7

PROGRAM RUNOFF FUNCTIONS AND DESCRIPTIONS

FORTRAN software

Functions	Descriptions
ALOG	Natural logarithm in single precision.
DABS	Absolute value in double precision.
DATAH	Arc tangent in double precision.
DEXP	Exponential in double precision.
DFLOAT	Converts from integer single precision to real double precision.
DLOG10	Common logarithm in double precision.
DMAX1	Maximum value in double precision.
DMOD	Same as MOD except in double precision.
DSQRT	Square root in double precision.
EXP	Exponential in single precision.
FLOAT	Converts from integer single precision to real single precision.
IDINT	Truncation in double precision.
IFIX	Converts from real single precision to integer single precision.
MOD	Integer modular arithmetic in single precision (used to abstract fractional part of numbers).
SIN	Sine in single precision.
SNGL	Obtains most significant part of a real double precision number and returns to a real single precision number.

FIGURE 10

CLIST for Interactive Computer Runs

```
/*CLIST FOR TVA-HYSIM */
CONTROL NOMSG
/*
/* RUN PROGRAM "DATSET" TO SET UP A DATA SET FOR PROGRAM "RUNOFF" */
/*
    FREE ATTR(PDSOUT,PDSIN,RO,TEM)
    ATTR PDSOUT OUTPUT
    FREE F(FT05F001, FT10F001)
    ALLOC DA(*) F(FT05F001)
    ALLOC DA('H.HP326246.SSAM.DATA(TEMPNAME)') F(FT10F001) +
          USING(PDSOUT)
/*
    CALL 'H.HP326246.PROGRAM.LOAD(DATSET)'
/*
WRITE ARE YOU READY TO RUN THE PROGRAM?(YES OR NO)
READ &ANS
IF &ANS NE YES THEN GOTO END
/*
/* RUN PROGRAM "RUNOFF" */
/*
    ATTR PDSIN INPUT
    FREE F(FT01F001,FT02F001,FT03F001,FT05F001,FT10F001)
    DEL TEMP.SPACE
    DEL '$HDAI04.PRINTDAY.DATA'
    DEL '$HDAI04.PRINTSTO.DATA'
    ALLOC DA('H.HP326246.SSAM.DATA(TEMPNAME)') F(FT05F001) USING(PDSIN)
    ATTR RO BLKSIZE(133) LRECL(133) RECFM(F,B,A)
    ALLOC DA('$HDAI04.PRINTDAY.DATA') F(FT03F001) NEW SPACE(9900,500) +
          BLOCK(133) USING(RO)
    ALLOC DA('$HDAI04.PRINTSTO.DATA') F(FT01F001) NEW SPACE(59900,500) +
          BLOCK(133) USING(RO)
    ATTR TEM  BLDSIZE(80) LRECL(80) RECFM(F,B)
    ALLOC DA(TEMP.SPACE) F(FT02F001) NEW SPACE(2,1) BLOCK(80) USING(TEM)
    ALLOC DUMMY F(FT04F001)
/*
    CALL 'H.HP326246.PROGRAM.LOAD(RUNOFF9)'
    SET &LTCC=&LASTCC
/*
    DEL TEMP.SPACE
/*
    IF &LTCC NE 99 THEN GOTO END
         WRITE DO YOU WISH TO PRINT THE STORM HYDROGRAPHS?(YES OR NO)
         READ &ANS
         IF &ANS NE YES THEN GOTO END
              L '$HDAI04.PRINTSTO.DATA' NONUM
/*
END: STOP
```

	sages from commands or statement in the CLIST.
145	Releases attribute names PDSOUT, PDSIN, RO, and TEM.
150	Assigns the file attribute of OUTPUT to PDSOUT. OUTPUT specifies that the data set is to be used as output only to the program DATSET.
160	Releases (frees) files allocated to the data set reference numbers 5 & 10.
170	Allocates the terminal to data set reference number 5 using attributes assigned to PDSOUT.
180	Allocates RUNOFF input data file to data set reference number 10.
200	Calls program DATSET to run the program.
220	Writes to terminal "ARE YOU READY TO RUN THE PROGRAM? (YES OR NO)".
230	Reads the response to the previous question. If YES, then the operations proceed on through the CLIST to call program RUNOFF. If NO, then go to line 550 to end the CLIST.
280	Assigns the file attribute of INPUT to PDSIN. INPUT specifies that the data set is to be used as input only to the program RUNOFF.
290	Frees files allocated to data set reference numbers 1, 2, 3, 5, & 10.
300-400	In these statements, three files are deleted then re-created. Typically the files could be created one time and used repeatedly. However, on the TVA system, deleting and re-creating these files seems to work better.
300-320	Delete three files TEMP.SPACE, $HDAI04.PRINTDAY.DATA, and $HDAI04. PRINTSTO.DATA.

330	Allocates RUNOFF input data file to data set reference number 5 using the attribute assigned to PDSIN.
340	Assigns to RO the attributes of block size (133) record length (133), and record format of fixed (F) and blocked (B) and American National Standards Institute control characters (A).
350-360	Creates the file "$HDAI04.PRINTDAY. DATA" and allocates it to data set reference number 3 using the attributes RO.
370-380	Creates the file "$HDAI04.PRINTSTO. DATA" and allocates it to data set reference number 1 using the attributes assigned to RO.
390	Assigns to TEM the attributes of block size (80), record length (80), and record format of fixed (F) and block(B).
400	Creates the file "TEMP.SPACE" and allocates it to data set reference number 2 using the attributes assigned to TEM.
410	Allocates data set reference number 4 to a dummy file since it is not used.
430	Calls program RUNOFF to run the program.
435	Assigns the last return code from program RUNOFF to the variable &LTCC. &LASTCC is a built-in function command procedure to obtain the last return code.
470	Delete file TEMP.SPACE.
490	This statement checks the return code from program RUNOFF to see if it equals 99. If it is not equal to 99, the operations proceed to line 550 and stops the CLIST. If it is equal to 99, then the operations proceed on through the CLIST.

500	Writes to terminal "DO YOU WISH TO PRINT THE STORM HYDROGRAPHS? (YES OR NO)".
510	Reads the response input to the previous question. If YES, then the operations proceed on through the CLIST to print the storm hydrographs. If NO, then the operations proceed to line 550 to stop the CLIST.
530	Prints the storm hydrographs which have been stored on file "$HDAI04. PRINTSTO.DATA" by program RUNOFF.
550	Stops the CLIST.

D. JOB CONTROL LANGUAGE (JCL) FOR BATCH RUNS

This section will describe the JCL used to run TVA-HYSIM in a batch mode in TVA. Figure 11 is a listing of the JCL used in TVA. This can be used as a guide to setting up JCL for a different computer system. The following will describe lines of the JCL that may need additional explanation:

Line #	Description
50	The JOBLIB card. It provides the file name for the partition data set where the programs are stored in load mode form.
70	Calls program DATSET to run the program.
100	Allocates the printer to data set reference number 6.
110	Allocates RUNOFF input data file to data set reference number 10.
130	Allocates the card input to data set reference number 5.
140	These are the responses to the interactive questions in Figure 1, Section II. These response are punched on cards with a comma or blank between each value. This amounts to 19 cards or less.

FIGURE 11

Job Control Language for Batch Computer Runs

```
//NXYSIM JOB 326285,HPRATT.ENGR.LAB,MSCLEVEL=1,CLASS=K                  010
//* VERSION DATE:  12/14/79.                                            020
//* PROCEDURE TO RUN "HYSIM" BATCH.                                     030
//*                                                                     040
//JOBLIB DD  DISP=SHR,DSN=H.HP325133.LIB                                050
//*                                                                     060
//DATSET EXEC PGM=DATSET                    --RUN PROGRAM "DATSET" TO   070
//*                                           SET UP DATA FOR PROGRAM   080
//*                                           "RUNOFF".                 090
//FT06F001 DD SYSOUT=A                      --PRINT QUESTIONS AT PRINTER 100
//FT10F001 DD DISP=SHR,                     --CREATED INPUT DATA FOR    110
//DSN=H.HP326246.SSAM.DATA(TEMPNAME)            PROGRAM "RUNOFF".       120
//FT05F001  DD  *                                                       130
//*                                                                     135
    ***(Data cards with the responses to interative questions)***       140
//*                                                                     150
//RUNOFF EXEC PGM=RUNOFF9,REGION=230K,      --RUN PROGRAM "RUNOFF" TO   160
// TIME=3                                     SIMULATE FLOW.           170
//FT01F001 DD SYSOUT=A,                     --PRINT STORM HYDROGRAPH    180
//DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3059)     RESULTS.                   190
//FT02F001 DD UNIT=SYSPL,DISP=NEW,          --TEMPORARY STORAGE FILE FOR 200
// SPACE=(80,(100,100)),DSN=&&STORM,          STORM HYDROGRAPH MODEL    210
// DCB=(RECFM=FBA,LRECL=80,BLKSIZE=400)       INPUT DATA.               220
//FT03F001 DD SYSOUT=A,                     --PRINT DAILY FLOW RESULTS. 230
// DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3059)                               240
//FT04F001 DD DUMMY                         --PLOT DATA FILF IF SET UP. 250
//FT05F001 DD DISP=SHR,                     --INPUT DATA TO "RUNOFF"    260
// DSN=H.HP326246.SSAM.DATA(TEMPNAME)         PROGRAM.                  270
//FT06F001 DD SYSOUT=A                      --PRINT SHORT FORM & ERRORS. 280
```

160	Calls program RUNOFF to run the program.
180-190	Allocates data set reference number 1, the storm hydrograph results, to the printer.
200-220	Allocates data set reference number 2 to a temporary storage file for storm hydrograph model input data.
230-240	Allocates data set reference number 3, the daily flow results, to the printer.
250	Allocates data set reference number 4 to a dummy file since it is not used.
260-270	Allocates RUNOFF input data file to data set reference number 5.
280	Allocates data set reference number 6, the interactive output, to the printer.

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APPENDIX

ENGLISH TO METRIC CONVERSION FACTORS

English Unit	Multiplied By	Converts To
inches (in)	2.54	centimeters (cm)
feet (ft)	0.305	meters (m)
miles (mi)	1.61	kilometers (km)
square feet (ft^2)	0.093	square meters (m^2)
acres (ac)	0.405	hectares (ha)
square miles (mi^2)	2.59	square kilometers (km^2)
cubic feet (ft^3)	0.0283	cubic meters (m^3)
pounds (lb)	0.454	kilograms (kg)
tons	907.2	kilogram (kg)
pounds/acre (#/ac)	1.120	kilogram/hectare (kg/ha)
tons/sq mi (Tons/mi^2)	3.5	kilogram/hectare (kg/ha)
ft^3/second/mi^2	0.0109	m^3/second/km^2
acre-feet (ac-ft)	1223.	cubic meters (m^3)

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16. ABSTRACT

TVA-HYSIM is a computer package containing complex hydrologic models specifically designed for ease of application in land-use planning studies.

This user's guide outlines the information required to operate the programs and how this information is obtained, shows examples of input and output, and provides examples of job controls needed to operate the program. Model components are described in sufficient detail so that changes to the algorithms may be made if so desired.

TVA-HYSIM is not adapted to handling dynamic land-use conditions, but rather is designed to be used as a planning tool so that the end effects of the land-use change can be evaluated before the change occurs. Thus in a typical land-use change evaluation, the model package would first be used to simulate hydrology under present land-use conditions and then used to simulate the post land-use change hydrology. Some strategies for using TVA-HYSIM to determine the effects of land-use change on the hydrologic balance are offered.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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