EVALUATION OF THE PRECIPITATION-RUNOFF MODELING SYSTEM, BEAVER CREEK BASIN, KENTUCKY

By David E. Bower

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CONTENTS

ILLUSTRATIONS

TABLES

TABLES--Continued

Conversion of inch-pound units to International System of Units (SI)

Data in this report are given in inch-pound units. To convert inch-pound units to SI units, the following conversion factors are used:

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton, short	0.0972	megagram (Mg) or metric ton (t)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

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ABSTRACT

The Surface-Mining Control and Reclamation Act of 1977 (Public Law 95-87) requires hydrologic information on permit applications. Much of this information can only be obtained quickly by modeling. However, watershed models need to be evaluated for their capability to simulate these data. The Precipitation-Runoff Modeling System was evaluated with data from Cane Branch and Helton Branch in the Beaver Creek basin of Kentucky. Because of previous studies, 10.6 years of record were available to establish a data base for the basin including 60 storms for Cane Branch and 50 storms for Helton Branch.

The model was calibrated initially using data from the 1956-58 water years. Runoff predicted by the model was 97.4 percent of the observed runoff at Cane Branch (mined area) and 96.9 percent at Helton Branch (unmined area). After the model and data base were modified, the model was refitted to the 1956-58 data for Helton Branch. It then predicted 98.6 percent of the runoff for the 10.6-year period. The model parameters from Helton Branch were then used to simulate runoff and discharge for Cane Branch. The model predicted 102.6 percent of the observed runoff at Cane Branch for the 10.6 years. The simulations produced reasonable storm volumes and peak discharges. Sensitivity analysis of model parameters indicated the parameters associated with soil moisture are the most sensitive. The model was used to predict sediment concentration and daily sediment load for selected storm periods, and the results indicate that reasonable concentrations and loads can be predicted for storms.

INTRODUCTION

The Surface-Mining Control and Reclamation Act (Public Law 95-87) was passed by the 95th Congress in 1977. This Act requires that applications for permits to mine coal contain baseline hydrologic conditions in and around proposed mine sites so that impacts of mining can be determined. In many states, projects were started to study methodologies of collecting and analyzing hydrologic data associated with coal-mining areas. Some projects resulted in computer models capable of simulating various hydrologic characteristics of a watershed and, under the Act, these modeling techniques are acceptable for simulating characteristics where existing data are inadequate. Doyle (1981) made tentative appraisals of several of the models including the model developed by the U.S. Geological Survey and later named the Precipitation-Runoff Modeling System (PRMS). The PRMS model was further tested and evaluated during this study using data from the Beaver Creek basin in Kentucky. During this study, the PRMS model was being documented (G. W. Leavesly, U.S. Geological Survey, written commun., 1982) and modifications were made as a result of this study.

Purpose and Scope

The purposes of this study were to (1) compile a data base for a surface mining area in the eastern United States, and (2) use the data base to evaluate the capability of the PRMS model to simulate hydrologic data in mining areas. Evaluation of the model included: (1) modeling of stream discharge in a small basin, (2) checking the transferability of model parameters from one basin to a similar basin and, (3) checking the sensitivity of the model to errors in selected parameters.

Acknowledgment

The author expresses sincere appreciation to the staff of the Precipitation-Runoff Modeling Unit, U.S. Geological Survey, Lakewood, Colorado, for their assistance in providing model documentation and fitting the model to produce some of the results described in this report.

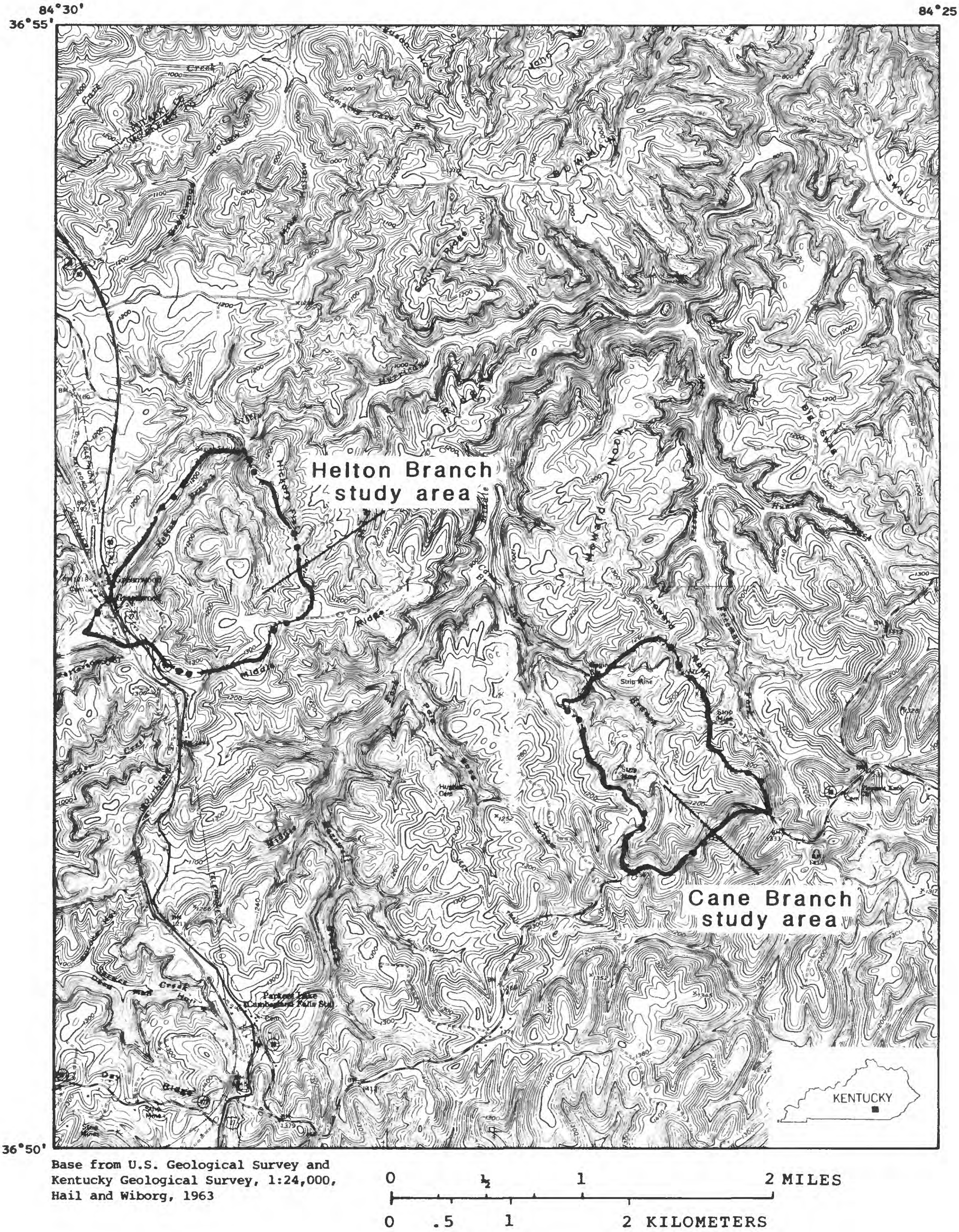
BEAVER CREEK BASIN

Description

The Beaver Creek basin is in the Appalachian coal region of McCreary County in southeastern Kentucky (fig. 1). Data used in the study were for the small watersheds of Cane Branch and Helton Branch in the basin (Collier and others, 1964, 1970; and Musser, 1963).

Cane Branch (fig. 2) is in the southern part of the Beaver Creek basin. It has a drainage area of 0.67 mi^2 and the elevation ranges from 979 to 1,390 ft above sea level. Although bedrock forms several small waterfalls and numerous riffles, it makes up only a small part of the streambed. The larger part of the streambed consists of sediment along the relatively flat parts of the stream and in pools that occur between riffles and falls. Intermittent mining from 1955 to 1959 resulted in 10.4 percent of the basin being strip mined (Collier and others, 1964). Various stages of reclamation took place during the remainder of the data-base period ending in 1966.

Helton Branch (fig. 3) is in the southwestern part of the Beaver Creek basin. It has a drainage area of 0.85 mi^2 and the elevation ranges from 994 to 1,390 ft above sea level. The streambed is bedrock and sediment and it has a 15-foot waterfall about 2,300 ft upstream from the streamflow gaging station. Most of the sediment is confined to small pools between the rock riffles and numerous small waterfalls.



Base from U.S. Geological Survey and Kentucky Geological Survey, 1:24,000, Hail and Wiborg, 1963

Figure 1.--Part of Beaver Creek basin containing Cane Branch and Helton Branch study areas.

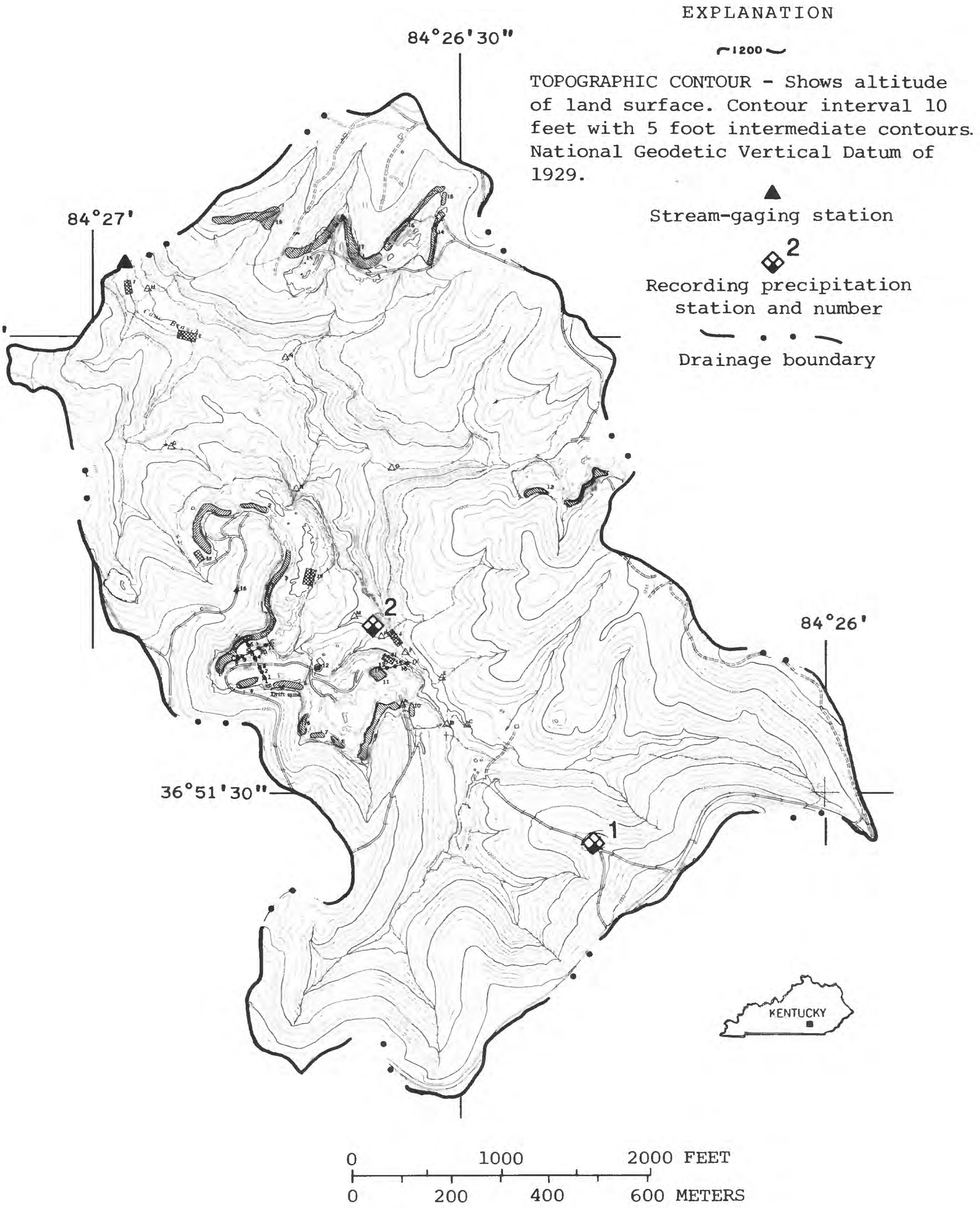


Figure 2.--Cane Branch basin showing location of gaging station and rain gages (modified from Musser,1963).

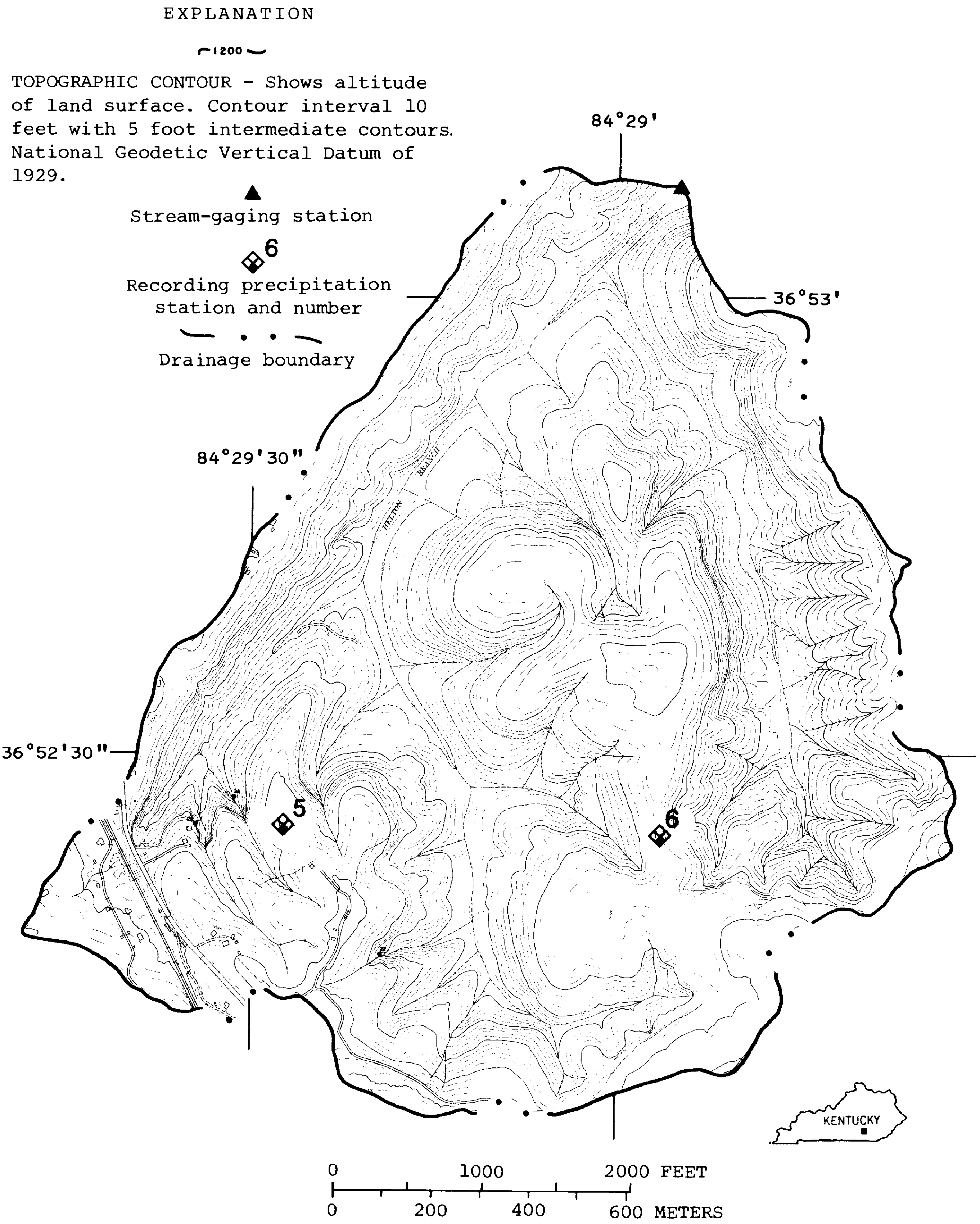


Figure 3.--Helton Branch basin showing location of gaging station and rain gages (modified from Collier and others, 1964).

The Helton Branch basin is in its natural state except where highway construction took place in August and September 1965 (Collier and others, 1970, p. 16). About 92 percent of the basin is in the Daniel Boone National Forest and has been declared a wilderness area. No significant change in land use occurred in the 8 percent of the basin outside the national forest during the period 1956-66 (Collier and others, 1970, p. 31).

Physiography and Topography

The overall characteristics of the study area are described by a quote from Musser (1963, p. 3) which says:

> The Beaver Creek basin is in the Cumberland Plateau physiographic section, in the part known as the Eastern Kentucky Mountains. The Cumberland Plateau is underlain by nearly horizontal strata composed of interbedded sequences of sandstone and shale. These beds have been eroded by streams to form a maturely dissected, irregular land surface with narrow, winding ridges and deep steep-sided valleys.
>
> * * * * The average elevation of the divides is 1,300 feet above sea level. The relief along the steep walls of the valley ranges from 200 to 400 feet. The valley floors are narrow, and the flood plains are small; the streams meander slightly in small incised channels. In many places the channel floors consist of bedrock.

Climate

Climate within the study area is characterized by a moderately severe winter with frequent thunderstorms throughout the remainder of the year. Floods during the summer usually are the result of an intense, localized thunderstorm and are of short duration that produce sharp flood peaks. Floods during the winter and spring, however, are generally caused by precipitation spread out over a longer period of time. As a result, flood peaks last longer and have a more gentle rise and fall than floods of comparable magnitude occurring in the summer.

AVAILABLE DATA

Data used for this study were collected for earlier studies (Musser, 1963; Collier and others, 1964) during the period 1956-66. These data and other data, (table 1) were loaded into WATSTORE in either the daily values file, which stores mean daily values, or in the units file, which stores measured values for selected subdivisions of time.

Table 1.--Data loaded in WATSTORE file for Precipitation-Runoff Modeling System evaluation

Station number	Parameter code[1]	Statistics code[1]	Length of record[2]	Data loaded
03407100	00060	00003	11	Cane Branch daily discharge (cubic feet per second).
03407100	60	11	92	Cane Branch unit discharge (cubic feet per second).
03407100	80155	3	10	Cane Branch daily sediment load (tons per day).
03407300	60	3	11	Helton Branch daily discharge (cubic feet per second).
03407300	60	11	88	Helton Branch unit discharge (cubic feet per second).
03407300	80155	3	2	Helton Branch daily sediment load (tons per day).
03407300	80155	[3]21	1	Helton Branch daily sediment load (pounds per day).
365200085090000	20	1	11	Wolf Creek Dam U.S. Weather Bureau (daily maximum temperature in degrees Celsius).
365200085090000	20	2	11	Wolf Creek Dam U.S. Weather Bureau (daily minimum temperature in degrees Celsius).
365200085090000	50	6	11	Wolf Creek Dam U.S. Weather Bureau (daily pan evaporation in inches per day).
365205084265701	45	6	11	Cane Branch daily rainfall (inches) Rain gage number 1.
365205084265701	45	6	92	Cane Branch unit rainfall (inches) Rain gage number 1.
365205084265702	45	6	11	Cane Branch daily rainfall (inches) Rain gage number 2.
365205084265702	45	6	92	Cane Branch unit rainfall (inches) Rain gage number 2.
365307084285506	45	6	11	Helton Branch daily rainfall (inches) Rain gage number 6.
365307084285506	45	6	88	Helton Branch unit rainfall (inches) Rain gage number 6.
370700084370000	20	1	3	Somerset 1N U.S. Weather Bureau (daily maximum air temperature in degrees Celsius).
370700084370000	20	2	3	Somerset 1N U.S. Weather Bureau (daily minimum air temperature in degrees Celsius).

[1] WATSTORE codes.

[2] Years for daily values; days for unit values.

[3] Stored under statistics code Tidal High (Daily) because no statistics code for pounds per day.

Hydrologic

Streamflow gaging stations were operated on Cane Branch and Helton Branch from 1956 to 1966. Daily stream discharge data have been published for these stations, but it was necessary to rework the original records to obtain daily rainfall, 15-minute rainfall, and discharge data needed for the PRMS model.

Problems with the gaging station at Helton Branch affected stages above 0.85 ft (8.0 ft^3/s), however, reconstructed peaks for this record probably were reasonable and static tubes installed in 1964 eliminated the problem. Further, the rating is insensitive for stages above 1.0 ft (18 ft^3/s), and a 0.1 ft error in stage may cause a change in discharge of about 100 percent (N. Macon Jackson, Jr., U.S. Geological Survey, written commun., Oct. 26, 1981). Stage was computed to the nearest 0.005 ft at both Cane Branch and Helton Branch.

Climatologic

Daily Air Temperature

Daily air temperature data, both maximum and minimum, were obtained from U.S. Weather Bureau stations at Wolf Creek Dam, approximately 35 miles west of the basin, and at Somerset 1N, approximately 25 miles north-northwest of the basin. These data were taken from the monthly Climatological Data Bulletin for Kentucky (U.S. Department of Commerce). The elevations above sea level for the stations are 585 and 1,050 ft, respectively.

Daily Pan Evaporation

Daily pan evaporation data were obtained from the Wolf Creek Dam station. Because pan evaporation data were not collected throughout the winter, the missing periods of record were filled with synthesized data produced by a daily evaporation generator program (Carrigan and others, 1977).

Solar Radiation

Daily shortwave radiation (ORAD, langleys per day) data are required by the model because of the runoff from snowmelt within the basin. These data were not available so ORAD was estimated using the daily air-temperature data and PRMS algorithms.

Rainfall

Rainfall data were collected at sites shown in figures 2 and 3. Storms for unit values computation were selected from those listed in Collier and others (1964, p. B10). Some additional storms were added in order to test seasonal responses as well as large and small storm responses of the model. The storms used are listed in table 2.

PRECIPITATION-RUNOFF MODELING SYSTEM

A precipitation-runoff modeling system (PRMS) has been developed to provide deterministic physical-process modeling capabilities. Each component of the hydrologic cycle is expressed in the form of known physical laws or empirical relations that have some physical interpretation and relate to measurable watershed characteristics. The system is designed to function as either a lumped- or distributed-parameter type model and will simulate both mean daily flows and stormflow hydrographs. (Leavesley and others, 1981)

Table 2.--Beginning date and duration of unit storms

Storm number	Cane Branch			Helton Branch		
	Date		Duration (days)	Date		Duration (days)
1	1956	Feb. 17	2	1956	Feb. 17	2
2		Mar. 13	2		Apr. 6	1
3		Apr. 6	1	1957	Jan. 28	2
4		May 26	1		Feb. 1	2
5		June 13	2		May 22	1
6		June 25	1		June 23	1
7		July 2	1		July 18	2
8		July 23	1		Nov. 17	3
9		Dec. 21	2		Dec. 19	2
10	1957	Jan. 22	2	1958	Apr. 20	2
11		Jan. 27	3		Apr. 24	3
12		Apr. 8	1		May 5	3
13		Nov. 17	3		Nov. 1	1
14		Dec. 20	1	1959	June 2	1
15	1958	Apr. 24	2		June 12	1
16	1959	June 12	1		July 17	3
17		July 1	1		Aug. 27	2
18		July 19	1		Sept. 10	1
19		Aug. 6	1		Dec. 17	3
20		Sept. 10	1	1960	May 7	1
21		Oct. 8	1		June 16	2
22		Nov. 23	2		July 10	1
23		Dec. 17	2		Nov. 28	2
24	1960	Feb. 10	1	1961	Apr. 30	2
25		May 7	1		July 12	1
26		June 16	2		July 15	2
27		June 22	2		Dec. 9	2
28		July 10	1	1962	Feb. 26	3
29		Sept. 16	2		Apr. 5	3
30		Dec. 11	1		Apr. 10	3
31	1961	Mar. 6	1	1962	Sept. 16	1
32		Mar. 21	1		Oct. 2	2
33		Mar. 31	2	1963	Mar. 4	2
34		Apr. 9	2		Mar. 11	2
35		Apr. 30	2		Mar. 16	3
36		July 12	1		Apr. 29	2
37		July 16	1	1964	Mar. 8	1
38		Dec. 9	2		July 12	1
39	1962	Feb. 26	3		Aug. 8	1
40		Apr. 6	2		Aug. 22	1
41		Apr. 10	2		Sept. 28	2
42		Nov. 8	3		Dec. 3	2
43	1963	Mar. 11	1	1965	Mar. 24	3
44		Mar. 16	2		Mar. 29	1
45		May 27	2		July 23	1
46		Aug. 19	1	1966	Apr. 28	1
47		Aug. 25	1		Aug. 11	1
48	1964	Mar. 8	1		Aug. 30	1
49		May 28	1		Sept. 13	1
50		Sept. 28	2		Sept. 19	1
51		Dec. 3	2			
52	1965	Mar. 24	3			
53		Apr. 25	1			
54		May 27	1			
55		June 7	1			
56		July 23	1			
57	1966	Apr. 12	2			
58		Apr. 28	1			
59		June 6	1			
60		July 10	1			

Because most basins are not homogeneous in all hydrologic characteristics, PRMS allows for subdividing a basin into smaller areas that may be considered homogeneous. These subdivisions are called Hydrologic Response Units (HRU's), each of which can be subdivided into even smaller units called overland-flow plane and channel segments. The model computes the sum of the responses of the individual HRU's and flow plane segments as the total output of the basin. PRMS will simulate discharge from mean daily flow values or from shorter time intervals (5-minute, 15-minute, 1-hour, and so forth) in the unit mode. Table 3 gives a condensed list of parameters and their definitions.

Table 3.--Parameters and definitions

[Parameter definitions have been condensed. A more complete explanation is in the Precipitation-Runoff Modeling System User's Manual. (G. H. Leavesley, U.S. Geological Survey, written commun., 1982)]

Parameter	Definition
	One value for each HRU
COVDNS	Summer vegetation cover density
COVDNW	Winter vegetation cover density
TRNCF	Winter radiation transmission coefficient
SNST	Winter vegetation storage capacity
CTX	Air temperature-evapotransporation coefficient
TXAJ	Slope and aspect-maximum air temperature adjustment
TXNJ	Slope and aspect-minimum air temperature adjustment
SMAX	Maximum holding capacity of soil
REMX	Maximum holding capacity of recharge
SRX	Maximum snowmelt infiltration capacity
SCX	Maximum proportion of HRU contributing
SCN	Minimum proportion of HRU contributing
RNSTS	Summer vegetation storage capacity
RNSTW	Winter vegetation storage capacity
KSAT	Hydrologic conductivity
PSP	Combined effect of moisture deficit and potential
DRN	Redistribution factor (saturated moisture to base)
RGF	Ratio of moisture deficit and potential
D50	
KR	Parameter coefficient in soil detachment
HC	Parameter coefficient in rain detachment
KF	Parameter coefficient in runoff detachment
KM	Parameter coefficient in transport capacity
EN	Parameter coefficient in transport capacity
SC1	Coefficient in moisture index relations
SEP	Maximum daily recharge rate (soil-ground water)
DRCOR	Rain correction for daily precipitation
DSCOR	Snow correction for daily precipitation
TST	Temperature index for start of transpiration
	One value for each subsurface flow-routing reservoir
RCF	Subsurface flow-routing coefficient
RCP	Subsurface flow-routing coefficient
RSEP	Recharge from reservoir (I) to ground water (J)
RESMX	Recharge from reservoir (I) to ground water (J)
REXP	Recharge from reservoir (I) to ground water (J)
	One value for each ground-water flow-routing reservoir
RCB	Ground-water routing coefficient
GSNK	Coefficient for ground water to sink
	One value for each month (12 values)
TLX	Lapse rate for maximum daily air temperature
TLN	Lapse rate for minimum daily air temperature
RDM	Slope of air temperature-degree day relations
RDC	Air temperature-degree day intercept
EVC	Evaporation pan coefficient
PAT	Maximum air temperature for rain or snow
	One value for each overland flow planes
ALPHA	PARM1 (dependent on type flow)
EXPM	PARM2 (dependent on type flow)
	One value for each channel and reservoir segments
ALPHA	PARM1 (dependent on type flow)
EXPM	PARM2 (dependent on type flow)
	One value required
CTS	Air temperature-evapotranspiration correlation value
BST	Rainfall-snowfall temperature
SETCDN	Snowpack settlement time constant
PARS	Summer precipitation-solar radiation correction factor.
PARW	Winter precipitation-solar radiation correction factor.
CSEL	Climate station elevation
RMXA	Rain-snow correlation value
RMXM	Snowpack-melt correlation value
CTW	Evapotranspiration-snow correlation value
EAIR	Emissivity of dry air
FWCAP	Holding capacity of snowpack
DENI	Initial density of new-fallen snow
DENMX	Average maximum snowpack density

The minimum driving input variables required to run the model in the daily[1] mode in areas without runoff from snowmelt are (1) daily precipitation, and (2) maximum and minimum daily air temperatures or daily pan

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[1] "Daily" refers to mean daily values in the WATSTORE daily values file.

evaporation data. In areas that have runoff from snowmelt, daily solar radiation data are needed and if not available can be estimated from the maximum and minimum daily air temperature. To simulate unit[2] storm data, rainfall data of 15-minute frequency, or less, is required. If the model simulations are to be fitted to observed data, then the observed discharge (unit and daily) must be matched to the observed rainfall data.

Daily and unit storm-discharge computations in the model are interchangeable; however, only one type can be computed at the same time and the user can select from the following computation options: (1) daily computations only, (2) daily and unit computations without flow routing, (3) daily and unit computations with flow routing in the unit computation only, and (4) daily and unit computations with flow and sediment routing. Option 3 was used to obtain most of the predicted values shown in this report. On days of unit computations, the daily values shown are obtained by averaging or adding the values computed during the day.

Fitting the model can be done either manually or by using one of two "built-in" optimizing features. These are the Rosenbrock (1960) optimization technique used in the earlier Survey rainfall-runoff model (Dawdy and others, 1972) and the Gauss-Newton optimization technique, which is essentially identical to the linearization method described by Draper and Smith (1966, p. 267-270) and Beck and Arnold (1977, p. 340-349).

The model can do sensitivity analyses to determine which parameters are sensitive to adjustments and the degree to which the parameters are interrelated. A more complete discussion of sensitivity analyses is given in Mein and Brown (1978) and Beck and Arnold (1977).

Output from PRMS is extensive and includes the variables listed in table 4 (basin results) and table 5 (HRU results). Output from the model on the line printer can be in several forms. Plots (unit and daily) indicating the observed and predicted discharge along with tables for annual, monthly, or daily summaries of major climate and water balance elements may be obtained. Output of the predicted values also may be stored in the computer system for future use.

Procedure for Evaluation

In order to evaluate the versatility and response of the model, many steps were taken that usually would not be taken during a modeling study. Some erroneous parameter values were left in purposely, and different computational methods were used to evaluate their effect on model simulations. Parameter sensitivity and correlation were run mainly for demonstration rather than for precise determination of parameter values. The study was an evaluation of the model rather than an exercise of precisely fitting the model to the study area.

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[2] "Unit" refers to recorded data values of shorter-than-a-day duration in the WATSTORE units value file.

Table 4.--Variable identifiers and their definitions used in output summary tables for basin averages and totals.
[G. H. Leavesley, U.S. Geological Survey, written commun., 1982]

Variable	Definition
TMX	Maximum temperature (degrees Fahrenheit or Celsius, depending on input data).
TMN	Minimum temperature (degrees Fahrenheit or Celsius, depending on input data).
ORAD	Observed solar radiation (langleys)
O-PPT	Observed precipitation (inches)
N-PPT	Net precipitation (inches)
INLOS	Interception loss (inches)
P-ET	Potential evapotranspiration (inches)
A-ET	Actual evapotranspiration (inches)
SMAV	Available water in soil profile (inches)
%SN	Percent of basin with snow cover
#SN	Number of Hydrologic Response Units with snow cover
PWEQV	Snowpack water equivalent (inches)
SMELT	Snowmelt (inches)
GW-ST	Ground-water reservoir storage (inches)
RS-ST	Subsurface reservoir storage (inches)
GW-FL	Ground-water flow (inches)
RS-FL	Subsurface flow (inches)
SRO	Surface runoff (inches)
TRO	Predicted runoff (inches)
P-ROFF	Predicted mean daily discharge (cubic feet per second)
O-ROFF	Observed mean daily discharge (cubic feet per second)
GW-IN	Inflow to ground-water reservoirs from Hydrologic Response Units (inches).
SSR IN	Inflow to subsurface reservoirs (inches)
SSR-TO-GW	Inflow to ground-water reservoirs from subsurface reservoirs (inches).
SURFACE RO	Total surface runoff (inches)
SSR FLOW	Total outflow from subsurface reservoir (inches)
GW FLOW	Total outflow from ground-water reservoir (inches)
GW SINK	Seepage to ground water that does not contribute to ground-water outflow from basin (inches).

Throughout this study, Helton Branch was maintained as 1 HRU, 1 solar radiation plane, 1 subsurface flow-routing reservoir, 1 ground-water flow-routing reservoir, no surface-water detention storage reservoirs, 1 overland-flow plane, and 27 channel segments. The Cane Branch basin was divided into 7 hydrologic response units (see fig. 4) based on slope, land use, and other characteristics, 6 solar radiation planes, 2 subsurface flow-routing reservoirs, and 1 ground-water flow-routing reservoir. No surface-water detention storage reservoirs were used at Cane Branch. The basin was subdivided into 28 channel segments for routing of storms.

Both stations were fitted using the temperature data obtained for the Weather Bureau station Somerset 1N, (table 1) because the elevation of this station was closer to that of the study basin than other data stations. Daily pan evaporation data were obtained from Wolf Creek Dam. Fitting was slanted towards runoff volume rather than peak discharge for this study.

Table 5.--Variable identifiers and their definitions used in output summary tables for Hydrologic Response Units values [G. H. Leavesley, U.S. Geological Survey, written commun., 1982]

Variable	Definition
SWR	Shortwave solar radiation (langleys)
TMX	Maximum temperature (degrees Fahrenheit)
TMN	Minimum temperature (degrees Fahrenheit)
OPPT, O-PPT	Observed precipitation (inches)
NPPT, N-PPT	Net precipitation (inches)
INT	Computed interception (inches)
INLS, INTCP	Evaporated and sublimated moisture loss from interception (inches).
PET, POTET	Potential evapotranspiration (inches)
AET, ACTET	Actual evapotranspiration (inches)
SMAV, SM-AV	Available water in soil profile (inches)
PWEQV	Snowpack water equivalent (inches)
DEN	Snowpack density
PACT	Snowpack temperature (degrees Celsius)
ALB	Computed albedo
TCAL	Net energy balance of snowpack (calories)
SMELT	Snowmelt (inches)
INFL	Infiltration (inches)
UGS	Seepage to ground-water reservoir (inches)
USS	Seepage to subsurface reservoir (inches)
SRO	Surface runoff (inches)
SA, SL-AS	Slope and aspect
ELEV	Elevation (feet)
SSR-IN	Inflow to subsurface reservoir (inches)
SSR-STO	Storage to subsurface reservoir (inches)
SSR-FLOW	Outflow from subsurface reservoir to streamflow (inches)
SSR-TO-GW	Outflow from subsurface reservoir to ground-water reservoir (inches).
GW-IN	Inflow to ground-water reservoir from Hydrologic Response Units (inches).
GWSS-IN	Inflow to ground-water reservoir from subsurface reservoirs (inches).
GW-STOR	Storage in ground-water reservoir (inches)
GW-FLOW	Outflow from ground-water reservoir (inches)
GW-SINK	Seepage to ground water that does not contribute to ground-water outflow from basin (inches).

This study was done in three steps. In step 1, the model was fitted to Cane and Helton Branch data for the period Feb. 16, 1956 to Sept. 30, 1958 (958 days or about 2.6 years). Fifteen storms (table 2) were used at Cane Branch, and 10 were used at Helton Branch. Data for storms 1 and 6 for Helton Branch were not available during step 1.

In step 2, after the addition of some data and model modifications, the model was refitted to the same period of data as used in step 1. The model was then verified by using it to predict runoff for the entire period of record of 3,880 days (Feb. 16, 1956 to Sept. 30, 1966) for Helton Branch and comparing the predicted values to the observed values.

In step 3, parameter values used for Helton Branch were used to predict runoff for the entire period of record for Cane Branch. Rainfall data and parameter values unique to Cane Branch such as drainage area and slope were not transferred.

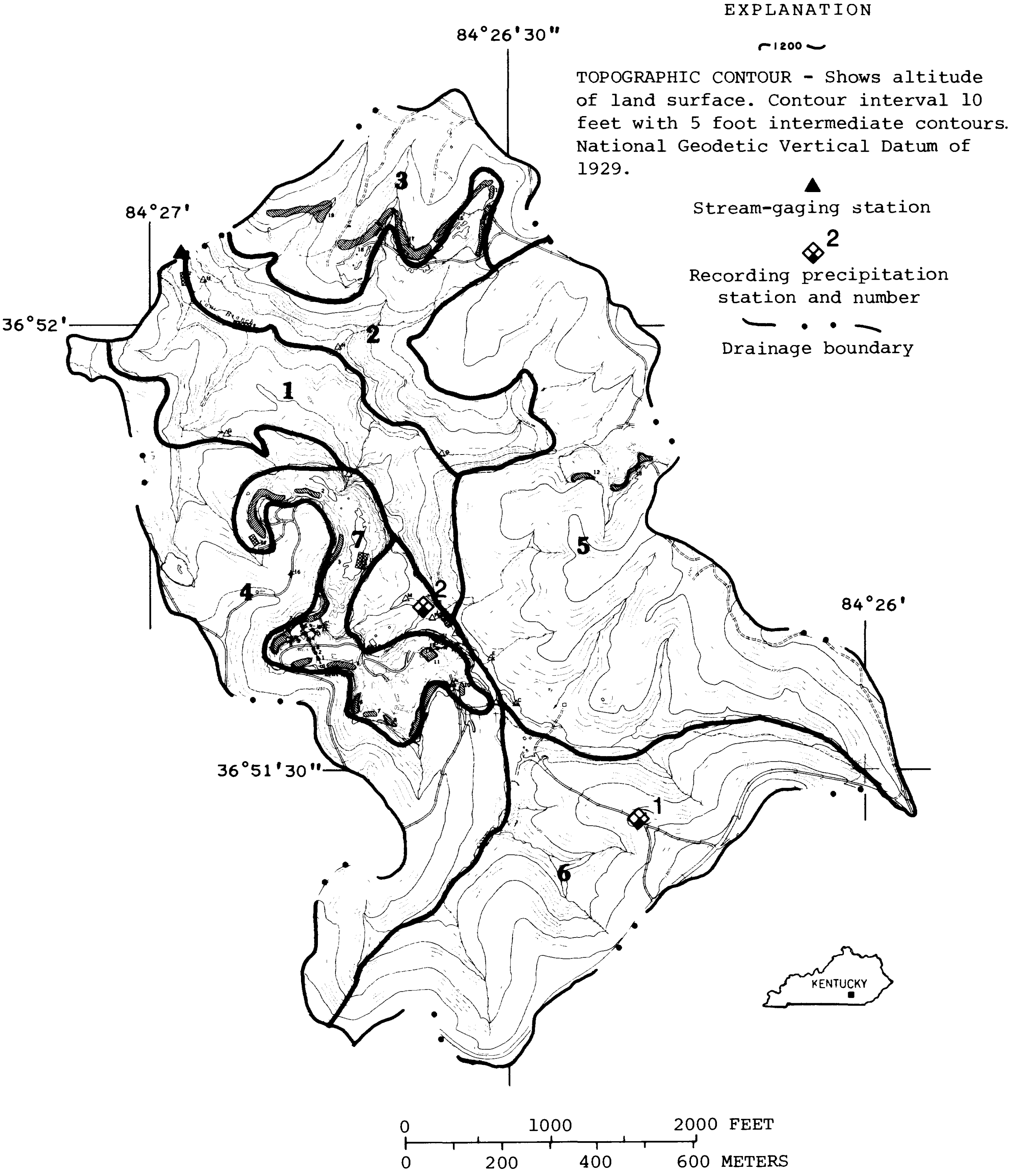

Figure 4.--Cane Branch hydrologic response units (modified from Musser, 1963).

Table 6 indicates that the rainfall was uniformly distributed between the two gages in Cane Branch. Because early model results at Cane Branch did not seem to benefit from the use of data from both rain gages, all subsequent modeling runs for this basin used data only from rain gage number 2.

In step 1, the potential evapotranspiration (ET) was computed by the model for both stations using temperature data read in the model and the computed solar radiation. After step 1 the potential evapotranspiration was computed by the model using pan evaporation data from the Weather Bureau station at Wolf Creek.

Calibration of Model

A hydrologic model must be fitted to the area it is modeling. The ultimate goal is to fit the model so that the standard deviation of the observed runoff or discharge minus predicted runoff or discharge is equal to zero. This precision is virtually impossible. In this study the PRMS was fitted arbitrarily to Cane Branch and Helton Branch so that the standard deviation of observed minus predicted runoff was 1.50 in. or better in the daily mode. Fitting in the unit mode was done on 15 storms for Cane Branch (table 6) and 10 storms for Helton Branch (table 7) with most fitting done on volume of runoff rather than peak discharge. Storm volumes were fitted until the standard deviation of the observed minus predicted storm runoff was ≤ 0.52 in. Storm peaks were fitted until the standard deviation of the observed minus predicted peak discharges was ≤ 52 ft^3/s.

Table 6.--Rainfall-runoff data for Cane Branch

[Observed rainfall-runoff in inches]

Date	Storm number	Day of storm	Daily rainfall, rain gage 1	Daily rainfall, rain gage 2	Storm total, rain gage 1	Storm total, rain gage 2	Runoff[1] Daily	Runoff[1] Storm total
2-17-56	1	1	2.81	2.71	---	---	1.41	---
2-18-56		2	.36	.57	3.17	3.28	1.41	2.82
3-13-56	2	1	.85	.84			.18	
3-14-56		2	.89	.94	1.74	1.78	1.33	1.52
4-06-56	3	1	1.82	1.84	1.82	1.84	1.18	1.18
5-26-56	4	1	.32	.45	.32	.45	.01	.01
6-13-56	5	1	.40	.40			.00	
6-14-56		2	.20	.16	.60	.56	.01	.01
6-25-56	6	1	.77	.78	.77	.78	.02	.02
7-02-56	7	1	.68	.61	.68	.61	.02	.02
7-23-56	8	1	1.22	1.40	1.22	1.40	.05	.05
12-21-56	9	1	1.86	1.84			.29	
12-22-56		2	.24	.24	2.10	2.08	.64	.93
1-22-57	10	1	1.71	1.61			.60	
1-23-57		2	.04	.04	1.75	1.65	.47	1.07
1-27-57	11	1	.07	.71			.13	
1-28-57		2	1.14	1.18			.68	
1-29-57		3	4.52	4.83	6.40	6.72	4.70	5.51
4-08-57	12	1	1.41	1.50	1.41	1.50	.58	.58
11-17-57	13	1	2.21	2.21			.76	
11-18-57		2	1.89	1.88			1.28	
11-19-57		3	.09	.15	4.19	4.24	.44	2.48
12-20-57	14	1	1.00	1.03	1.00	1.03	.73	.73
4-24-58	15	1	2.63	2.58			1.14	
4-25-58		2	.02	.02	2.65	2.60	1.02	2.16

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[1] Base flow not deducted. Computation may not include full recession.

Table 7.--Rainfall-runoff data for Helton Branch

[Observed rainfall-runoff in inches]

Date	Storm number	Day of storm	Daily rainfall, rain gage 6	Storm total, rain gage 6	Runoff[1]	
					Daily	Storm total
4- 6-56	2	1	1.65	1.65	0.95	0.95
1-28-57	3	1	1.19		.48	
1-29-57		2	5.42	6.61	3.68	4.16
2-01-57	4	1	.79		.52	
2-02-57		2	.0	.79	.41	.93
5-22-57	5	1	.76	.76	.03	.03
7-18-57	7	1	.88		.02	
7-19-57		2	.0	.88	.01	.03
11-17-57	8	1	2.29		.51	
11-18-57		2	2.27		.81	
11-19-57		3	.05	4.61	.61	1.94
12-19-57	9	1	.81		.07	
12-20-57		2	1.13	1.94	.58	.65
4-20-58	10	1	.66		.03	
4-21-58		2	1.29	1.95	.48	.51
4-24-58	11	1	2.31		.41	
4-25-58		2	.01		.81	
4-26-58		3	.89	3.21	.47	1.69
5-05-58	12	1	1.02		.22	
5-06-58		2	1.15		.68	
5-07-58		3	.26	2.43	.62	1.52

[1] Base flow not deducted. Computation may not include full recession.

Flow Routing

Flow routing can affect the results significantly. This option allows for a more precise computation of the hydrologic balance and response (including time lag) to a given storm. This option is recommended whenever possible and especially during major storms within the basin.

The flow-routing option is not available in the daily mode computations. Because of this and because of the time lag between the maximum storm intensity and response, it is possible for a storm to occur on one day while the observed response actually occurs on the following day. Thus predicted discharges at the beginning of a storm may be greater than that actually observed. A poor definition of surface-subsurface parameters may also give high predicted discharge at the beginning of a storm.

To demonstrate the effects of flow routing, the data for Cane Branch were run in both a daily mode (no flow routing) and a daily and unit mode with flow routing in the unit mode. The resulting standard deviation of error was 1.06 in. without flow routing and 0.87 in. with flow routing. Some of this difference is probably due to better definition of precipitation timing and intensity in the unit mode although some may be related to the different parameters used in daily and unit computations.

Daily Mode Computations

The close correlation between the observed and predicted daily mean discharge generated by the model is illustrated by a part of a hydrograph for Cane Branch (fig. 5). Storms 10 and 11 (table 6, Jan. 22-23, 1957 and Jan. 27-29, 1957, respectively) are included in this part of the hydrograph. A unit computational mode was used for the storms and a daily computational mode for the remainder of the predicted hydrograph.

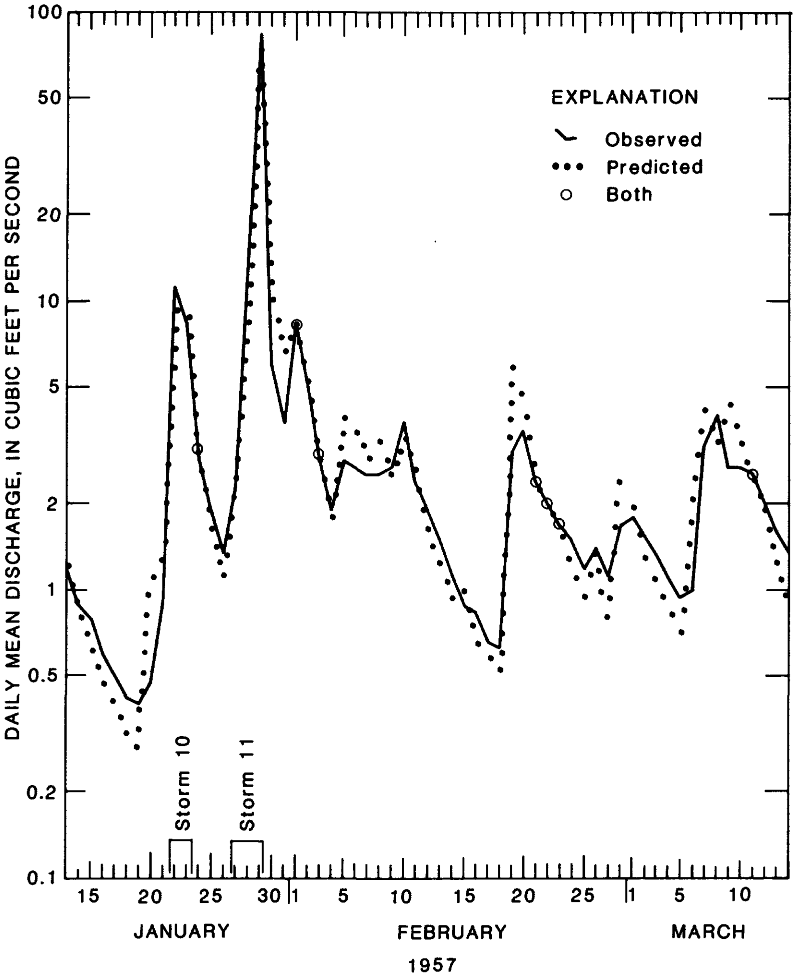

Figure 5.--Daily mean discharge for Cane Branch.

Table 8 shows that the model predicted 97.5 percent (58.03 of 59.52 in.) of the observed runoff at Cane Branch for the 958 days, and the standard deviation of the prediction residuals (observed minus predicted daily runoff) was 0.87 in. Table 9 shows that the model predicted 96.9 percent (55.94 of 57.73 in.) of the observed runoff at Helton Branch, and the standard deviation of the prediction residuals was 1.19 in.

Table 8.--Model results for predicting monthly runoff (inches) from Cane Branch basin for 1956-58, step 1

[Standard deviation is standard deviation of observed minus predicted daily runoff]

	1956			1957			1958		
Month	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation
October	--	--	--	0.13	0.05	0.06	0.25	0.16	0.18
November	--	--	--	.09	.04	.06	3.10	3.88	1.31
December	--	--	--	2.69	3.60	1.44	2.83	3.37	.86
January	--	--	--	8.98	9.12	2.31	1.54	2.00	1.09
February	[1]4.97	[1]4.77	[1]1.65	3.56	3.88	.71	2.13	1.83	.75
March	5.05	4.56	1.26	2.14	2.07	.52	2.48	1.96	.74
April	3.63	3.11	1.02	2.49	2.09	.36	6.83	5.32	2.17
May	.40	.41	.14	.44	.37	.21	3.06	2.79	1.09
June	.22	.27	.22	.47	.30	.17	.16	.22	.04
July	.45	.57	.56	.12	.10	.04	.27	.27	.09
August	.24	.17	.07	.05	.05	.00	.12	.08	.04
September	.08	.04	.03	.35	.34	.10	.20	.24	.10
Annual total	[1]15.04	[1]13.90	[1].76	21.51	22.01	0.84	22.97	22.12	0.94
Overall total	--	--	--	--	--	--	59.52	58.03	0.87

[1] Partial record for month or year.

Table 9.--Model results for predicting monthly runoff (inches) from Helton Branch basin for 1956-58, step 1

[Standard deviation is standard deviation of observed minus predicted daily runoff]

	1956			1957			1958		
Month	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation
October	--	--	--	0.16	0.15	0.05	0.35	0.30	0.14
November	--	--	--	.19	.12	.06	2.79	4.38	2.82
December	--	--	--	2.47	3.35	2.62	3.11	3.28	.49
January	--	--	--	8.00	8.09	2.53	1.57	1.83	.83
February	[1]5.20	[1]4.21	[1]3.47	3.88	3.93	.64	2.11	1.80	.60
March	4.59	3.96	2.72	2.08	2.07	.57	2.40	1.77	.72
April	3.04	2.44	2.22	2.13	2.11	.54	5.78	4.86	1.17
May	.52	.42	.21	.46	.44	.16	3.31	2.96	.70
June	.22	.28	.06	.46	.38	.13	.36	.40	.10
July	.43	.30	.18	.30	.29	.05	.33	.33	.06
August	.26	.22	.06	.18	.23	.04	.26	.26	.02
September	.13	.16	.02	.38	.38	.28	.28	.24	.08
Annual total	[1]14.39	[1]11.99	[1]1.55	20.69	21.54	1.11	22.65	22.41	.98
Overall total	--	--	--	--	--	--	57.73	55.94	1.19

[1] Partial record for month or year.

Unit Mode Computations

Tables 10 and 11 summarize the unit computations done at Cane Branch and Helton Branch during the calibration period. The tables list the storm number, predicted volume, routed outflow, observed outflow, predicted peak, and observed peak. The values reported are per storm, which may include periods of up to 3 days. No attempt was made to subdivide the storm. The predicted peak discharge and volume of runoff during unit computations were better at Cane Branch than at Helton Branch. Considering the preliminary fitting that was done in the unit mode, the predicted values are reasonably good.

Table 10.--Summary of unit computations for Cane Branch, 1956-58 data

Storm	Predicted volume (inches)	Outflow, in inches		Peak, in cubic feet per second	
		Routed	Observed	Predicted	Observed
1	2.40	2.36	2.82	97.22	83.80
2	1.19	1.15	1.52	69.50	75.00
3	.97	.92	1.17	77.07	97.80
4	.02	.01	.01	.49	.61
5	.04	.04	.01	1.63	.64
6	.04	.04	.02	2.57	1.46
7	.09	.08	.02	12.08	2.80
8	.24	.20	.05	16.18	7.00
9	1.37	1.29	.93	120.40	61.00
10	1.06	1.03	1.07	70.30	73.00
11	4.90	4.75	5.51	293.34	198.00
12	.56	.52	.58	28.21	30.50
13	2.41	2.24	2.04	114.13	96.00
14	.61	.58	.73	23.96	36.20
15	1.41	1.27	1.14	144.06	154.00
Total	17.31		17.62		
Mean	1.15	1.10	1.17	71.41	61.19

Storm volume error summary

	Sum of absolute differences between observed and predicted values		Sum of squares of differences between observed and predicted values	
	Non log	Log	Non log	Log
Sum	3.10	7.92	1.15	8.99
Mean	.21	.53	.08	.60
Percent	17.95		23.56	

Storm peak error summary

	Sum of absolute differences between observed and predicted values		Sum of squares of differences between observed and predicted values	
	Non log	Log	Non log	Log
Sum	260.37	6.32	14,019.84	4.99
Mean	17.36	.42	934.66	.33
Percent	28.37		49.96	

The summary for Cane Branch (table 10) shows the mean of the absolute differences between the predicted and observed runoff was 0.21 in., or 17.95 percent of the observed mean. The coefficient of variation of the prediction residuals was 134.7 percent. The mean absolute difference between the predicted and observed peak discharge was 17.36 ft^3/s and the coefficient of variation of the prediction residuals was 176.1 percent.

The summary for Helton Branch (table 11) shows the mean absolute difference between the predicted and observed runoff was 0.26 in. or 20.80 percent of the observed mean and the coefficient of variation of the prediction residuals was 153.8 percent. The model predicted peak discharges with a mean absolute prediction residual of 20.16 ft^3/s and a coefficient of variation of the prediction residuals of 174.4 percent.

Table 11.--Summary of unit computations for Helton Branch, 1956-58 data

Storm	Predicted volume (inches)	Outflow, in inches		Peak, in cubic feet per second	
		Routed	Observed	Predicted	Observed
2	0.47	0.46	0.95	22.67	104.00
3	3.64	3.64	4.18	207.70	136.00
4	.86	.87	.94	16.22	19.80
5	.02	.01	.03	.40	.81
7	.03	.02	.03	.72	2.00
8	2.94	2.96	1.95	74.86	54.00
9	.62	.60	.66	19.83	26.00
10	.36	.35	.52	10.67	20.50
11	1.60	1.60	1.70	30.91	36.00
12	1.32	1.32	1.53	18.53	19.90
Total	11.86		12.49		
Mean	1.19	1.18	1.25	40.25	41.90

Storm volume error summary

	Sum of absolute differences between observed and predicted values		Sum of squares of differences between observed and predicted values	
	Non log	Log	Non log	Log
Sum	2.62	2.69	1.60	1.13
Mean	.26	.27	.16	.11
Percent	20.80		32.05	

Storm peak error summary

	Sum of absolute differences between observed and predicted values		Sum of squares of differences between observed and predicted values	
	Non log	Log	Non log	Log
Sum	201.82	5.35	12,367.43	4.72
Mean	20.16	.54	1,236.74	.47
Percent	48.12		83.93	

Statistical analysis of natural logarithms of observed and predicted values also are listed in tables 10 and 11. In table 10 the sum of absolute difference of the logs of the volumes was 7.92 and the sum of square residuals was 8.99. The use of log or non-log values will be discussed later.

With the exception of storm 4 for Cane Branch (fig. 6) the observed and predicted plots tend to parallel each other. Some of the storms (figs. 7 and 8) appear to have a slight time discrepancy between the observed unit rainfall and discharge, or possibly the storm was not well represented in the basin by the rain gage used. Storm 4 at Cane Branch may fall into this category because rain gage 2 (table 6) had about one-third more rainfall than rain gage 1, although most of the problem here is probably due to timing and parameter definition.

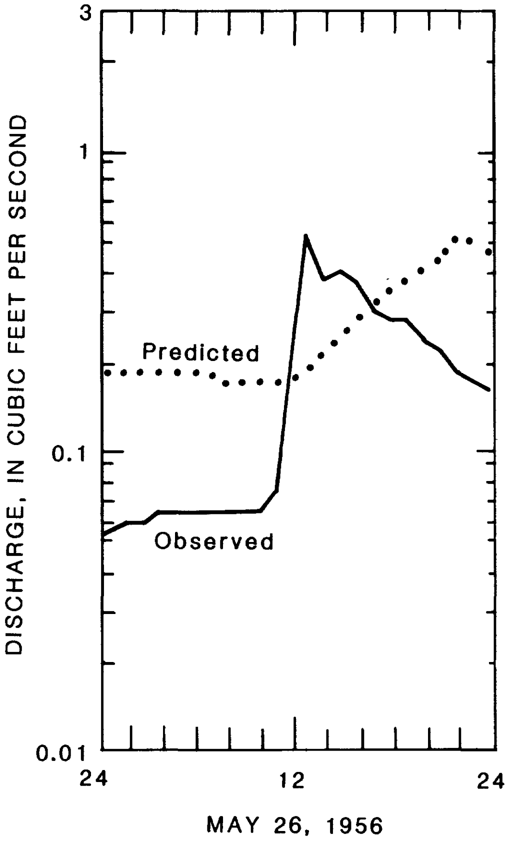

Figure 6.--Storm 4 for Cane Branch.

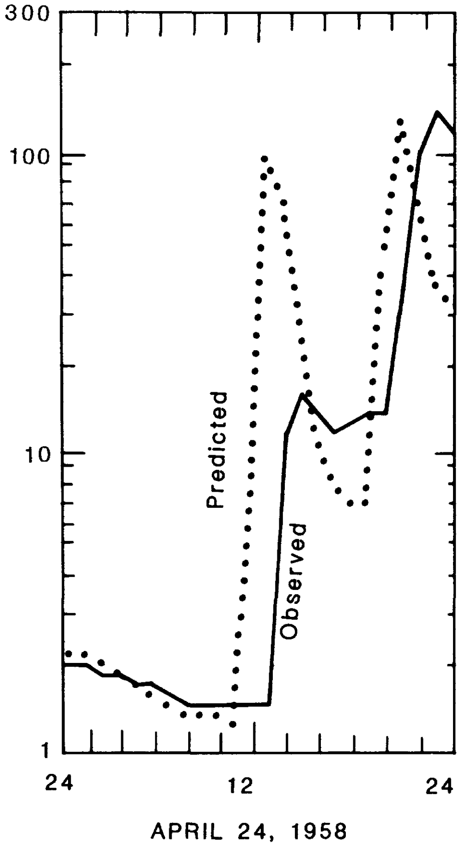

Figure 7.--Storm 15 for Cane Branch.

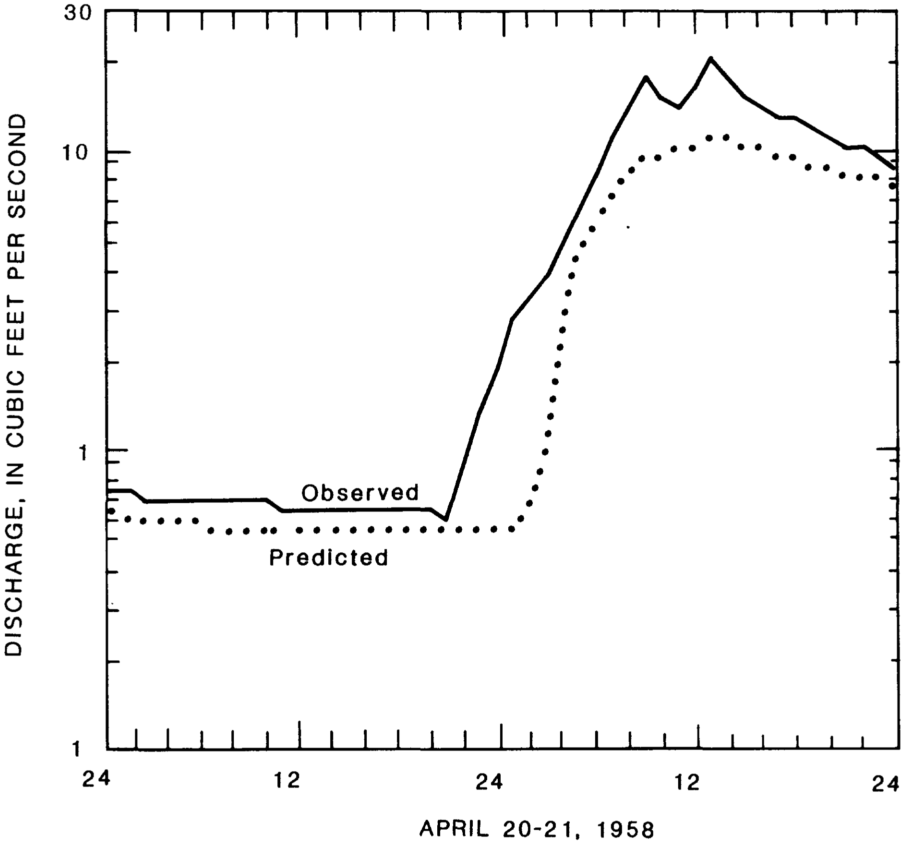

Figure 8.--Storm 10 for Helton Branch.

Verification of Model

As mentioned previously, addition of data and changes in modeling algorithms made it desirable to refit the model to the Helton Branch data (Feb. 16, 1956 to Sept. 30, 1958) at the beginning of step 2 and before verification. This was done by using one of the optimizing procedures (Rosenbrock, 1960) available in the model with fitting slanted toward volume of runoff rather than peak discharge in the unit mode. The results from this refitting (table 12) and those from the fit in step 1 (table 9) are very close.

Table 12.--Model results for predicting monthly runoff (inches) from Helton Branch basin for 1956-58 data during refitting, step 2

[Standard deviation is standard deviation of observed minus predicted daily runoff]

	1956			1957			1958		
Month	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation
October	--	--	--	0.16	0.10	0.10	0.35	0.37	0.14
November	--	--	--	.19	.06	.10	2.79	4.25	2.98
December	--	--	--	2.47	3.77	2.46	3.11	3.44	.54
January	--	--	--	8.00	8.05	2.00	1.57	1.84	.73
February	[1]5.20	[1]4.71	[1]2.59	3.88	4.30	.76	2.11	1.97	.62
March	4.59	4.17	2.71	2.08	2.67	.67	2.40	1.86	.63
April	3.04	2.88	1.85	2.13	2.37	.62	5.78	4.80	1.22
May	.52	.81	.26	.46	.83	.28	3.31	3.31	.56
June	.22	.46	.20	.46	.55	.14	.36	.76	.33
July	.43	.44	.17	.30	.49	.17	.33	.47	.14
August	.26	.32	.10	.18	.24	.00	.26	.28	.00
September	.13	.16	.00	.38	1.46	1.53	.28	.52	.45
Annual total	[1]14.39	[1]13.95	[1]1.51	20.69	24.89	1.08	22.65	23.87	1.02
Overall total	--	--	--	--	--	--	57.73	62.71	1.18

[1] Partial record for month or year.

Following refitting, verification was done by using the model to predict runoff for the entire period (Feb. 16, 1956 to Sept. 30, 1966) of record of 3,880 days and comparing the predicted runoff with the observed runoff. Table 13 shows that the model predicted 98.6 percent (181.08 of 183.68 in.) of the observed runoff for the 10.6 years of record. The overall standard deviation of the runoff prediction residuals was 1.00 in. Although the data used for model fitting were included in the verification procedure, it probably did not significantly affect the predicted runoff because its length is short compared to the entire period of record.

Discrepancies in Modeling Procedure

The annual mean daily discharge for the period of record at Helton Branch, along with the annual standard deviation of the mean daily discharge, and the percentage of the annual mean discharge represented by the standard deviation (SD/Qm) is shown in table 14. While the standard deviation tends to increase with the mean daily discharge, a plot of the mean daily discharge against percentage of error shows the error to be inversely proportional to the mean daily discharge (fig. 9), and any given error of estimation of discharge would have a greater significance on a smaller value than a large one. Therefore it is important to note that the runoff in the two basins in this study is very small and, in many cases, the model prediction is to a greater degree of refinement than the input (observed) data.

Table 13.—Model results for monthly runoff (inches) and standard deviation of observed minus predicted daily runoff for Helton Branch for 1956-66, step 2

[OBS, observed; PRE, predicted; SD, standard deviation of observed minus predicted daily runoff]

Year	Description	October	November	December	January	February	March	April	May	June	July	August	September	Annual
1956	OBS	-	-	-	-	5.20	4.59	3.04	0.52	0.22	0.43	0.26	0.13	14.40
	PRE	-	-	-	-	4.71	4.17	2.88	.81	.46	.44	.32	.16	13.94
	SD	-	-	-	-	2.58	2.70	1.85	.26	.20	.17	.10	.00	1.51
1957	OBS	0.16	0.19	2.47	8.00	3.88	2.08	2.13	.46	.46	.30	.18	.38	20.69
	PRE	.10	.06	3.77	8.05	4.30	2.67	2.37	.83	.55	.49	.24	1.46	24.88
	SD	.10	.10	2.46	1.99	.76	.67	.62	.28	.14	.17	.00	1.53	1.08
1958	OBS	.35	2.79	3.11	1.57	2.11	2.40	5.78	3.31	.36	.33	.26	.28	22.65
	PRE	.37	4.26	3.44	1.84	1.97	1.86	4.80	3.31	.76	.47	.28	.52	23.88
	SD	.14	2.98	.54	.73	.62	.63	1.22	.56	.33	.14	.00	.45	1.02
1959	OBS	.27	.40	.35	1.42	1.85	1.34	2.17	.59	1.64	.27	.26	.32	10.99
	PRE	.27	.13	.86	2.26	2.05	1.22	1.30	.46	1.49	.30	.18	.22	10.73
	SD	.00	.30	.61	.89	.47	.32	1.30	.17	1.80	.00	.10	.39	.75
1960	OBS	.41	1.13	3.77	1.82	3.42	4.03	1.44	1.47	2.54	2.17	.29	.26	22.76
	PRE	.06	1.48	4.12	2.06	2.57	3.30	1.47	.94	2.86	2.03	.49	.27	21.65
	SD	.28	.94	.59	.35	1.70	1.13	.35	1.56	2.34	1.66	.17	.10	1.17
1961	OBS	.38	.64	1.22	1.99	2.74	4.48	3.14	1.71	.63	.42	.25	.25	17.83
	PRE	.17	.14	1.38	1.99	1.96	3.51	2.39	1.38	.47	.93	.30	.15	14.76
	SD	.17	.56	.39	1.74	1.48	1.66	.97	.94	.40	1.03	.04	.09	.98
1962	OBS	.23	.28	2.01	3.91	6.13	4.33	4.95	.63	1.34	.27	.20	.21	24.48
	PRE	.08	.05	1.65	3.23	5.31	4.25	5.71	1.17	1.16	.59	.32	.22	23.74
	SD	.10	.17	1.37	1.30	2.48	1.25	.70	.44	.84	.24	.10	.00	1.01
1963	OBS	.27	.61	.87	1.07	1.89	7.57	.49	.62	.45	.33	.26	.23	14.64
	PRE	.34	1.15	1.21	1.00	1.51	6.97	.88	.52	.31	.20	.12	.07	14.27
	SD	.17	.76	.82	.24	.82	1.79	.32	.45	.17	.14	.10	.10	.69
1964	OBS	.19	.22	.17	1.09	1.57	3.24	1.86	.32	.19	.18	.29	.36	9.67
	PRE	.04	.03	.02	2.88	1.60	2.76	1.32	.49	.28	.18	.27	1.05	10.92
	SD	.10	.14	.14	2.16	.37	.94	.74	.14	.10	.00	.39	2.42	1.01
1965	OBS	.52	.70	2.58	2.98	1.83	5.51	1.91	.42	.44	.34	.23	.22	17.67
	PRE	1.28	.23	1.68	2.39	1.56	4.58	1.31	.55	.32	.65	.19	.09	14.83
	SD	1.16	.61	1.35	1.79	.86	1.94	.73	.17	.26	1.07	.00	.10	1.05
1966	OBS	.24	.24	.19	.28	1.38	1.17	1.69	1.39	.23	.23	.42	.43	7.90
	PRE	.05	.03	.02	.39	2.37	1.47	.57	1.00	.25	.15	.39	.78	7.48
	SD	.14	.17	.14	.24	1.40	.62	1.84	.74	.10	.10	.26	.74	.76
	OBS													183.68
	PRE													181.08
	SD[1]	0.24	0.72	0.84	1.14	1.10	1.10	0.88	0.59	0.65	0.45	0.11	0.59	1.00

[1] Data for 1956 omitted from monthly values of standard deviation.

There are several additional sources of error in the model predictions. First, the fit of the model is not so good as to claim the least possible error. Second, the possibility of bad data exists. For example, storm 2 (fig. 10), produces an extremely poor fit of the data but most storms, such as storm 11 (fig. 11), produce hydrographs corresponding reasonably close to the observed data. Third, even though rainfall and discharge normally are not stored to more than two decimal places, the model interprets and computes values to more refinement (table 15) which are then compared to the observed data. For these reasons, the actual predicted error may be smaller than indicated.

Table 14.--Annual results of discharge computations for years 1956-66, Helton Branch

Year		Mean daily discharge (ft^3/s)	Standard deviation	Percent from mean
1956		1.44	1.51	104.86
1957		1.29	1.08	83.72
1958		1.41	1.02	72.34
1959		.68	.75	110.29
1960		1.42	1.17	82.39
1961		1.11	.98	88.29
1962		1.53	1.01	66.01
1963		.91	.69	75.82
1964		.60	1.01	168.33
1965		1.10	1.05	95.45
1966		.49	.76	155.10
	Mean	1.09	1.00	--
	SD/Qm	--	--	91.74

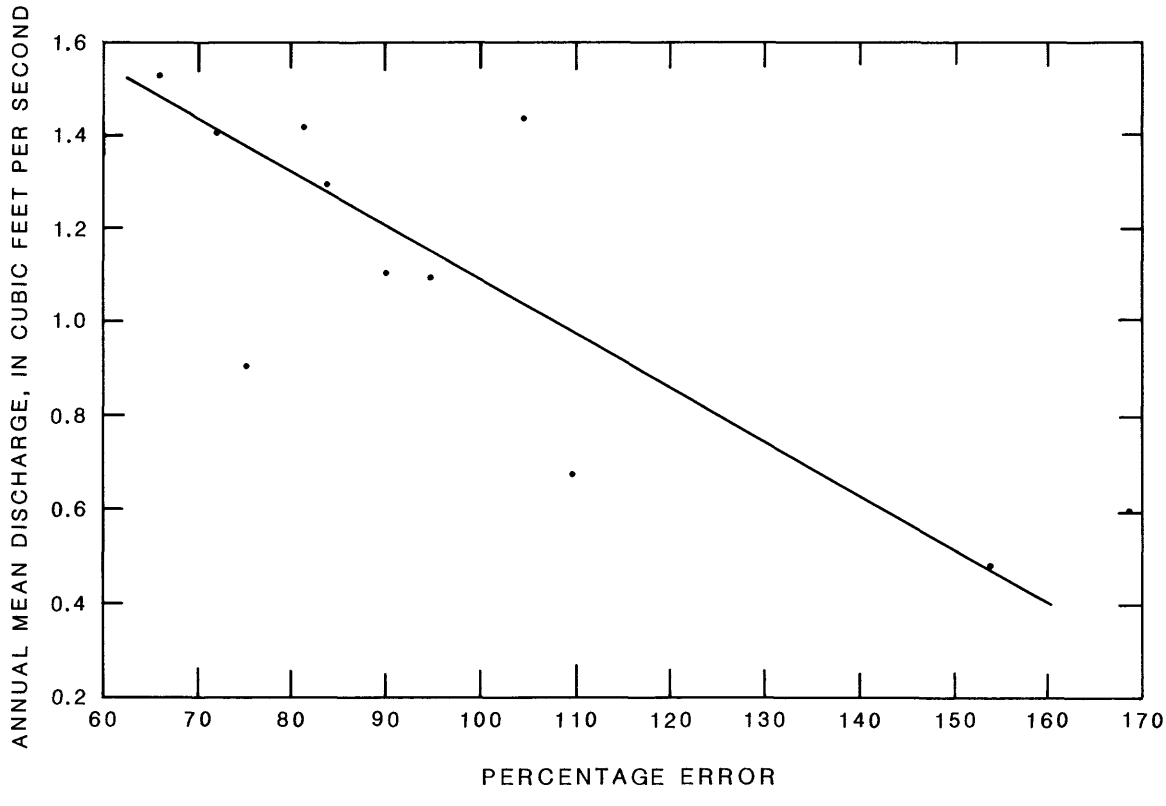

Figure 9.--Annual mean discharge versus percentage error for Helton Branch.

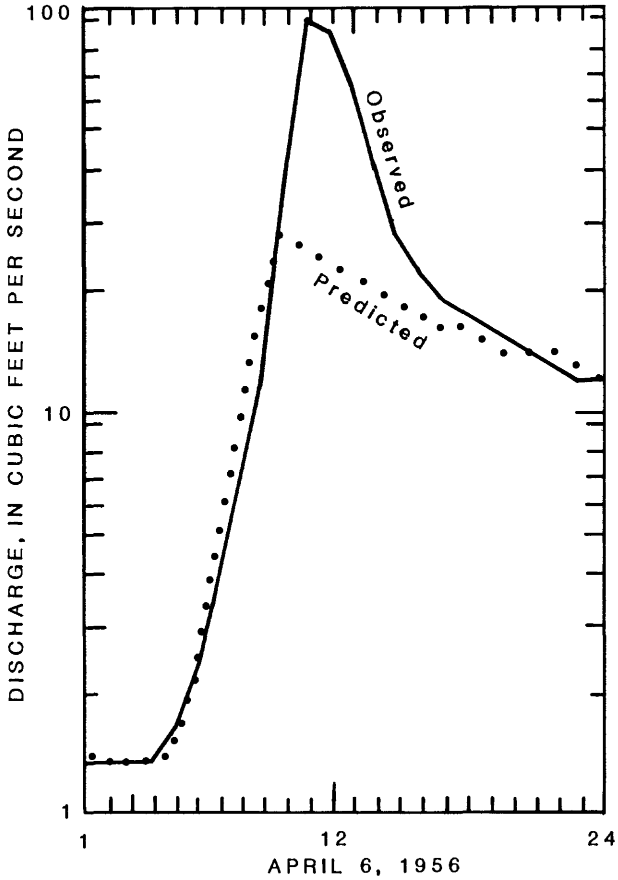

Figure 10.--Storm 2 for Helton Branch.

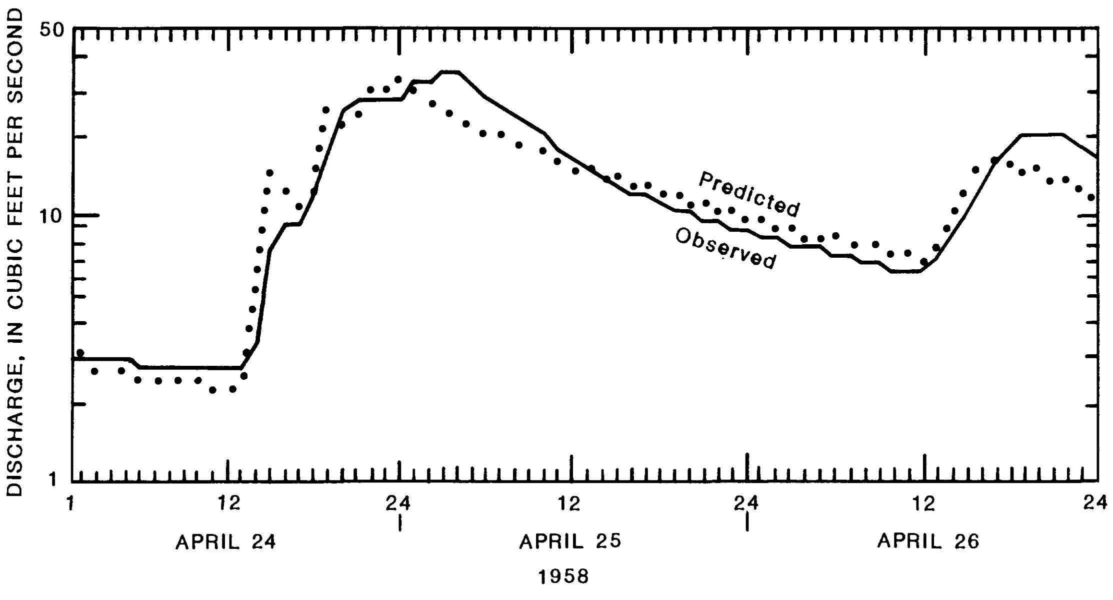

Figure 11.--Storm 11 for Helton Branch.

Table 15.--Summary statistics for Helton Branch for 1966

Month	Mean runoff, in cubic feet per second		Total runoff, in cubic feet per second-days	
	Observed	Predicted	Observed	Predicted
October	0.176	0.039	5.470	1.215
November	.181	.025	5.430	.751
December	.141	.014	4.360	.437
January	.207	.284	6.420	8.812
February	1.124	1.926	31.460	53.927
March	.863	1.078	26.750	33.419
April	1.286	.435	38.590	13.048
May	1.021	.737	31.650	22.850
June	.173	.189	5.190	5.659
July	.170	.112	5.280	3.479
August	.307	.285	9.520	8.838
September	.327	.595	9.810	17.848
Mean	0.498	0.476	--	--
Total	--	--	179.930	170.283

Unit Mode Computations

The results of unit mode computations for the 50 storms selected for Helton Branch are listed in table 16. Calibration and fitting was done with the first 12 storms and the model predicted 93.9 percent (15.00 of 15.98 in.) of the observed runoff during the 24 days of the 12 storms (15.98 in. calculated from first 12 storms in table 16).

Table 16 shows that for the 50 storms, the model predicted 89.0 percent (33.60 of 37.76 in.) of the observed runoff. The mean absolute difference of observed minus predicted runoff was 0.20 in. and the coefficient of variation of the prediction residuals was 165.8 percent. The mean absolute difference of observed minus predicted discharge 15.54 ft^3/s and coefficient of variation of the prediction residuals was 169.7 percent.

Transfer of Parameter Values from Helton Branch to Cane Branch

Parameters

Parameter values and input data, except those unique to Cane Branch, such as drainage area, slope, and observed rainfall data were transferred from Helton Branch to Cane Branch. For this test, Cane Branch was assumed homogeneous (same as Helton Branch) and to represent the era prior to any mining activity. All HRU's, subsurface reservoirs, and so forth, were assigned the same parameter values used for Helton Branch. Runoff for the entire period of record was simulated and compared with the observed discharge.

Table 16.--Model results for unit storms for Helton Branch

Storm	Predicted volume (inches)	Outflow, in inches		Peak, in cubic feet per second	
		Routed	Observed	Predicted	Observed
1	2.39	2.41	3.47	105.23	136.00
2	.56	.55	.95	27.26	104.00
3	3.78	3.79	4.18	179.75	136.00
4	.85	.87	.94	17.27	19.80
5	.03	.03	.03	.62	.81
6	.03	.03	.02	2.24	1.08
7	.04	.04	.03	1.93	2.00
8	3.03	3.05	1.95	65.69	54.00
9	.75	.73	.66	24.37	26.00
10	.44	.43	.52	13.33	20.50
11	1.68	1.69	1.70	37.49	36.00
12	1.42	1.42	1.53	20.70	19.90
13	.01	.01	.01	.27	.47
14	.11	.11	.49	9.38	18.20
15	.10	.10	.08	11.86	6.30
16	.05	.05	.04	1.34	.61
17	.03	.03	.03	2.07	1.16
18	.13	.13	.04	34.78	2.90
19	1.74	1.75	1.74	41.37	54.00
20	.13	.13	.45	15.16	34.00
21	.63	.62	.37	42.15	18.20
22	.37	.36	.76	31.60	65.00
23	.13	.13	.26	21.25	16.00
24	.22	.21	.45	8.15	15.50
25	.02	.02	.02	1.54	1.25
26	.27	.26	.09	7.78	3.50
27	.09	.08	.21	2.24	6.90
28	3.44	3.47	4.37	87.10	186.00
29	1.36	1.37	1.33	33.45	30.50
30	1.46	1.46	1.33	34.63	40.00
31	.04	.04	.03	2.79	1.50
32	.07	.07	.04	6.19	3.00
33	.70	.69	1.56	24.88	68.00
34	2.09	2.10	2.50	79.09	134.00
35	1.25	1.24	1.32	29.02	38.00
36	.05	.05	.07	.80	10.10
37	.30	.29	.44	11.65	20.70
38	.01	.01	.01	.20	.30
39	.13	.12	.03	33.98	5.00
40	.04	.02	.04	4.74	7.70
41	.61	.59	.15	28.65	6.40
42	.60	.59	.52	11.97	10.60
43	.93	.92	1.28	23.79	39.20
44	.84	.83	1.14	31.74	44.40
45	.35	.35	.09	79.26	9.00
46	.05	.04	.29	2.95	25.60
47	.04	.03	.06	4.88	18.00
48	.06	.05	.02	7.69	3.36
49	.02	.01	.05	.83	5.60
50	.13	.12	.07	5.64	9.75
Total	33.60		37.76		
Mean	.67		.76	25.45	30.34

Storm volume error summary

	Sum of absolute differences between observed and predicted values		Sum of squares of differences between observed and predicted values	
	Non log	Log	Non log	Log
Sum	10.07	25.56	5.66	24.26
Mean	.20	.51	.11	.49
Percent	26.32		43.92	

Storm peak error summary

	Sum of absolute differences between observed and predicted values		Sum of squares of differences between observed and predicted values	
	Non log	Log	Non log	Log
Sum	776.76	36.66	34,780.05	47.53
Mean	15.54	.73	695.60	.95
Percent	51.21		86.94	

Daily Mode Computations

The model, using the transferred values, predicted very closely the runoff observed for the entire period of record at Cane Branch. Table 17 shows that the model predicted 102.6 percent (192.26 of 187.32 in.) of the observed runoff. The overall standard deviation of the prediction residuals was 1.28 in.

Table 17.--Model results for monthly runoff (inches) and standard deviation of observed minus predicted daily runoff for Cane Branch for 1956-66, step 3

[OBS, Observed; PRE, Predicted; SD, Standard deviation of observed minus predicted daily discharge]

Year	Description	October	November	December	January	February	March	April	May	June	July	August	September	Annual
1956	OBS	--	--	--	--	4.97	5.05	3.63	0.40	0.22	0.45	0.24	0.08	15.04
	PRE	--	--	--	--	3.89	4.30	3.14	.78	.45	.52	.46	.16	13.70
	SD	--	--	--	--	3.13	1.81	1.92	.24	.24	.26	.20	.00	--
1957	OBS	0.13	0.09	2.69	8.98	3.56	2.14	2.48	.44	.47	.12	.05	.35	21.50
	PRE	.10	.08	4.56	8.16	3.88	2.66	2.51	.79	.50	.28	.16	1.21	24.89
	SD	.00	.00	2.15	5.64	.53	.40	.95	.37	.20	.10	.00	1.16	1.82
1958	OBS	.25	3.10	2.83	1.54	2.13	2.48	6.83	3.06	.19	.27	.12	.20	23.01
	PRE	.34	3.97	3.34	1.82	2.00	2.04	4.80	3.03	.82	.58	.31	.65	23.72
	SD	.17	1.83	1.10	12.22	1.00	.54	2.68	1.55	.39	.24	.14	.48	1.16
1959	OBS	.17	.44	.34	1.48	2.08	1.53	2.49	.43	.31	.54	.34	.27	10.41
	PRE	.28	.24	1.15	2.60	2.04	1.31	1.33	.45	.29	.82	.38	.28	11.19
	SD	.10	.35	.62	.95	.24	.20	1.20	.14	.14	.49	.14	.10	.53
1960	OBS	.41	1.49	4.13	2.05	3.90	4.16	1.27	2.03	2.99	2.89	.25	.20	25.77
	PRE	.21	1.97	3.52	2.09	2.80	3.36	2.21	1.31	3.36	1.94	.47	.29	23.53
	SD	.30	.95	2.30	.28	1.54	2.26	.77	2.64	1.73	3.82	.17	.14	1.81
1961	OBS	.26	.36	.93	1.56	3.14	5.04	3.41	1.81	.65	.56	.17	.14	18.04
	PRE	.18	.12	1.15	1.94	2.10	4.04	2.83	1.41	.77	1.40	.30	.15	16.38
	SD	.10	.46	.32	.82	1.65	2.07	.65	1.52	.45	1.05	.10	.00	1.00
1962	OBS	.19	.23	1.89	4.18	7.30	4.72	5.83	.46	.41	.20	.17	.13	25.78
	PRE	.11	.12	2.30	3.37	5.12	4.07	5.61	1.13	.69	.41	.26	.13	23.41
	SD	.10	.10	1.42	1.30	4.47	2.07	2.18	.44	.26	.14	.14	.24	1.62
1963	OBS	.23	.60	.67	.75	1.56	8.27	.37	1.03	.32	.41	.34	.16	14.71
	PRE	.22	1.68	1.19	1.53	2.01	7.07	.96	.94	.55	.32	.39	.12	16.97
	SD	.22	1.29	7.76	8.42	.78	4.65	.41	.92	.20	.20	.14	.10	1.48
1964	OBS	.13	.20	.17	1.30	1.81	3.51	2.16	.41	.21	.13	.16	.34	10.54
	PRE	.07	.05	.14	3.26	2.13	2.86	1.09	.52	.28	.17	.12	.98	11.68
	SD	.00	.10	.10	1.32	.45	.82	.87	.10	.00	.00	.14	1.64	.71
1965	OBS	.28	.44	1.92	2.71	1.88	5.51	1.78	.40	.39	.33	.08	.10	15.83
	PRE	1.52	.50	1.83	2.63	1.91	4.86	1.40	.67	.53	.79	.26	.16	17.04
	SD	1.21	.30	1.06	1.40	.62	2.33	.48	.26	.40	.57	.10	.10	.97
1966	OBS	.09	.14	.11	.16	.94	1.18	1.68	1.21	.18	.16	.33	.50	6.69
	PRE	.08	.08	.04	.32	2.78	1.62	.84	1.11	.33	.27	1.02	1.26	9.75
	SD	.00	.10	.66	.17	1.60	.86	1.39	.48	.17	.17	.80	.62	.73
	OBS													187.32
	PRE													192.26
	SD[1]	0.22	0.55	1.75	3.25	1.29	1.62	1.16	0.84	0.39	0.68	0.19	0.44	1.28

[1] Data for 1956 omitted from monthly values of standard deviation.

Computations for the 1956-58 data (table 18) using transferred values, were compared with the computations for the same period of data (table 8) which did not use transferred values. The model using transferred values, predicted

104.6 percent (62.29 of 55.52 in.) of the observed runoff and the standard deviation of the prediction residuals was 1.51 in. The fitted model, without transferred values predicted 97.5 percent (58.03 of 59.52 in.) of the observed runoff and the standard deviation of the prediction residuals was 0.87 in.

Table 18.--Model results for predicting monthly runoff (inches) from Cane Branch basin for 1956-58 data, step 3

[Standard deviation is standard deviation of observed minus predicted daily runoff]

	1956			1957			1958		
Month	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation	Observed	Predicted	Standard deviation
October	--	--	--	0.13	0.10	0.00	0.25	0.34	0.17
November	--	--	--	.09	.08	.00	3.10	3.97	1.83
December	--	--	--	2.69	4.56	2.15	2.83	3.34	1.10
January	--	--	--	8.98	8.16	5.64	1.54	1.82	12.22
February	[1]4.97	[1]3.89	[1]3.13	3.56	3.88	.53	2.13	2.00	1.00
March	5.05	4.30	1.81	2.14	2.66	.40	2.48	2.04	.54
April	3.63	3.14	1.92	2.49	2.51	.95	6.83	4.80	2.68
May	.40	.78	.24	.44	.79	.37	3.06	3.03	1.55
June	.22	.45	.24	.47	.50	.20	.16	.82	.39
July	.45	.52	.26	.12	.28	.10	.27	.58	.22
August	.24	.46	.20	.05	.16	.00	.12	.31	.14
September	.08	.16	.00	.35	1.21	1.06	.20	.65	.48
Annual total	[1]15.04	[1]13.70	[1]1.47	21.51	24.89	1.82	22.97	23.70	1.16
Overall total	--	--	--	--	--	--	59.52	62.29	1.51

[1] Partial record for month or year.

Unit Mode Computations

Table 19 summarizes the unit computations for the 60 storms (92 days) at Cane Branch using parameter values transferred from Helton Branch. The model predicted 70.94 percent (32.13 of 45.29 in.) of the observed runoff. The mean absolute difference of the observed minus predicted runoff was 0.31 and the coefficient of variation of the prediction residuals was 158.0 percent. The mean absolute difference of the observed minus predicted discharge was 24.93 and the coefficient of variation of the prediction residuals was 149.3 percent.

Computations for the first 15 storms, using transferred values, in table 19 was compared to the computations for the same 15 storms (table 10) which did not use transferred values. Addition of observed and predicted values for the first 15 storms in table 19 show that 75.0 percent (14.30 of 19.08 in.) of the observed runoff was predicted. This compares to 98.2 percent (17.31 of 17.62 in.) for the 15 storms in table 10. The peaks, using transferred values, had a mean absolute difference of observed minus predicted discharge of 52.08 ft^3/s and a coefficient of variation of the prediction residuals of 136.1 percent. This compares to a mean absolute difference of observed minus predicted discharge of 17.36 ft^3/s (table 10) and a coefficient of variation of the prediction residuals of 176.1 percent.

Table 19.--Model results for unit storms for Cane Branch

Storm	Predicted volume (inches)	Outflow, in inches		Peak, in cubic feet per second	
		Routed	Observed	Predicted	Observed
1	1.64	1.60	2.82	30.30	83.80
2	.99	.94	1.52	24.53	75.00
3	.69	.63	1.17	26.42	97.80
4	.02	.02	.01	.38	.61
5	.03	.03	.01	.33	.64
6	.02	.02	.02	.34	1.46
7	.02	.02	.02	.51	2.80
8	.03	.02	.05	.99	7.00
9	1.04	.98	.93	30.10	61.00
10	.85	.80	1.07	20.75	73.00
11	3.85	3.71	5.51	103.43	198.00
12	.41	.36	.58	13.94	30.50
13	2.76	2.69	2.48	42.18	96.00
14	.51	.47	.73	13.88	36.20
15	1.44	1.39	2.16	37.56	154.00
16	.04	.03	.05	1.89	10.30
17	.06	.21	.09	36.48	19.80
18	.16	.12	.16	17.24	30.00
19	.10	.08	.11	7.91	16.50
20	.14	.12	.12	14.07	25.00
21	.07	.01	.06	3.05	13.00
22	.62	.58	.40	10.80	9.90
23	.55	.48	1.15	15.45	35.00
24	.36	.31	.56	15.38	36.30
25	.18	.14	.95	6.33	60.00
26	.65	.57	.56	18.60	43.00
27	.62	.57	.89	18.80	62.00
28	.26	.22	1.39	12.65	71.00
29	.02	.02	.04	.22	2.75
30	.08	.06	.10	1.69	4.95
31	.28	.23	.56	13.55	28.60
32	.24	.20	.33	5.68	9.60
33	.42	.39	.60	6.99	14.60
34	.34	.31	.48	5.43	15.30
35	.21	.18	.66	.65	17.80
36	.03	.02	.05	.73	19.00
37	.39	.33	.22	8.55	22.40
38	.46	.42	.28	9.63	8.00
39	3.27	3.20	5.20	58.68	184.00
40	1.34	1.28	1.85	22.82	44.00
41	.95	.90	1.37	24.18	50.00
42	.47	.40	.26	10.74	11.80
43	1.02	.86	2.10	53.00	127.00
44	.75	.72	1.06	19.59	44.70
45	.17	.13	.59	2.79	74.00
46	.02	.01	.05	.43	16.00
47	.11	.10	.10	12.03	29.70
48	.28	.25	.38	8.31	12.20
49	.06	.05	.06	3.81	25.90
50	.59	.49	.26	15.86	27.60
51	.70	.65	.48	9.96	11.90
52	1.02	.96	1.42	18.63	40.10
53	.04	.03	.11	.79	15.10
54	.05	.03	.08	1.87	23.20
55	.05	.03	.15	1.20	15.10
56	.40	.34	.20	48.91	42.00
57	.09	.07	.41	1.64	14.10
58	.04	.02	.18	1.00	16.70
59	.05	.02	.05	1.17	15.30
60	.08	.08	.04	20.38	10.00
Total	32.13		45.29		
Mean	.54		.75	15.34	39.05

Storm volume error summary

	Sum of absolute differences between observed and predicted values Non log	Sum of squares of differences between observed and predicted values Non log
Sum	18.66	14.68
Mean	.31	.24
Percent	41.20	65.52

Storm peak error summary

	Sum of absolute differences between observed and predicted values Non log	Sum of squares of differences between observed and predicted values Non log
Sum	1495.79	83,138.5
Mean	24.93	1,385.6
Percent	63.84	95.32

Time for Model to Reach Stability

The PRMS model adjusts initial parameters by optimization to obtain better agreement between computed and observed runoff. The model can handle 6 years of data in a single run. Because only 10.6 years of data were available, it was decided to overlap the 1961 water year (Oct. 1, 1960 through Sept. 20, 1961) when making two runs to cover the entire period of record. This permitted a comparison between predicted values for the 12 months ending the first run with predicted values for the same 12 months at the beginning of the second run. The same initial parameters were used for each run. Thus, initial parameters that were selected as appropriate to start the first run beginning in February were also used to start the second run beginning in October. This was done as an exercise, and not as an accepted modeling technique, to see how long it would take the model to start duplicating the simulated values of the first run when poor input data were used to start the second run. Table 20 gives the results for monthly variance of standard error for the predicted values. Runs were made for both Cane Branch and Helton Branch in the daily mode with unit computations and flow routing used for the unit (storm) days shown in table 20. Runs were also made in the daily mode only for Helton Branch.

Table 20.--Monthly variance of standard error (observed minus predicted daily mean discharge, in cubic feet per second), 1961 water year

	October	November	December	January	February	March	April	May	June	July	August	September	Annual
						Cane Branch							
Last year of first run	0.01	0.21	0.12	0.68	2.72	4.29	0.42	2.31	0.20	1.11	0.01	0.00	1.00
First year of second run	1.73	.19	.24	.70	2.70	4.27	.41	2.31	.20	1.11	.01	.00	1.15
Days having unit computations.	0	0	1	0	0	3	4	1	0	2	0	0	11
						Helton Branch							
Last year of first run	0.03	0.31	0.15	3.03	2.19	2.75	0.95	0.88	0.16	1.07	0.00	0.01	0.96
First year of second run	2.66	.20	.17	3.02	2.16	2.72	.94	.87	.16	1.07	.00	.01	1.17
Days having unit computations.	0	2	0	0	0	0	1	1	0	3	0	0	7
Last year of first run (daily mode only).	.03	.97	.16	3.03	2.18	2.74	.95	1.32	.16	.62	.00	.01	1.01
First year of second run (daily mode only).	2.66	.84	.18	3.02	2.15	2.72	.94	1.32	.15	.62	.00	.01	1.22

Several observations are obvious from the predicted values in table 20. First, it took 3 to 4 months for the monthly variance of standard error, at the beginning of the second run, to track within 0.02 ft^3/s of those at the end of the first run and about 6 months to track within 0.01 ft^3/s. Second, after 2 months the values for Helton Branch in the daily mode and unit mode were close except for months having unit (storm) days. This indicates that unit computations affect monthly values in which they occur but have little or no lingering effect on subsequent computations. Third, the daily and unit mode values for April for Helton Branch are close even though the month contained one unit day. However, this unit day occurred on the last day of the month and the predicted runoff lagged the observed runoff (fig. 12) by several hours and the unit computation did not affect the April value.

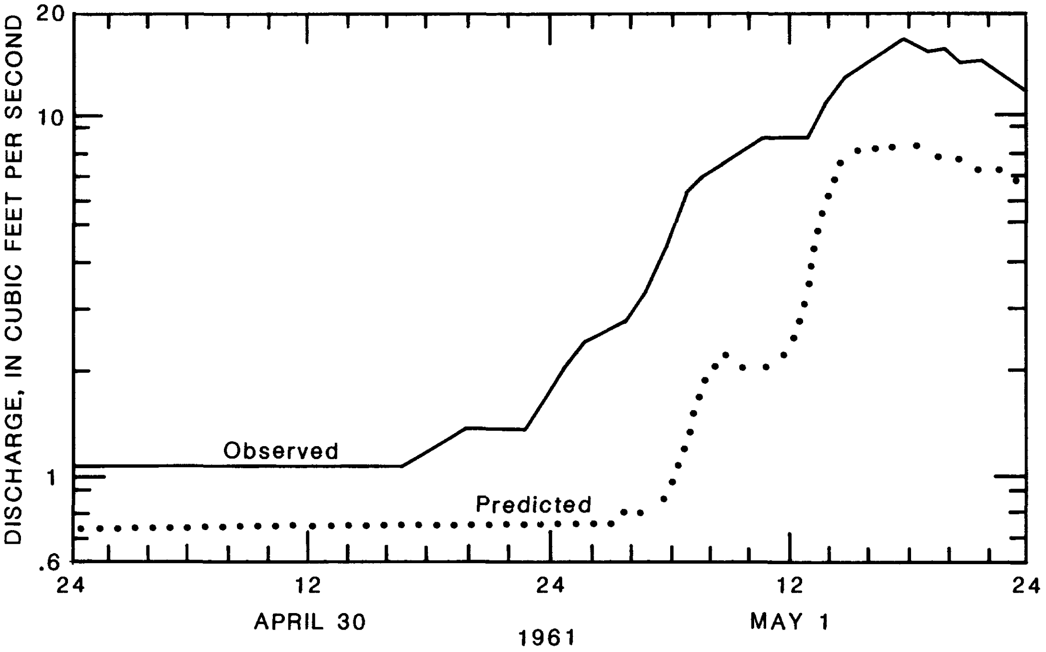

Figure 12.--Storm 24 for Helton Branch.

Optimization and Sensitivity Analysis of Parameter Values

Optimization and sensitivity components in PRMS can be used to adjust model parameters. Three objective functions are used in the optimization routine. These are: (1) absolute difference between observed and predicted runoff and discharge, (2) square of the differences, and (3) square of the differences of the logarithmic values. The user also has the option of computing the objective function using daily runoff volumes, storm volumes, storm peaks, or storm volumes and peaks simultaneously. The same choices are available for the sensitivity analysis. Only one set of choices can be run at a time in either the daily or unit mode.

If a sensitivity analysis is run without log transformation, more weight is given to the larger values, and, if fitting to discharge peaks, to the larger peaks rather than the smaller ones. Log transformation brings the values closer together and distributes the effects more equally. Selection of log or non-log values should be made on the basis of which values are to be given the most weight.

All of the parameters in PRMS are interwoven. If sensitivity analysis is coupled with optimization, the user can assess the magnitude of parameter standard errors and parameter intercorrelations. Should the model be at its best fit, then the values in the sensitivity analysis would indicate the amount of worsening (increased variance) that would occur should the parameter value be changed by the specified amount.

Table 21 shows the changes in predicted variance that would occur if parameter values were changed by a specified amount for Helton Branch. This table is based on non-log values obtained from daily mode computations. When this analysis was done, the model was limited to 1 year of input data. The table shows that the model was insensitive to parameters SRX, SCX, and CTS (table 3). The model was most sensitive to parameter SMAX and a change of 50 percent in this parameter value would cause the variance to increase by 1.003.

Table 21.--Mean-squares runoff-prediction error resulting from parameter error for Helton Branch, 1958 data[1]

	Magnitude of parameter error			
Parameter	5 percent	10 percent	20 percent	50 percent
	Daily mode minus variance = 1.770			
TRNCF	0.000	0.000	0.000	0.000
SMAX	.010	.040	.160	1.003
REMX	.002	.008	.031	.192
SRX[2]	.0	.0	.0	.0
SCX[2]	.0	.0	.0	.0
SCN	.000	.001	.004	.024
SC1	.005	.018	.072	.450
RCF	.000	.000	.000	.003
RCP	.003	.012	.047	.295
SEP	.001	.006	.024	.149
RESMX	.009	.037	.146	.915
REXP	.004	.017	.067	.419
RCB	.000	.000	.001	.004
CTS[2]	.0	.0	.0	.0
BST	.000	.000	.000	.000
CTW	.000	.000	.000	.000

[1] Based on the difference between the observed and predicted values.

[2] Output insensitive to parameter input value.

Table 22 shows the changes in predicted variance that would occur if parameter values were changed by a specified amount for Cane Branch. This table is based on log values obtained from daily and unit mode computations. Although the Cane Branch basin was divided in 7 HRU's (fig. 4) for this study, the sensitivity analysis shown in table 22 was inadvertently run using only 1 HRU. Because this study was an evaluation of the model, table 22 was retained for comparison with other sensitivity runs discussed in the following paragraph. Table 22 shows that the model was insensitive to parameters SCX and CTS and the most sensitive to parameter BST in the daily mode.

Table 22.--Mean-squares runoff-prediction error resulting from parameter error for Cane Branch, 1957-58 data[1]

	Magnitude of parameter error			
Parameter	5 percent	10 percent	20 percent	50 percent
	Daily mode minus variance of logs = 0.03489			
TRNCF	0.00000	0.00000	0.00000	0.00000
SMAX	.00000	.00001	.00006	.00037
REMX	.00000	.00000	.00000	.00000
SRX[2]	.00000	.00000	.00000	.00000
SCX[2]	.0	.0	.0	.0
SCN	.00000	.00000	.00000	.00002
SC1	.00000	.00001	.00005	.00034
RCF	.00001	.00002	.00008	.00050
RCP	.00002	.00007	.00127	.00171
SEP	.00000	.00002	.00008	.00047
RESMX	.00000	.00002	.00207	.00047
REXP	.00000	.00002	.00006	.00040
RCB	.00000	.00001	.00004	.00023
CTS[2]	.0	.0	.0	.0
BST	.00017	.00068	.00272	.01703
CTW	.00000	.00000	.00000	.00002
	Unit mode minus variance of log = 0.81704			
KSAT	0.00000	0.00002	0.00007	0.00044
PSP	.00000	.00001	.00004	.00022
DRN	.00000	.00000	.00000	.00000
RGF	.00000	.00001	.00003	.00020

[1] Based on the difference between the natural log of the observed and predicted values.

[2] Output insensitive to parameter input value.

Additional sensitivity analyses were run for Cane Branch when all the data had been entered in the data base and 7 HRU's were used instead of one. The results from these additional runs are not shown, but they indicated the same relative relations of the parameters shown in table 22. The magnitude of parameter error tended to be somewhat higher and no parameter was completely insensitive. For example, the variance for parameter SMAX at 5 percent changed from 0.00000 (table 22) to 0.00030 and at 50 percent it changed from 0.00037 to 0.03014. The variance for parameter SC1 at 5 percent changed from 0.00000 to 0.00031 and at 50 percent it changed from 0.00034 to 0.03116.

Tables 23 and 24 show parameter intercorrelations and the magnitude of parameter standard errors. Values were obtained from daily and unit mode computations and the input data were the same as used for tables 21 and 22.

The closer the values are to the absolute value of 1 in tables 23 and 24 the greater the intercorrelation is between two parameters. A positive correlation indicates that an increase or decrease in same direction of either parameter would have similar effects on model results. A negative correlation, however, indicates an increase of one parameter would require a decrease in the other parameter to produce similar effects on model results.

The standard error (standard deviation) is a measure of uncertainity that the value of a parameter is correct. Because approximately 95 percent of a population must fall within two standard deviations of the mean in a normal distribution, the standard errors can be used in determining upper and lower confidence limits in fitting parameter values. For example, the correct value for parameter RCB in table 23 has a 95 percent chance of being in the interval 0.2000±0.013 if the joint error is used. If adjusting only one parameter, the individual error could have been used.

Table 23.--Parameter correlation matrix (Cane Branch, 1957-58 data)

Daily mode

Parameter	TRNFC	SMAX	REMX	SRX	SCN	SC1	RCF	RCP	SEP	RESMX	REXP	RCB	BST	CTW
TRNFC	1.000	0.006	0.008	-0.060	-0.002	0.007	-0.049	0.027	-0.024	-0.024	0.003	0.006	0.255	-0.029
SMAX	-----	1.000	.922	.004	-.534	-.296	-.040	.038	.020	.014	-.054	-.019	-.019	-.018
REMX	-----	-----	1.000	.004	-.482	-.288	-.086	.071	.020	.021	-.009	-.047	-.021	-.028
SRX	-----	-----	-----	1.000	-.003	-.001	-.056	.092	-.025	-.024	.018	-.019	-.344	-.023
SCN	-----	-----	-----	-----	1.000	-.624	-.001	.099	-.014	-.015	.089	.093	-.004	.022
SC1	-----	-----	-----	-----	-----	1.000	.033	-.184	-.017	-.016	-.170	-.028	.018	-.021
RCF	-----	-----	-----	-----	-----	-----	1.000	-.806	.142	.138	.128	.176	.084	.327
RCP	-----	-----	-----	-----	-----	-----	-----	1.000	-.167	-.165	.016	-.048	-.095	-.238
SEP	-----	-----	-----	-----	-----	-----	-----	-----	1.000	1.000	-.147	.033	.009	.036
RESMX	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	-.152	.034	.009	.034
REXP	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	-.531	.055	.149
RCB	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	.014	.083
BST	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	.057
CTW	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000
Value used	.4200	6.0000	2.0000	1.0000	.0016	.3000	.2000	.6000	.0500	1.0000	1.0000	.2000	33.800	.1000

Standard error

Joint	.8320	5.1334	23.5107	2.6767	.0068	.2611	.0756	.0996	3.9328	79.3243	.4681	.0065	.9919	.0884
Individual	.7992	1.0787	9.0028	2.5027	.0013	.0560	.0308	.0502	.0079	.1602	.1721	.0045	.8953	.0819

Unit mode

Parameter	KSAT	PSP	DRN	RGF
KSAT	1.000	-0.945	0.193	0.883
PSP	-----	1.000	-.326	-.987
DRN	-----	-----	1.000	.373
RGF	-----	-----	-----	1.000
Value used	.500	.100	1.000	9.500

Standard error

Joint	29.029	23.504	427.74	1620.6
Individual	1.7969	.7789	374.53	77.452

Table 24.--Parameter correlation matrix (Helton Branch, 1958 data)

Daily mode

Parameter	TRNFC	SMAX	REMX	SCN	SC1	RCF	RCP	SEP	RESMX	REXP	RCB	BST	CTW
TRNCF	1.000	0.006	0.049	0.012	-0.015	0.000	0.029	0.005	0.003	-0.010	0.027	0.979	-0.033
SMAX	-----	1.000	.171	-.386	.305	.671	-.133	.004	-.062	-.626	.282	.007	-.006
REMX	-----	-----	1.000	.006	-.028	.260	-.021	.004	-.023	-.261	.158	-.005	-.508
SCN	-----	-----	-----	1.000	-.987	-.190	.396	.042	.56	.216	-.157	.010	.007
SC1	-----	-----	-----	-----	1.000	.136	-.473	-.057	-.063	-.155	.109	-.013	-.009
RCF	-----	-----	-----	-----	-----	1.000	-.437	-.037	-.125	-.845	.187	-.003	-.057
RCP	-----	-----	-----	-----	-----	-----	1.000	.174	.187	.247	.131	.032	.048
SEP	-----	-----	-----	-----	-----	-----	-----	1.000	.995	.010	.028	.005	.002
RESMX	-----	-----	-----	-----	-----	-----	-----	-----	1.000	.102	-.009	.004	.005
REXP	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	-.401	-.006	.044
RCB	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	.032	.175
BST	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000	.032
CTW	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.000
Value used	.39920	4.9900	.5030	.0012	.3150	.0458	.2714	.0878	1.0200	2.5100	.0045	33.800	.1000

Standard error

Joint	10.315	.0506	.0091	.0006	.0345	.0292	.0094	.1246	.5853	.1238	.0005	127.97	.0091
Individual	1.9646	.0313	.0072	.0000	.0029	.0054	.0031	.0014	.0067	.0243	.0004	24.386	.0789

Unit mode

Parameter	KSAT	PSP	DRN	RGF
KSAT	1.000	-0.980	-0.104	0.709
PSP	-----	1.000	.115	-.760
DRN	-----	-----	1.000	-.150
RGF	-----	-----	-----	1.000
Value used	1.00	1.00	1.00	10.00

Standard error

Joint	0.9827	3.8476	54.413	84.467
Individual	.1900	.6856	53.787	52.587

The correct value for parameter DRN in the unit mode for Cane Branch has a 95 percent chance of being in the interval 1.00±855.48. This large joint error emphasizes the poor fit for unit mode computations. It also serves to illustrate that if two standard deviations are substracted from the parameter value a negative value for a parameter may result. A negative value for a parameter may not be physically possible, and if so, the lower confidence limit for a particular parameter value would be less than two standard deviations.

SUSPENDED SEDIMENT

The PRMS model has the capability of computing suspended sediment during the unit storm computation stage. No provision is available however, for computing suspended sediment in the daily mode.

Suspended sediment is computed using five parameters and includes computations involving rainfall intensity, overland flow routing, and transport capacity. If the model were to be modified to allow for daily computations, rainfall intensity and overland flow routing would be unavailable in the daily mode and this would probably reduce the modeling accuracy for daily suspended sediment.

Although sediment predictions were made for the unit mode runs in the latter stages of this study, none of the results are given because the total suspended-sediment load is based on the peak discharge and sediment concentration, neither of which was fitted in this study. A visual observation of the results look good however, and it is believed that a reasonable fitting could be achieved.

CONCLUSIONS

The PRMS model is designed to take into consideration all known factors affecting the mathematical computation of a hydrologic balance of a given area. It is a complex model that can utilize a wide variety of data, some of which may require estimating by the modeler. Nevertheless (as demonstrated) the model works very well with a minimum of actually measured raw data. The basic conclusions of this study are summarized below.

1. A data base, suitable for model evaluations, was established for two basins (one mined and one unmined) in the coal fields of eastern United States, each containing 10.6 years (1956-66) of data. The mined basin contained two rain gages, each of which recorded data for 60 storms (92 unit days). The unmined basin contained one rain gage and recorded data for 50 storms (88 unit days).

2. The fitted model can accurately predict streamflow volumes. In this study, the model predicted 98.6 percent (181.08 of 183.68 in.) of the total observed runoff for the period of record for Helton Branch. The standard deviation of the prediction residuals was 1.00 in. The model predicted 89.0 percent (33.60 of 37.76 in.) of observed runoff and the coefficient of variation of the prediction residuals was 165.8 percent for the 50 storms (88 days) of unit computation. With little to no fitting, the model predicted storm peaks with a mean absolute difference of observed minus predicted discharge of 15.54 ft^3/s and the coefficient of variation of the prediction residuals was 169.7 percent.

3. The insertion of unit storm computations with flow routing can improve the overall predictions during a computation period. In this study, the overall standard deviation of error was reduced from 1.06 to 0.87 ft^3/s by utilizing unit computations with flow routing in a part of the study data. However some of the improvement could also be attributed to better definition of precipitation timing and intensity.

4. It is possible to transfer parameter values selected from one basin to a second similar basin. Using parameter values transferred from Helton Branch, the model predicted 102.6 percent (192.26 of 187.32 in.) of the observed runoff at Cane Branch for the period of record, and the overall standard deviation of the prediction residuals was 1.28 in.

The model predicted 70.94 percent (32.13 of 45.29 in.) of the total observed runoff for the 60 storms (92 unit days) using transferred parameter values and assumed conditions. Peak discharges were predicted with a coefficient of variation of the prediction residuals of 149.3 percent and this was achieved with little fitting to peak discharges in the Helton Branch basin.

Better results probably would have been observed if all HRU's had not been considered homogeneous, and determination of more parameter values for the basin had been used rather than transferring them.

5. Initial fitting of the model should be done using either actual or realistic parameter values. Optimization should be done only to enhance the existing parameter definition to achieve a more realistic response to a known situation. Optimization should be done for values that are possibly in error, and changes should be within reasonable physical limits.

6. The correlation and sensitivity analysis indicate how parameters are interrelated and what effect they have upon the predicted output of the model. Some parameters, in this study were found to be relatively insensitive but those associated with soil moisture were the most sensitive. The sensitivity of parameters is based on a set of parameter values and a data base used; any change in either will change the indicated sensitivity of the parameters.

7. The PRMS model has the capability of computing suspended sediment in the unit mode. Although the peak discharge and sediment concentration were not fitted during this study, sediment concentrations were computed for some of the runs in the unit mode during the latter stages of this study. Visual observation of the results appear good and a reasonable fit could probably be achieved for observed and predicted sediment concentrations.

8. Based on this study, the use of the PRMS model to simulate hydrologic data in coal basins is feasible. More testing will be needed to fully evaluate the model. Soil moisture parameters for Helton Branch were used in model simulations for Cane Branch to predict runoff. These transfer values worked. However, the use of model to predict hydrologic data in basins, where nearly 100 percent transfer of input data may be necessary, remains to be evaluated. How will the distance from Weather Bureau stations affect model simulations if rainfall data are transferred from them to a model site that is to be evaluated? Also, additional work needs to be done in evaluating the model in simulating the effects of land-use changes and in simulating sediment discharge.

REFERENCES

Beck, J. V., and Arnold, K. J., 1977, Parameter estimation in engineering and science: New York, John Wiley and Sons, Inc., 501 p.

Carrigan, P. H., Jr., Dempster, G. R., Jr., and Bower, D. E., 1977, User's guidefor U.S. Geological Survey rainfall-runoff model--revision of Open-File Report 74-33: U.S. Geological Survey Open-File Report 77-884, 273 p.

Collier, C. R., and others, 1964, Influences of strip mining on the hydrologic environment of parts of Beaver Creek basin, Kentucky, 1955-59: U.S. Geological Survey Professional Paper 427-B, 85 p.

Collier, C. R., Pickering, R. J., and Musser, J. J., eds., 1970, Influences of strip mining on the hydrologic environment of parts of Beaver Creek basin, Kentucky, 1955-66: U.S. Geological Survey Professional Paper 427-C, 80 p.

Dawdy, D. R., Lichty, R. W., and Bergman, J. M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geological Survey Professional Paper 506-B, 28 p.

Doyle, W. H., Jr., 1981, The U.S. Geological Survey coal hydrology programs and the potential of hydrologic models for impact assessment: U.S. Geological Survey Open-File Report 81-542, 56 p.

Draper, N. R., and Smith, H., 1966, Applied regression analysis: New York, John Wiley and Sons, Inc., p. 267-270.

Frank, E. C., and Lee, R., 1966, Potential solar beam irradiation on slopes: Fort Collins, Colorado, Rocky Mountain Forest and range experimental station, U.S. Department of Agriculture, Forest Service Research Paper, RM-18, 116 p.

Hutchison, N. E., and others, 1975, National water data storage and retrieval system: U.S. Geological Survey Open-File Report 75-426, v. 6, 453 p..

Leavesley, G. H., Lichty, R. W., Troutman, B. M., and Saindon, L. G., 1981, A precipitation-runoff modeling system for evaluating the hydrologic impact of energy resources development, in Proceedings of Western Snow Conference, 1981, p. 65-76.

Mein, R. G., and Brown, B. M., 1978, Sensitivity of optimized parameters in watershed models: Water Resources Research, v. 14, no. 2, p. 299-303.

Musser, J. J., 1963 (1964), Description of physical environment and of strip-mining operations in parts of Beaver Creek basin, Kentucky: U.S. Geological Survey Professional Paper 427-A, 25 p.

Rosenbrock, H. H., 1960, An automatic method of finding the greatest or least value of a function: Computer Journal, v. 3, p. 175-184.

U.S. Congress, 1977, The surface mining control and reclamation act of 1977, Public Law 95-87, 30 U.S.C. 1201, 95th Congress, First Session.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1955-66, Climatological Data-Kentucky (monthly): Asheville, N. C., National Climatic Center, v. 51-53.