APPLICATION OF A PRECIPITATION-RUNOFF MODELING SYSTEM IN THE BALD MOUNTAIN AREA, AROOSTOOK COUNTY, MAINE

by Richard A. Fontaine

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4221

Prepared in cooperation with the

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION

Augusta, Maine
1989

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CONTENTS

ILLUSTRATIONS

TABLES

TABLES--Continued

CONVERSION FACTORS AND ABBREVIATIONS

For use of readers who prefer to use metric (International System) units, conversion factors for the inch-pound terms used in this report are listed below.

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
acre	4,047	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cfs-days	2,447	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per minute (gal/min)	0.06309	liter per second (L/s)
calorie (cal)	4.186	joule
langley (ly)	4.186	joule per square centimeter
degree Fahrenheit (°F)	C=5/9(°F-32)	degree Celsius (°C)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level".

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ABSTRACT

A massive copper-zinc ore body was discovered on the northwestern slopes of Bald Mountain, Aroostook County, Maine, in 1977. Potential environmental problems associated with extraction of the ore prompted a hydrologic study of the watersheds in the vicinity of the deposit by the U.S. Geological Survey in cooperation with the Maine Department of Environmental Protection. Hydrologic information was collected from June 1979 through June 1984 to describe existing surface-water quality, streamflow characteristics, and meteorologic conditions, and to provide the data necessary for detailed hydrologic studies of the Bald Mountain and Bishop Mountain Brook watersheds. Streamflow and sediment discharge data were collected at four locations, precipitation data at three locations, water-quality data at 14 locations, air temperature and solar radiation data at one location, and snow-survey data at 13 locations.

Water-quality analyses were made of samples collected at 11 stream and 3 lake sites. With the exception of locally elevated iron concentrations all analyses met drinking-water standards established by the Maine Department of Human Services. Specific conductance ranged from 15 to 250 μs/cm (microsiemens per centimeter at 25° Celsius) and averaged 50 μs/cm. Suspended-sediment concentrations during nonstorm periods generally were less than 10 mg/L (milligrams per liter). Of 3,400 analysis of suspended sediment, only 13 water samples had concentrations that exceeded 100 mg/L. The lowest dissolved-oxygen reading was 6.7 mg/L made at a water temperature of 21.0 °C. Values of pH ranged from 5.9 to 7.4.

Water samples were analyzed for seven metals. Total aluminum (as aluminum) ranged from 0 to 1,900 μg/L (micrograms per liter) and averaged 1,080 μg/L. Total iron (as iron) ranged from 5 to 8,300 μg/L and averaged 426 μg/L. The maximum concentrations observed for the five other trace metals were less than 2 μg/L for total cadmium, 6 μg/L for total chromium, 30 μg/L for total lead, 66 μg/L for total copper, and 120 μg/L for total zinc.

Annual runoff averaged 27.8 inches during the study. Precipitation totals ranged from a low of 39.4 inches during the 1982 water year to 44.0 inches during the 1983 water year.

Detailed hydrologic studies of Bald Mountain Brook and Bishop Mountain Brook watersheds were completed with the aid of the U.S. Geological Survey's precipitation-runoff modeling system. The precipitation-runoff model was calibrated and verified in both the Bald Mountain Brook and Bishop Mountain Brook watersheds. Daily discharges predicted by the model compared favorably with observed data in the test watersheds, indicating the utility of the precipitation-runoff modeling system in the study area. The predicted total discharge for the verification period was within 6.5 percent of the observed total discharge in the Bald Mountain Brook watershed and within 3.2 percent of the observed in the Bishop Mountain Brook watershed. Coefficients of determination for the verification period were 0.71 and 0.84 for the Bald Mountain Brook and Bishop Mountain Brook watersheds, respectively. A hypothetical application of the model to simulate basin clear-cutting forestry practices illustrates the model's utility in evaluating development scenarios.

INTRODUCTION

Background

Geologists have known for many years that the two ancient volcanic belts in Maine (shown in figure 1) contain copper, zinc, lead, gold, silver, and ores of other metals. Until 1977, few ore bodies that were economical to mine had been discovered in Maine. This situation changed when a massive copper-zinc ore body was discovered on the northwestern slope of Bald Mountain.

The Bald Mountain deposit, said to be one of the largest ever discovered in the United States, was estimated to contain 36 million tons of ore (Turkel, 1981, p. 1-D). The deposit is more than 800 feet deep and has a projected surface area of about 22 acres. Removal of the ore body by open-pit mining would create a pit 2,800 by 2,200 feet wide and greater than 800 feet deep. Several hundred additional acres of land would be disturbed for construction of ore-processing buildings and for disposal sites for the over-burden deposits and tailings.

Mining is not new to Maine. Granite, limestone, peat, gemstones, and many other minerals have been mined but these operations would be dwarfed in comparison to the proposed Bald Mountain project. The discovery of the Bald Mountain deposit has prompted additional mineral-exploration operations in Maine.

Purpose and Scope

The large-scale extraction and processing of mineral ores proposed for the Bald Mountain deposit could result in a variety of environmental problems. Therefore, the Maine Department of Environmental Protection (MDEP) entered into a cooperative agreement with the U.S. Geological Survey in 1979 to study the hydrology of the Bald Mountain area. The objective of this report is to describe existing surface-water quality, streamflow characteristics, and meteorologic conditions in the watersheds likely to be impacted by mining. The report also describes the calibration and verification of a distributed parameter watershed model and evaluates the utility of the model in northern Maine.

Location of Study Area

Bald Mountain is located in Township 12, Range 8, in Maine. The township is in central Aroostook County, about 20 miles west of the towns of Portage and Ashland. Bald Mountain is located on the watershed divide in the headwaters region of the Fish and Machias River basins. The Fish River flows in a northerly direction from the Bald Mountain watersheds and joins the St. John River in Ft. Kent, Maine. The Machias River flows in an easterly direction from the Bald Mountain watersheds and joins the Aroostook River in Ashland, Maine. Figures 1 and 2 show the location of the Bald Mountain study area.

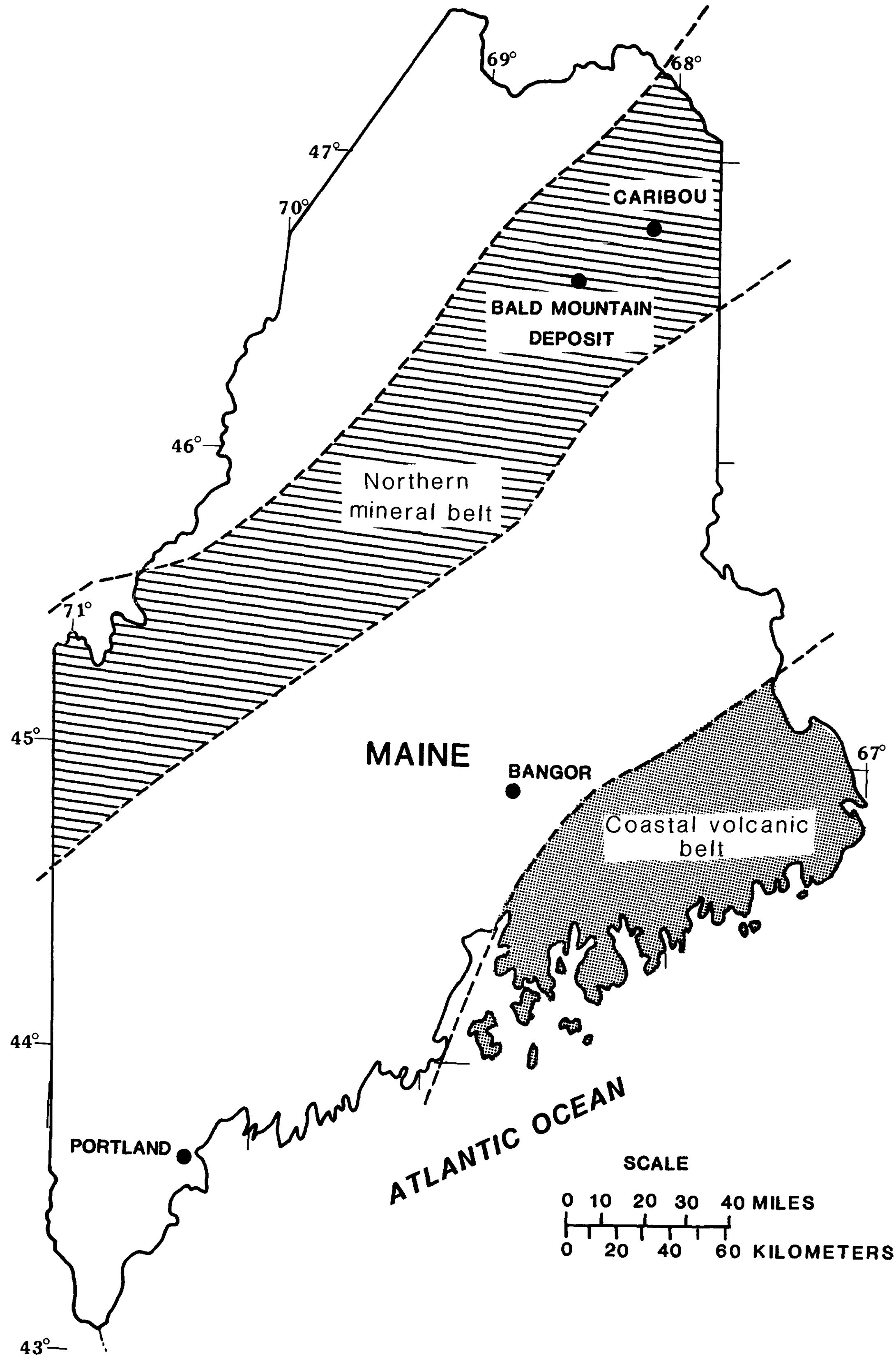

Figure 1.--Maine's volcanic belts and the Bald Mountain deposit. (From Turkel, T., 1981, Maine Sunday Telegram, Jan. 11, 1981, p.1-D).

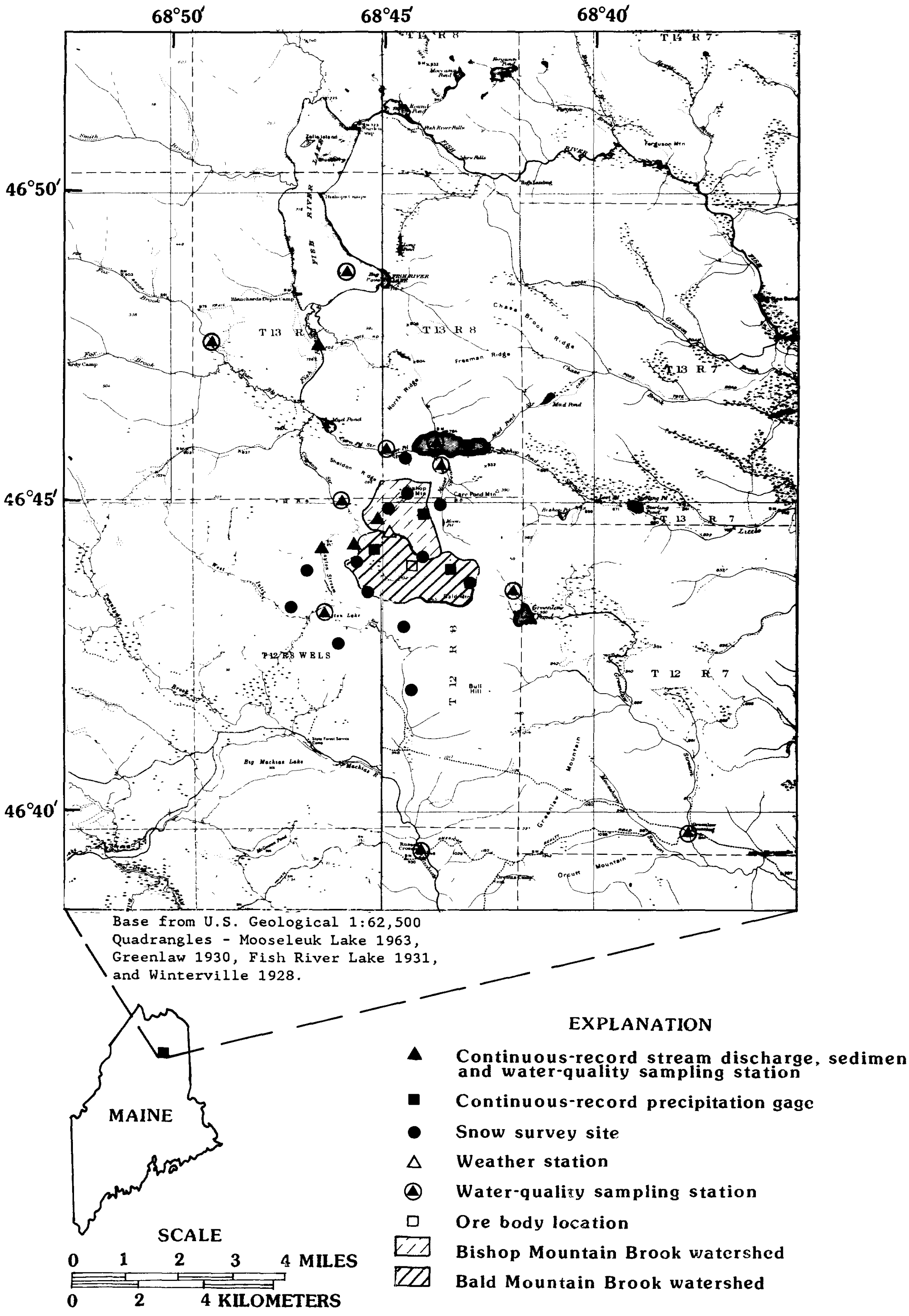

Figure 2.--The modeling study watersheds and data-collection stations.

Surface-Water Hydrology

To evaluate existing hydrologic conditions in the study area, a streamflow, water-quality, and meteorologic data-collection network was established and operated from June 1979 through June 1984. Data collected for the study included streamflow and suspended-sediment data at four locations, precipitation totals at three locations, records of air temperature and solar-radiation, water-quality determinations from surface water samples collected at 14 locations, and miscellaneous readings of snow depths and densities at 13 locations. The data-collection network, data-collection procedures, and collected data are included in a report by Fontaine (1989).

The data collected from 1979 to 1984 are typical of forested areas of northern Maine. Variations in hydrologic measurements throughout the study area were minor. Streamflows measured at the four streamflow-gaging stations ranged from 0.03 $(ft^3/s)/mi^2$ to 118 $(ft^3/s)/mi^2$ (cubic feet per second per square mile). Annual runoff averaged 27.8 in. (inches) during the study. Precipitation was evenly distributed over the study area, with totals ranging from 39.4 in. during the 1982 water year to 44.0 in. during the 1983 water year. Monthly totals ranged from 10.73 in. for July 1981 to 0.49 in. for May 1982. During the winter, as much as 47.7 in. of snow was measured. The maximum measured water-equivalent of the snow pack was 15.2 in.

Water-quality analyses were completed on samples collected at 11 stream and three lake sites. With the exception of locally elevated iron concentrations all water-quality analyses met drinking-water standards established by the Maine Department of Human Services (1983 and 1984). Samples generally contained small concentrations of dissolved solids, as indicated by specific-conductance values ranging from 15 to 250 $\mu s/cm$ (microsiemens per centimeter at 25° celsius) and averaging 50 $\mu s/cm$. Suspended-sediment concentrations during nonstorm periods generally were less than 10 mg/L (milligrams per liter). The maximum suspended-sediment concentration measured during storms was 300 mg/L. Suspended sediment exceeded 100 mg/L in only 13 of the 3,400 samples tested. Alkalinity ranged from 1 to 49 mg/L (as $CaCO_3$) and averaged 15 mg/L. Color values ranged from 5 to 120 platinum-cobalt units, and averaged 48. The lowest dissolved-oxygen reading was 6.7 mg/L measured at a water temperature of 21.0° C (75 percent saturation). Measured pH values ranged from 5.9 to 7.4. Total phosphorus (as phosphorus) averaged 0.012 mg/L, ammonia nitrogen (as nitrogen) averaged 0.003 mg/L, and nitrite plus nitrate nitrogen (as nitrogen) averaged 0.12 mg/L.

Water samples were analyzed for seven metals. Total aluminum (as aluminum) ranged from 0 to 1,900 $\mu g/L$ and averaged 1,080 $\mu g/L$. Total iron (as iron) ranged from 5 to 8,300 $\mu g/L$ and averaged 426 $\mu g/L$. Iron was the only constituent that was higher than the limits recommended by the State, the recommended limit for iron is 300 $\mu g/L$ (Maine Department of Human Services, 1983, 1984). The maximum concentrations observed for the five other trace metals were less than 2 $\mu g/L$ for total cadmium, 6 $\mu g/L$ for total chromium, 30 $\mu g/L$ for total lead, 66 $\mu g/L$ for total copper, and 120 $\mu g/L$ for total zinc.

Water-quality determinations from samples of surface water obtained at the streamflow-gaging stations in Bald Mountain Brook and Bishop Mountain Brook are summarized in tables 1 and 2. These results are typical of those found in the surrounding study area (Fontaine 1989).

Acknowledgments

Acknowledgment is made to Jeff Gammon and the entire staff of the MDEP field office in Presque Isle for their invaluable assistance during the project. Special recognition is given to John Moulton and Carl Allen who did most of the field work for the study, often under adverse field conditions.

DESCRIPTION OF PRECIPITATION-RUNOFF MODELING SYSTEM

The U.S. Geological Survey's precipitation-runoff modeling system (PRMS) was used in this study to simulate the hydrology of the Bald Mountain and Bishop Mountain watersheds. A more detailed description of the model than that following can be found in Leavesley, and others (1983).

The PRMS is a deterministic, modular-design, distributed-parameter modeling system. The model is primarily applicable to rural watersheds dominated by snowmelt processes (Lorens, 1982, p. 11), such as those in the Bald Mountain project area. PRMS models the complete watershed system, including sediment discharge, rainfall and snowmelt runoff, and other water-balance components. Rainfall and snowmelt runoff are computed as daily mean flows. Storm hydrographs and associated sediment discharge can be simulated for individual storm periods if data are available at intervals less than 1 day and if snowmelt does not contribute significantly to streamflow.

The PRMS system is deterministic in that it was designed to reproduce the hydrologic system as realistically as possible. Each component of the hydrologic cycle is expressed in the form of known physical laws or empirical relations that are based on measurable watershed characteristics. Deterministic models allow users to relate specific changes in meteorologic and basin characteristics to changes in hydrologic processes.

The PRMS system is modular in design so that the various components of the hydrologic cycle are defined by one or more linked and compatible subroutines. Modular design creates a system that can be tailored easily to a variety of geographic regions, data bases or basin characteristics. The modular design allows for future expansion of the model. A list of principal subroutines in the daily component of PRMS is given in table 3.

The PRMS is a distributed parameter model--that is, variations in watershed characteristics, such as slope, aspect, elevation, vegetation type, soil type, and precipitation distribution, can be described. To describe these variations, the watershed can be partitioned, or subdivided, into homogeneous units. Within the units, an average value is assigned to each characteristic. If there is no significant variation in a basin characteristic over the entire watershed, a single values for each can be assigned and the model then functions as a lumped-parameter model. By subdividing the watershed, spatial and temporal variations of watershed characteristics can be taken into account. Climatic changes or land-use such as open-pit mining or clear-cut forestry practices, can be evaluated for each unit as well as for the total watershed.

Table 1.--Selected chemical and physical characteristics of water from Bald Mountain Brook

Property	Number of analyses	Mean	Range
Temperature (°C)	53	7.7	0.0-20.0
Turbidity (NTU)	53	2.7	0.5-15.0
Color (Platinum cobalt units)	49	50	20-90
Specific conductance (μS/cm)	50	57	18-185
Dissolved oxygen (mg/L)	51	11.0	7.2-13.7
pH (standard units)	49	[1/] 6.7	6.0-7.8
Alkalinity (mg/L as $CaCO_3$)	54	16	2-40
Total solids, residue at 105 °C (mg/L)	38	72	33-119
Total ammonia nitrogen (mg/L as N)	12	<0.01	<0.01-0.03
Total nitrogen NO_2+NO_3 (mg/L as N)	13	0.12	<0.01-0.42
Total phosphorus (mg/L as P)	39	0.01	<0.01-0.04
Total cadmium (μg/L as Cd)	8	2	2-2
Total chromium (μg/L as Cr)	10	7	<5-20
Total copper (μg/L as Cu)	53	3	<1-16
Total iron (μg/L as Fe)	50	256	50-920
Total lead (μg/L as Pb)	23	10	<1-30
Total zinc (μg/L as Zn)	50	8	<1-20
Total aluminum (μg/L as Al)	7	256	100-360

[1/] Mean of pH readings

Table 2.--Selected chemical and physical characteristics of water from Bishop Mountain Brook

Property	Number of analyses	Mean	Range
Temperature (°C)	40	6.6	0.0-22.5
Turbidity (NTU)	39	3.1	0.6-18.0
Color (Platinum cobalt units)	39	61	25-180
Specific conductance (μS/cm)	38	50	16-155
Dissolved oxygen (mg/L)	36	10.7	6.7-13.8
pH (standard units)	39	1/ 6.4	5.9-7.1
Alkalinity (mg/L as $CaCO_3$)	40	14	3-44
Total solids, residue at 105 °C (mg/L)	32	68	45-117
Total phosphorus (mg/L as P)	33	0.01	<0.01-0.04
Total copper (μg/L as Cu)	44	2	<1-16
Total iron (μg/L as Fe)	44	425	60-1700
Total lead (μg/L as Pb)	13	all values below detection limits	
Total zinc (μg/L as Zn)	42	6	<3-13
Total aluminum μg/L as Al)	7	870	<100-1900

1/ Mean of pH readings

Table 3.--Principal subroutines in daily component of precipitation-runoff modeling system

Subroutine	Description
BASFLW	Computes baseflow and subsurface flow components of the streamflow hydrograph.
CALIN	Computes change in snowpack when a net gain in heat energy has occurred.
CALOSS	Computes change in snowpack when a net loss in heat energy has occurred.
INTLOS	Computes the evaporation and sublimation of intercepted rain and snow.
PETS	Computes daily estimate of potential evapotranspiration.
PKADJ	Adjusts snowpack water equivalent based on snowcourse data.
PRECIP	Computes precipitation form, total precipitation depth, depth intercepted by vegetation and the net precipitation.
RESVRD	Performs daily routing for surface-water detention reservoirs.
SMBAL	Performs daily soil-moisture accounting.
SNOBAL	Computes snowpack energy balance.
SOLRAD	Computes daily incoming shortwave solar radiation for each HRU.
SOLTAB	Computes potential solar radiation and daylight hours for radiation planes.
SRFRO	Computes daily storm runoff from rainfall.
SUMALL	Computes daily, monthly, and annual data summaries for total basin and individual HRU's.
TEMP	Adjusts daily maximum and minimum air temperature to account for differences in elevation and aspects from point of measurement to each HRU.
TIMEY	Performs initialization and maintenance of the time accounting variables.

The following paragraphs from Leavesley and others, (1983, p. 7-9) give a good summary of the conceptual PRMS watershed system.

The watershed system and its inputs are schematically depicted in figure 3. System inputs are precipitation, air temperature, and solar radiation. Precipitation, in the form of rain, snow, or a mixture of both is reduced by interception and becomes net precipitation to the watershed surface. The energy inputs of temperature and solar radiation drive the processes of evaporation, transpiration, sublimation, and snowmelt. The watershed system is conceptualized as a series of reservoirs whose outputs combine to produce the total response of the system.

The impervious-zone reservoir represents an area with no infiltration capacity. The reservoir has a maximum retention storage capacity (RETIP) that must be satisfied before surface runoff (SAS) will occur. Retention storage is depleted by evaporation when the area is free of snow.

The soil-zone reservoir represents that part of the soil mantle that can lose water through the processes of evaporation and transpiration. Average rooting depth of the predominant vegetation covering the soil surface defines the depth of this zone. Water storage in the soil zone is increased by infiltration of rainfall and snowmelt and depleted by evapotranspiration. Maximum retention storage occurs at field capacity; minimum storage (assumed to be zero) occurs at wilting point. The soil zone is treated as a two-layered system. The upper layer is termed the recharge zone and is user-defined as to depth and water-storage characteristics. Losses from the recharge zone are assumed to occur from evaporation and transpiration; losses from the lower zone occur only through transpiration.

The computation of infiltration into the soil zone is dependent on whether the input source is rain or snowmelt. All snowmelt is assumed to infiltrate until field capacity is reached. At field capacity, any additional snowmelt is apportioned between infiltration and surface runoff. At field capacity, the soil zone is assumed to have a maximum daily snowmelt infiltration capacity, SRX. All snowmelt in excess of SRX contributes to surface runoff. Infiltration in excess of field capacity (EXCS) first is used to satisfy recharge to the ground-water reservoir (SEP). SEP is assumed to have a maximum daily limit. Excess infiltration, available after SEP is satisfied, becomes recharge to the subsurface reservoir. Water available for infiltration as the result of a rain-on-snow event is treated as snowmelt if the snowpack is not depleted, and as rainfall if the snowpack is depleted.

For rainfall with no snowcover, the volume of water infiltrating the soil zone is computed as a function of soil characteristics, antecedent soil-moisture conditions, and storm size. For daily-flow computations, the volume of rain that becomes surface runoff is computed using a contributing-area concept. Daily infiltration is computed as net precipitation less surface runoff. To generate a stormflow hydrograph, infiltration is computed using a form of the Green and Ampt equation (Philip, 1954). Surface runoff for these events is net precipitation less computed infiltration. Infiltration in excess of field capacity is treated the same as daily infiltration.

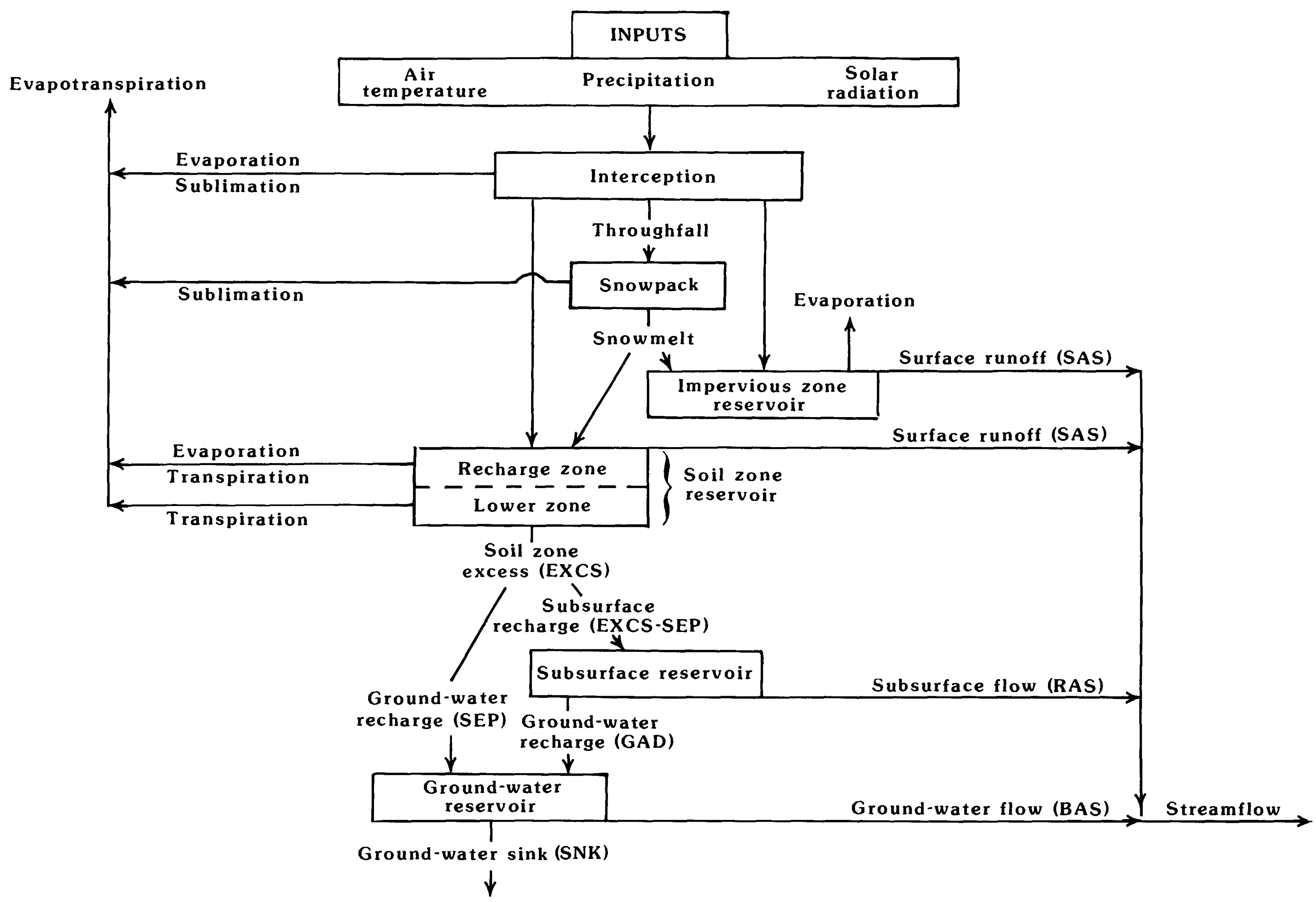

Figure 3.--Schematic diagram of the conceptual watershed system and its inputs. (From Leavesley, Lichty, Troutman, and Saindon, 1983, figure 2).

The subsurface reservoir performs the routing of soil-water excess that percolates to shallow ground-water zones near stream channels or that moves downslope from point of infiltration to some point of discharge above the water table. Subsurface flow (RAS) is considered to be water in the saturated-unsaturated and ground-water zones that is available for relatively rapid movement to a channel system. The subsurface reservoir can be defined either as linear or nonlinear.

Recharge to the ground-water reservoir can occur from the soil zone (SEP) and the subsurface reservoir (GAD). SEP has a daily upper limit and occurs only when field capacity is exceeded in the soil zone. GAD is computed daily as a function of a recharge rate coefficient (RSEP) and the volume of water stored in the subsurface reservoir. The ground-water reservoir is a linear reservoir and is the source of all baseflow (BAS). Movement of water through the ground-water system to points beyond the area of interest or measurement can be handled by flow to a ground-water sink (GSNK) which is computed as a function of storage in the ground-water reservoir.

Streamflow is the sum of SAS, RAS, and BAS. Only mean-daily flow simulations were computed for this study.

Daily values of precipitation, solar radiation, and maximum and minimum air temperature are required to use PRMS in the daily mean simulation mode. In addition to these data, physical data on the topography, soils, vegetation, and variation of climate over the watershed are required. To determine the adequacy of the hydrologic simulations based on these data, they are compared to recorded daily streamflow information for the watershed.

DATA COLLECTED FOR RUNOFF MODEL

Hydrologic Data

Values of daily mean streamflow recorded near the mouths of Bald Mountain Brook and Bishop Mountain Brook (fig.2) were used in the watershed modeling program. Streamflow data for Bald Mountain Brook from October 1, 1980, through September 30, 1984 and for Bishop Mountain Brook from November 5, 1981, through September 30, 1984 have been published in Fontaine (1989) and U.S. Geological Survey (1981-84).

In the data report by Fontaine, streamflow data are listed by water year. The streamflow data are categorized as excellent, good, fair, or poor and are summarized in table 4 of this report. About 95 percent of the daily discharges are accurate to within 5 percent for the excellent values, to within 10 percent for the good values , and within 15 percent for the fair values. Poor values have less accuracy than fair values.

Meteorologic Data

Daily precipitation totals from three continuous-recording rain gages were used in the modeling (fig. 2). Storm totals of as much as 5.45 inches (August 5-6, 1981) were recorded during the study. These data are available for the entire study period. On January 15, 1982, a weather station was installed in the study area to measure air temperature and solar radiation. These data were collected through June 12, 1984. During the on-site data-collection period, a temperature range of -35 to +33 °C was measured.

Table 4.--Accuracy of recorded streamflow data
[Good, 95 percent of the daily discharges are accurate to within 10 percent, to within 15 percent for fair value.]

Water year	Remarks
	Bald Mountain Brook
1981	Records good except those for winter period and period of no gage-height record Aug. 19 to Sept. 21, which are fair.
1982	Records good except those for winter period, which are fair. No gage-height record Dec. 15 to Mar. 16.
1983	Records good except those for winter period, which are fair.
1984	Records good except those for winter period, which are fair.
	Bishop Mountain Brook
1982	Records fair.
1983	Records good except those for winter period, which are fair. No gage height record Jan. 14 to Apr. 7.
1984	Records good except those for winter period, which are fair.

A concurrent data base of streamflow and meteorologic data is required in the modeling. Because streamflow data collection started on October 1, 1980, for Bald Mountain Brook, and on November 5, 1981, for Bishop Mountain Brook, the period of available air temperature and solar radiation data was extended back in time to these dates.

A linear-regression model was used to estimate maximum and minimum daily air temperatures and total daily solar radiation in the study area for the period from October 1, 1980, to January 15, 1982. Data collected at the National Weather Service station at Caribou located about 40 miles northeast of the study area (fig.1), were used as independent variables in the linear-regression model. Caribou is the only proximate National Weather Service site where solar radiation data were available. Suitable air temperature data were available at several nearby sites. However, correlation between the on-site and Caribou data gave the best results. The model was of the following form:

$$y = mx + b$$

where:

- y is the on-site dependent variable to be estimated;
- x is the corresponding value of the independent variable as recorded at the National Weather Service station at Caribou, Maine;
- m is the regression model coefficient;
- b is the regression model constant;

The above equation was evaluated for each of the three required on-site variables individually. The entire period of concurrent record for the on-site weather station and for the Caribou site was used to calibrate the models. The calibrated models and Caribou data were then used to estimate on site record back to October 1, 1980. The resultant regression models and coefficients of determination are shown in table 5.

Table 5.--Regression models for estimating air temperature and solar radiation at the Bald Mountain study area

Variable in study area	Regression Model	Correlation Coefficient
Solar radiation (langleys)	0.90 (Caribou value) + 27.6	0.94
Daily maximum air temperature (degrees Celsius)	.95 (Caribou value) + 0.51	.99
Daily minimum air temperature (degrees Celsius)	.98 (Caribou value) - 2.47	.97

APPLICATION OF PRECIPITATION-RUNOFF MODELING SYSTEM TO BALD MOUNTAIN BROOK AND BISHOP MOUNTAIN BROOK WATERSHEDS

In this section of the report, watershed characteristics and subdivision will be discussed, model calibration and verification procedures will be presented, and resultant model reliability will be considered.

Characteristics and Subdivision of Watersheds

The Bald Mountain Brook and Bishop Mountain Brook watersheds are heavily forested; spruce-fir species such as red spruce, black spruce and (or) white spruce, and balsam fir are the dominant types of vegetation. Also evident in the forested areas are moderate amounts of hardwood species, such as sugar maple, beech, and yellow birch. The only roads in the area are privately owned gravel logging roads. The maximum elevations in both watersheds are slightly greater than 1,500 feet above sea level, and the minimum elevations are about 820 feet. The soils of the watersheds can be generally classified as poorly sorted, loamy, glacial tills. Soils are deep, except in the upper elevations, where depths to bedrock in the range of 0 to 5 feet are common.

The Bald Mountain Brook watershed has a drainage area of 1.73 mi^2 at the gaging station. The main-channel length, as measured from the gaging station to the basin divide, is 2.56 mi. The main-channel slope, determined from elevations at points 10 percent and 85 percent of the distance along the channel from the gaging station to the divide is 102 feet per mile.

The Bishop Mountain Brook watershed has a drainage area of 1.15 mi^2 at the gaging station. The main channel length is 1.42 mi and the main channel slope is 271 feet per mile.

The PRMS model permits subdivision of watersheds into smaller, quasi-homogeneous units. If the subdivision pattern were designed with extremely small units, homogeneity of physical and climatic characteristics within each unit could be assumed. However, as demonstrated by Leavesley and Striffler (1978), this small-scale subdivision design does not necessarily improve model estimates. Excessive watershed subdivision may actually negatively influence the calibration fit of many model components. For that reason, watershed subdivision was limited in this study to that required to describe only major differences in the physical and climatic characteristics of Bald Mountain Brook and Bishop Mountain Brook watersheds. Characteristics such as slope, aspect, cover density, and proximity to rain gages were the major factors considered.

The topography, channel network, and subdivision of the Bald Mountain Brook watershed are shown in figure 4. The watershed is subdivided into 10 units, each of which is subsequently referred to as a HRU (hydrologic-response unit). The ore deposit is located within the boundaries of HRU 5. Characteristics of the 10 HRU's are summarized in table 6. Several values found in table 6 represent an average value of the characteristic for the HRU. Also, timber-harvesting operations were conducted on HRU 3, 7, and 9 during the fall of 1982. The values listed for several characteristics changed as a result of these operations. The first set of values represents average characteristics for the 1981 and 1982 water years, and the second set of values represents average characteristics for the 1983 and 1984 water years, after harvesting. Some timber harvesting occurred on HRU 5 in the fall of 1982; however, resultant changes were not significant enough to warrant changes in the HRU characteristics.

Areas of individual HRU's in the Bald Mountain Brook watershed vary from 44 acres up to 267 acres. Decimal values for effective-impervious area were determined to be the area of logging road surfaces within the HRU's divided by its total area. Although the logging roads have gravel surfaces, the degree to which they become compacted causes them to react as relatively impervious surfaces. Average land slopes within HRU's range from 0.02 to 0.35 foot per foot. Orientation of land forms within the Bald Mountain Brook watershed is principally to the northwest.

The topography, channel network, and subdivision of the Bishop Mountain Brook watershed are shown in figure 5. The watershed is subdivided into nine HRU's. Characteristics of the nine HRU's are summarized in table 7. As was the case for the Bald Mountain Brook watershed, several values found in table 7 represent an average value of the characteristic for the HRU. A limited amount of timber harvesting took place in the Bishop Mountain Brook watershed in the fall of 1982. Timber harvesting in the watershed was primarily confined to HRU 2; therefore, it was the only HRU that had characteristics that changed significantly during the study.

Areas of individual HRU's in the Bishop Mountain Brook watershed vary from 32 acres up to 125 acres. Compacted gravel logging roads within the watershed were again considered to be effective-impervious areas. Average land slopes within HRU's range from 0.02 to 0.30 foot per foot. Orientation of land forms within the Bishop Mountain Brook watershed is principally to the northwest.

Model Calibration and Verification

Calibration and verification of PRMS are two important operations that were performed prior to model application. Calibration is the process of adjusting the variables of the model to generate output that compares favorably with observed data. Verification involves model simulations incorporating parameters obtained from the calibration process, using a set of input and observed data independent of those used in calibration. Verification allows the model user to evaluate model error and gives an estimate of model capabilities under simulation conditions.

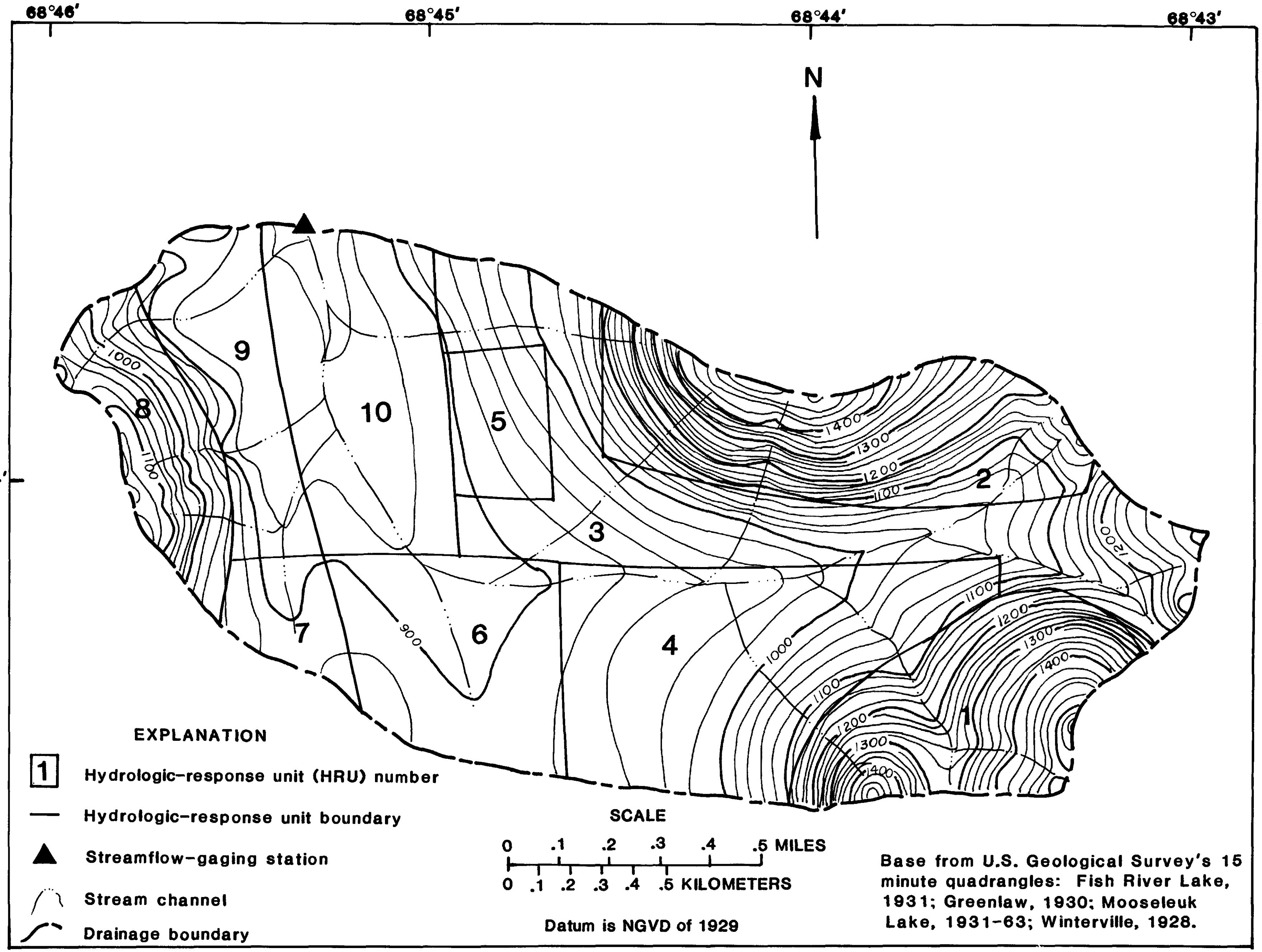

Figure 4.--Topography, channel network, and subdivision of Bald Mountain Brook watershed.

Table 6.--Hydrologic-response unit characteristics for Bald Mountain Brook watershed.

Characteristic	Hydraulic Response Unit 1	2	3	4	5	6	7	8	9	10
Drainage Area (acres)	93	154	267	105	44	68	54	54	134	134
Effective Impervious Area (decimal)	.00	.00	.01	.01	.02	.01	.02	.00	.02	.01
Mean Elevation (feet NGVD)	1,320	1,300	1,050	1,020	960	890	910	1,025	910	825
Slope (feet/feet)	.25	.35	.13	.10	.10	.04	.05	.22	.05	.02
Aspect (degrees)	310	180	250	295	240	320	30	60	40	315
Soil Type	loamy	loamy	loamy	loamy	loamy	loamy	loamy	loamy	loamy	loamy
Average soil depth (feet)	<5	>5	>5	>5	>5	>5	>5	<5	>5	>5
Predominant vegetation cover:										
1981-1982 water years	trees	trees	trees	trees	trees	trees	trees	trees	trees	trees
1983-1984 water years	trees	trees	shrubs	trees	trees	trees	shrubs	trees	shrubs	trees
Summer vegetation cover density (decimal)										
1981-1982 water years	.75	.75	.70	.60	.40	.70	.70	.75	.60	.45
1983-1984 water years	.75	.75	.40	.60	.40	.70	.25	.75	.25	.45
Winter vegetation cover density (decimal)										
1981-1982 water years	.60	.60	.55	.50	.25	.60	.60	.55	.50	.35
1983-1984 water years	.60	.60	.25	.50	.25	.60	.15	.55	.15	.35

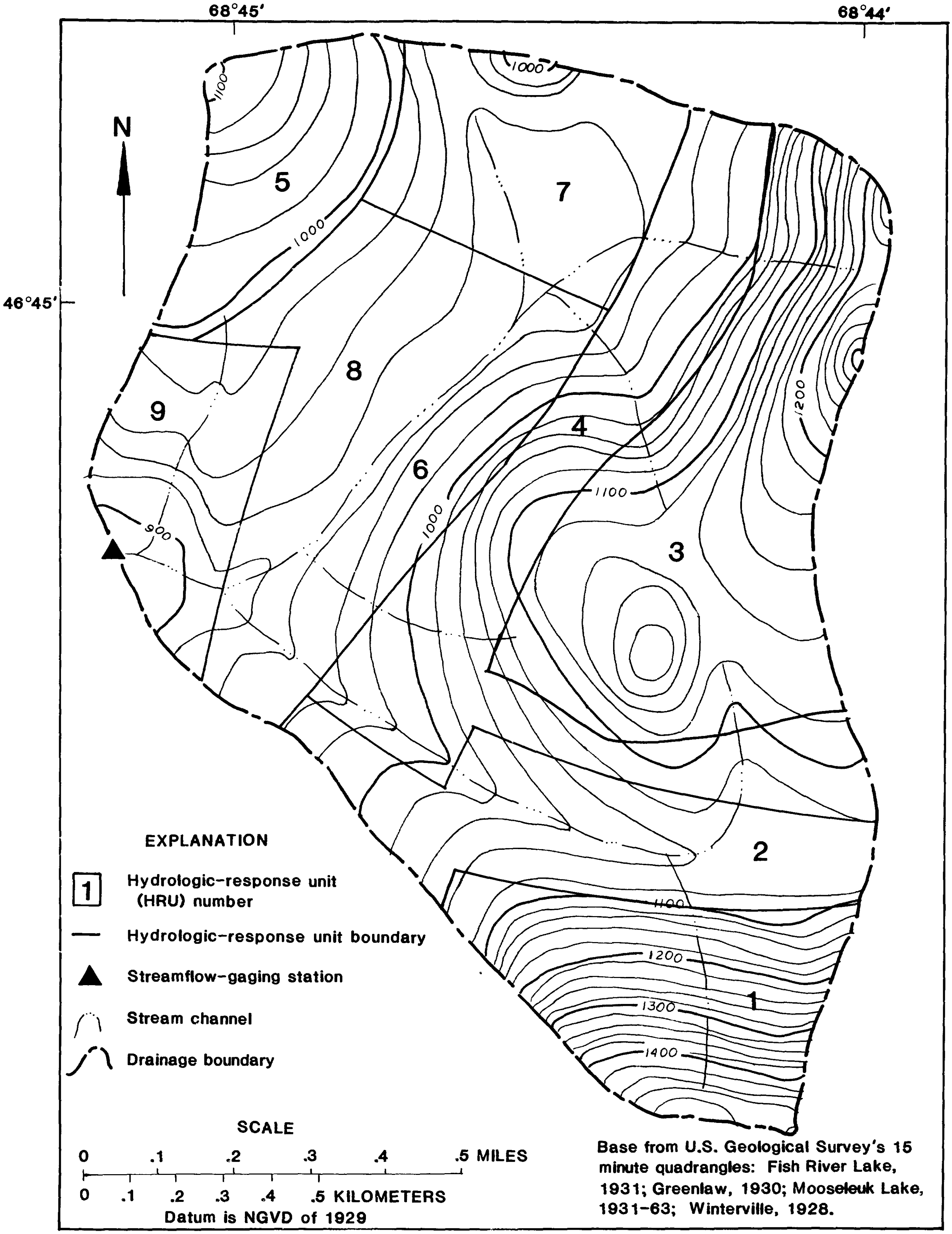

Figure 5.—Topography, channel network and subdivision of Bishop Mountain Brook watershed.

Table 7.--Hydrologic-response unit characteristics for Bishop Mountain Brook watershed.

Characteristic	Hydraulic Response Unit								
	1	2	3	4	5	6	7	8	9
Drainage Area (acres)	80	90	64	103	32	95	125	65	84
Effective impervious area (decimal)	.00	.02	.00	.02	.00	.01	.01	.00	02
Mean elevation (feet NGVD)	1,250	1,000	1,125	975	960	890	880	900	840
Slope (feet/feet)	.30	.15	.25	.15	.10	.05	.03	.04	.02
Aspect (degrees)	350	300	270	300	100	300	180	140	220
Soil Type	loamy	loamy	loamy	loamy	loamy	loamy	loamy	loamy	loamy
Average soil depth	<5	>5	<5	>5	<5	>5	>5	>5	>5
Predominant vegetation cover									
1981-82 water years	trees	trees	trees	trees	trees	shrubs	trees	trees	shrubs
1983-84 water years	trees	trees	trees	trees	trees	shrubs	trees	trees	shrubs
Summer vegetation cover density (decimal)									
1981-82 water years	.75	.75	.75	.75	.75	.40	.75	.65	.45
1983-84 water years	.75	.50	.75	.75	.75	.40	.75	.65	.45
Winter vegetation cover density (decimal)									
1981-82 water years	.60	.55	.60	.55	.60	.30	.60	.50	.30
1983-84 water years	.60	.30	.60	.55	.60	.30	.60	.50	.30

The first step in model calibration and verification is the division of the available data set into two parts--one for each function. It is important to have data that represent the reasonably expected range of watershed response in each data set. As an aid in determining this reasonable range, the regression equations developed by Morrill (1975) and Parker (1978) were used to estimate selected statistical streamflow characteristics (table 8). Table 9 summarizes the observed streamflow characteristics by water year for the Bald Mountain Brook and Bishop Mountain Brook watersheds.

Comparison of data in tables 8 and 9 indicates that peak discharges of a 25-to 50-year recurrence interval and flows in the range of the 7-day, 10-year low flow were observed at both sites during data collection. This broad range of discharge provides a reliable data base for both calibration and verification of the PRMS model at both sites. Data from water years 1983 and 1984 were used for model calibration at both sites. The remainder of the data were used for verification of the calibrated models.

Table 8.--Selected statistically estimated streamflow characteristics for Bald Mountain and Bishop Mountain Brooks

Streamflow characteristic	Streamflow (cubic feet per second)	
	Bald Mountain Brook	Bishop Mountain Brook
2-year peak discharge	52	46
5-year peak discharge	85	78
10-year peak discharge	113	106
25-year peak discharge	157	150
50-year peak discharge	195	190
100-year peak discharge	241	239
7-day, 10-year low flow	.08	.05

Table 9.--Selected observed annual streamflow characteristics for Bald Mountain and Bishop Mountain Brooks

Water year	Bald Mountain Brook		Bishop Mountain Brook	
	Peak discharge (ft^3/sec)	Minimum discharge (ft^3/sec)	Peak discharge (ft^3/sec)	Minimum discharge (ft^3/sec)
1981	84	0.14	1/---	1/---
1982	51	.05	2/61	2/.05
1983	198	.11	125	.04
1984	195	.27	136	.13

1/ No data available
2/ Data from partial water year, November 5, 1981, to September 30, 1982.

Calibration Procedure

The first step in the calibration process was to input the measured hydrologic and meteorologic data and characteristics for the subdivided watersheds (tables 6 and 7). These measured data are not adjusted in the calibration process. Next, initial values of model variables were selected based on physical characteristics and land uses of the watersheds, experience, results of previous PRMS applications, and research studies (U.S. Army, 1956; Leavesley and others, 1983; A. Lumb, U.S. Geological Survey, written commun., 1983; Scott, 1984; and G. Leavesley, U.S. Geological Survey, written commun., 1985). Possible extreme values for the model variables were noted as part of selection process to ensure that subsequent calibration adjustments did not attempt to alter them unrealistically.

In the calibration process, initial model runs were made to achieve reasonable simulation values of annual potential evapotranspiration (Farnsworth and others, 1982) and runoff mass balances. At this stage, primarily climatic model variables were varied to improve model fit. Subsequently, the relative contributions of direct-surface runoff, subsurface flow, and ground water flow (or base flow) were analyzed, and variables that control the subdivision of rainfall and snowmelt inputs between the components were adjusted. Final adjustments to the model were made to variables that control subsurface and base-flow-recession rates. Because of the interactive nature of several model components, the above process was repeated several times before values of parameters were accepted as final for use in the calibrated model.

Although the PRMS model contains variable optimization components, it was decided that, for this study, manual-fitting processes yielded better results than did the purely statistical approaches. In the manual-fitting process, statistical comparison of flow volumes and resultant coefficients of determination provided in model outputs were examined to determine if variable adjustments actually improved model estimates. Also, graphical time-series comparisons were made to evaluate the effect of changes to variables on model results. An additional consideration in the fitting process was the model's ability to simulate significant hydrologic events in the calibration period. Events such as peak runoff (both snowmelt and non-snowmelt related) and base-flow periods were considered especially significant. The relative accuracies of the input streamflow data also were considered in the manual-fitting process (table 4).

The climatic parameters that are fixed values for the entire water year are summarized in table 10. Climatic parameters that vary by month are summarized in table 11. Variable values from tables 10 and 11 were used in final calibration runs for both Bald Mountain and Bishop Mountain Brooks. The majority of the climatic variables required little or no adjustment during the calibration process. Variables that were slightly adjusted during calibration are flagged in tables 10 and 11. These adjustments were either less than 10 percent of the original value or involved single-unit adjustments of the last significant decimal place.

Table 10.--Annual climatic variables used for modeling Bald Mountain Brook and Bishop Mountain Brook watersheds

Variable	Description	Value
PARS	Predicted solar radiation correction factor for summer day with precipitation.	0.25
PARW	Predicted solar radiation correction factor for winter day with precipitation.	.25
RDMX	Maximum percent of potential solar radiation.	.80
RMXA	Proportion of rain in a rain-snow precipitation event above which snow albedo is not reset (snow-pack accumulation stage).	.8
RMXM	Same as RMXA but for snowpack melt stage.	.6
CTW 1/	Proportion of potential evapotransiration that is sublimated from a snow surface (decimal form).	.10
EAIR	Emissivity of air on days without precipitation.	.83
FWCAP 1/	Free water holding capacity of snowpack expressed as a decimal fraction of total snowpack water equivalent.	.05
DENI	Initial density of new-fallen snow.	.10
DENMX 1/	Average maximum snowpack density.	.45
SETCON	Snowpack settlement time constant.	.10
BST	Temperature above which precipitation is all rain and below which it is all snow, in degrees Celsius.	-1
RDB	First sky cover/solar radiation computation coefficient	.39
RDP	Second sky cover/solar radiation computation coefficient	.61

1/ Variable slightly adjusted during model calibration.

Table 11.--Monthly climatic variables values used for modeling Bald Mountain Brook and Bishop Mountain Brook watersheds

PAT, the maximum air temperature (in degrees Celsius) which, when exceeded, forces precipitation to be rain regardless of minimum temperature.

AJMX, adjustment factor for proportion of rain in a rain-snow mix event.

TLX, lapse rate for maximum daily air temperature (degrees Celsius per 1,000 feet elevation change).

TLN, lapse rate for minimum daily air temperature (degrees Celsius per 1,000 feet elevation change).

CTS, air temperature evapotranspiration coefficient.

RDM, slope of maximum-minimum air temperature/sky cover relationships.

RDC, Y-intercept of maximum-minimum air temperature/sky cover relationship.

MONTH	PAT[1/]	AJMX	TLX	TLN	CTS[1/]	RDM	RDC
January	2.9	1.0	1.45	1.5	0.0075	-0.102	2.15
February	2.9	1.0	1.45	1.5	.0075	- .102	2.15
March	2.9	1.0	1.45	1.5	.0075	- .102	2.15
April	2.9	1.0	1.45	1.5	.0065	- .102	2.15
May	2.9	1.0	1.45	1.5	.0065	- .071	1.64
June	2.9	1.0	1.45	1.5	.0065	- .071	1.64
July	2.9	1.0	1.45	1.5	.0065	- .071	1.64
August	2.9	1.0	1.45	1.5	.0065	- .071	1.64
September	2.9	1.0	1.45	1.5	.0065	- .071	1.64
October	2.9	1.0	1.45	1.5	.0075	- .071	1.64
November	2.9	1.0	1.45	1.5	.0075	- .102	2.15
December	2.9	1.0	1.45	1.5	.0075	- .102	2.15

[1/] Variable slightly adjusted during model calibration

The model variables used for daily runoff computations for each site are listed in table 12. The variables fitted during model calibration are flagged in table 12. Several calibrated variables differ by watershed and HRU. Determinations for these parameters are given in tables 13 and 14. The primary parameters fitted during the calibration of the watersheds are SMAX, SCN, SC1, SEP, RCF, and RCB. These parameters are the primary controls on the movement and distribution of water within the components of the Bald Mountain Brook and Bishop Mountain Brook watersheds.

A sensitivity analysis was run on the model parameters SMAX, SCN, SC1, SEP, RCF, and RCB for Bald Mountain and Bishop Mountain Brooks watersheds. For both watershed models SMAX was the most sensitive parameter, and SC1 was the next in terms of relative sensitivity. Changes in the values of these two parameters have a greater effect on predicted flows in Bald Mountain and Bishop Mountain Brooks than do changes in the other parameters. The remaining parameters rank in the following order in terms of sensitivity: RCF, SEP, RCB, and SCN.

Hydrographs of observed and predicted discharge and observed precipitation from model calibration for Bald Mountain and Bishop Mountain Brooks are shown in figures 6, 7, 8, and 9. Visual graphical analyses of the plots indicate that the calibrations for both Bald Mountain Brook and Bishop Mountain Brook watersheds favorably reproduced observed data except during summer low-flow periods. Modeling results during these summer low-flow periods were only fair. Refinements in the techniques used in the PRMS model to calculate evapotranspiration losses in and near stream channels are being considered. These model enhancements would likely improve the calibration results determined for the study. The predicted total discharge for the calibration period (1983 and 1984 water years) was within 8.1 percent of observed in the Bald Mountain Brook watershed and within 0.2 percent of observed in the Bishop Mountain Brook watershed. Coefficients of determination for monthly total discharges for the calibration period were 0.83 and 0.92 for the Bald Mountain Brook and Bishop Mountain Brook watersheds, respectively. Coefficients of determination for the calibration period were approximately 0.66 for both watersheds. These results are for watersheds in which snowmelt occurs in as many as 7 months of each year, and about two-thirds of the observed stream discharge records are rated as fair (table 4).

The quantity of water in each major model component as determined by the PRMS model for the calibration water years at each site is summarized in table 15. Surface runoff accounts for only 3.99 in. or 14 percent of the total predicted runoff from the Bald Mountain Brook watershed during the 1983 water year. In Bishop Mountain Brook watershed, surface runoff accounts for 4.75 in. or 15 percent of the total predicted runoff during the 1983 water year. These estimated values indicate the major role that subsurface flow and ground-water flow plays in the hydrology of the study watersheds. Model-estimated subsurface flow and ground-water flow, during the 1983 water year accounted for 86 percent of predicted runoff in Bald Mountain Brook and 85 percent of predicted runoff in Bishop Mountain Brook.

Table 12.--Variables used for daily runoff computations

Variable	Description
TRNCF[1/]	Transmission coefficient for short wave radiation through the winter vegetation canopy (decimal form).
SNST[1/]	Interception-storage capacity of major winter vegetation for snow (inches).
RNSTS[1/]	Interception-storage capacity of major summer vegetation for rain (inches).
RNSTW[1/]	Interception-storage capacity of major winter vegetation for rain (inches).
ITST	Month transpiration begins; determined to be May.
ITND	Month transpiration ends; determined to be November.
SMAX[1/]	Maximum available water-holding capacity of soil profile (inches.)
REMX[1/]	Maximum available water-holding capacity of soil recharge zone (inches).
SCN[1/]	First coefficient in contributing area-moisture index relationship.
SC1[1/]	Second coefficient in contributing area-moisture index relationships (non linear scheme).
SEP[1/]	Maximum daily recharge from soil moisture excess to designated ground-water reservoir (inches).
SRX[1/]	Maximum daily snowmelt infiltration capacity of soil profile when profile is at field capacity (inches).
RES	Initial storage in each subsurface flow routing reservoir (inches); determined to be 0.15 for Bald Mountain and 0.70 for Bishop Mountain.
GW	Initial storage in each ground-water flow routing reservoir (inches); determined to be 0.5 for Bald Mountain and 1.6 for Bishop Mountain.
RESMX	Coefficient for computing seepage from the subsurface reservoir to its designated ground-water reservoir; assigned a constant value of 1.00.
REXP	Exponent for computing seepage from a subsurface reservoir to its designated ground-water reservoir; assigned a constant value of 1.00.
GSNK	Coefficient used in computing the seepage rate from the ground-water reservoir to a ground-water sink; assigned a constant value of 0.0.
RCF[1/]	Subsurface flow-routing coefficient: determined to be 0.40 for both sites.
RCP	Subsurface flow-routing coefficient; assigned a constant value of 0.0.
RCB[1/]	Ground-water flow-routing coefficient; determined to be 0.01 for both sites.

[1/] Variable fit during model calibration

Table 13.--Variables for daily runoff comuptations defined by calibration for Bald Mountain Brook watershed.

HRU	TRNCF	SNST	RNSTS	RNSTW	SMAX	REMX	SCN	SCI	SEP	SRX
1	0.20	0.10	0.10	0.07	2.80	2.50	0.0015	0.50	0.08	1.10
2	.20	.10	.10	.07	2.80	2.50	.0015	.50	.08	1.10
3	.50	.05	.05	.05	3.20	2.70	.0035	.50	.12	1.10
4	.25	.10	.10	.07	3.20	2.70	.0035	.50	.12	1.10
5	.50	.05	.05	.05	3.20	2.70	.0015	.50	.12	1.10
6	.20	.10	.10	.07	3.20	2.70	.0035	.50	.12	1.10
7	.65	.05	.05	.05	3.20	2.70	.0015	.50	.12	1.10
8	.25	.10	.10	.07	2.80	2.50	.0015	.50	.08	1.10
9	.65	.05	.05	.05	3.20	2.70	.0015	.50	.12	1.10
10	.40	.05	.05	.05	3.20	2.70	.0045	.50	.12	1.10

Table 14.--Variables for daily runoff computations defined by calibration for Bishop Mountain Brook watershed.

HRU	TRNCF	SNST	RNSTS	RNSTW	SMAX	REMX	SCN	SCI	SEP	SRX
1	0.20	0.10	0.10	0.07	2.80	2.50	0.0015	0.50	0.08	1.10
2	.40	.05	.05	.05	3.20	2.70	.0025	.50	.12	1.10
3	.20	.10	.10	.07	2.80	2.50	.0015	.50	.08	1.10
4	.25	.10	.10	.07	3.20	2.70	.0035	.50	.12	1.10
5	.20	.10	.10	.07	2.80	2.50	.0015	.50	.08	1.10
6	.40	.05	.05	.05	3.20	2.70	.0045	.50	.12	1.10
7	.20	.10	.10	.07	3.20	2.70	.0040	.50	.12	1.10
8	.25	.10	.10	.07	3.20	2.70	.0040	.50	.12	1.10
9	.40	.05	.05	.05	3.20	2.70	.0050	.50	.12	1.10

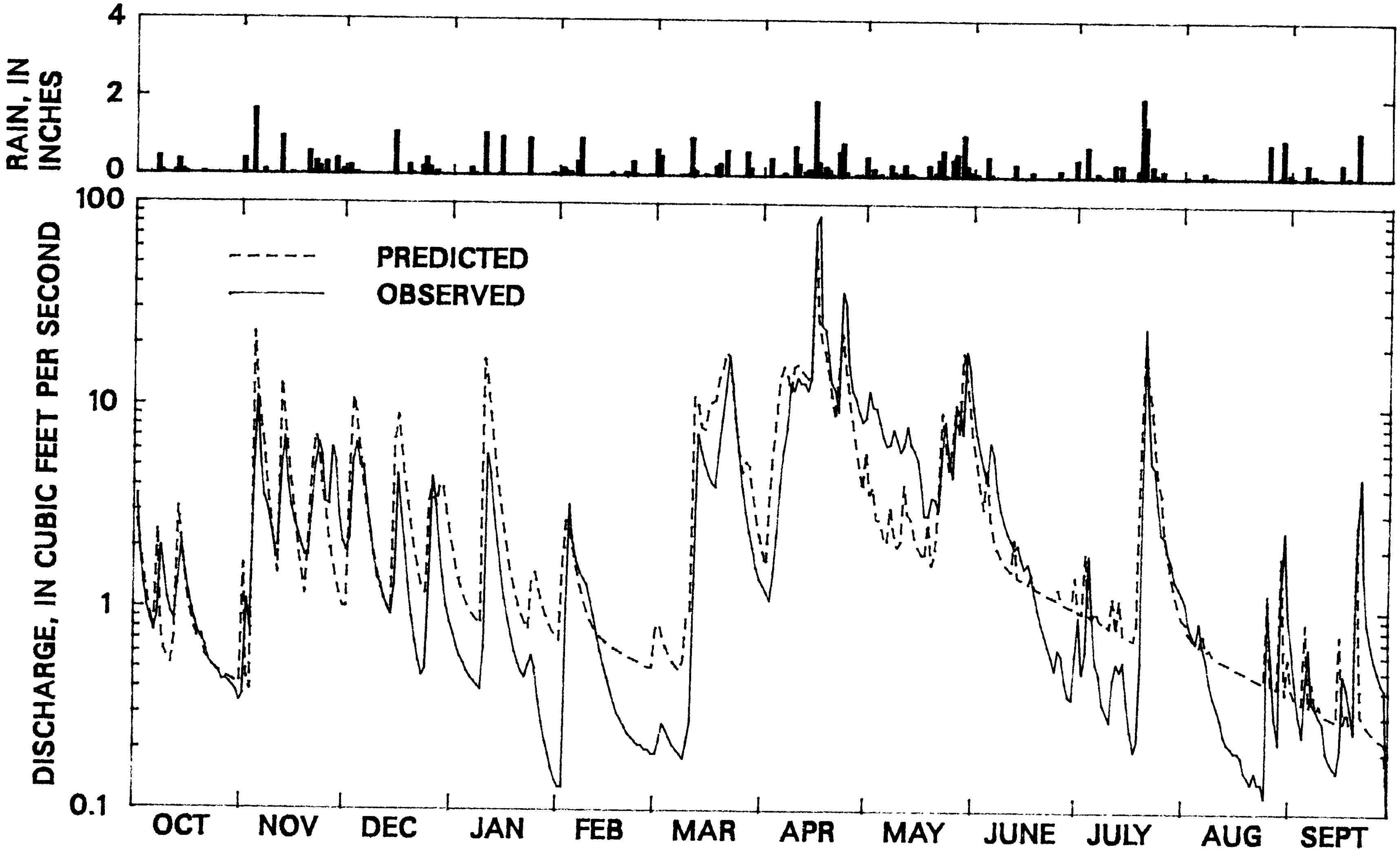

Figure 6.--Hydrographs of observed and predicted discharge and observed precipitation from model calibration for Bald Mountain Brook, 1983 water year.

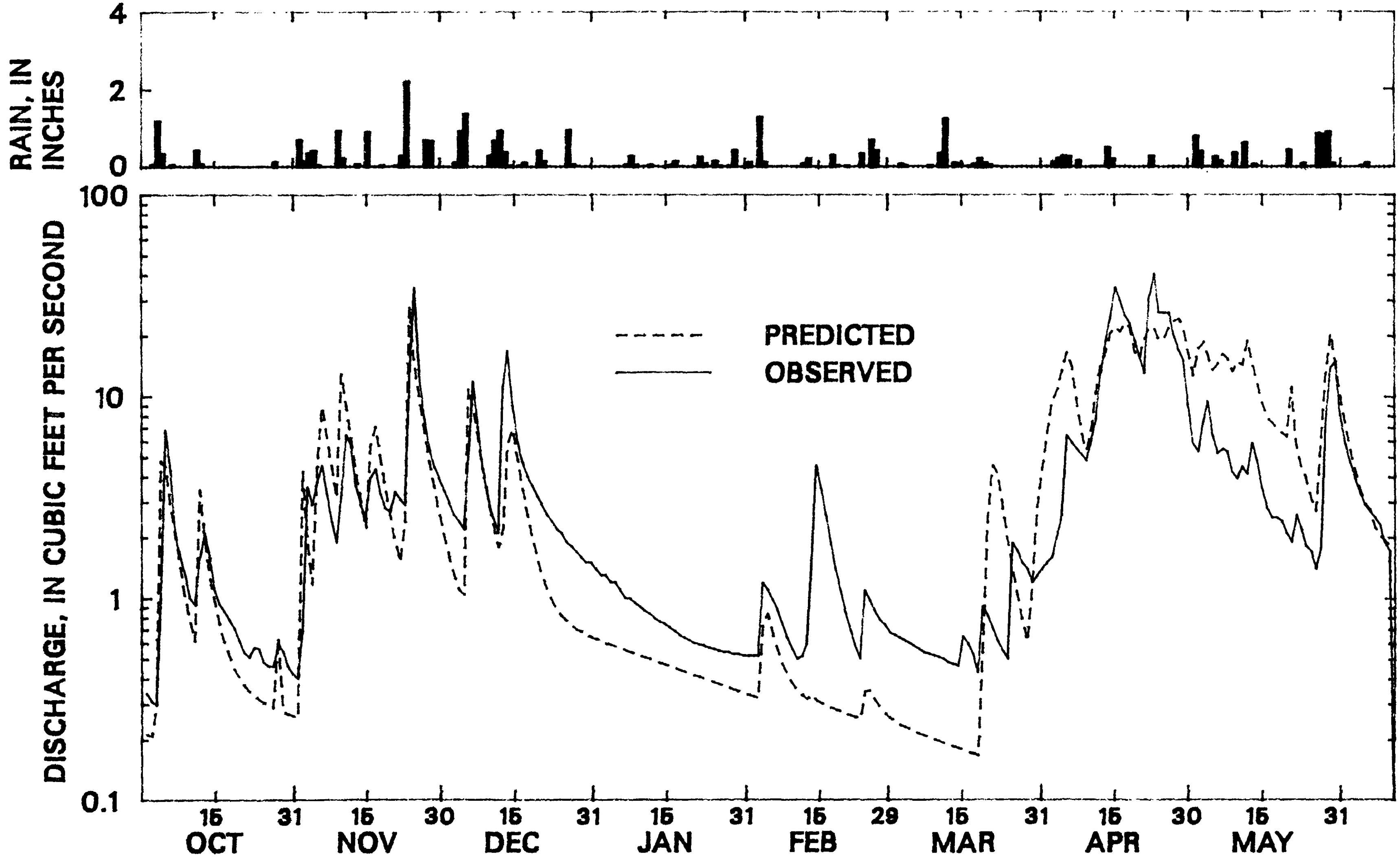

Figure 7.--Hydrographs of observed and predicted discharge and observed precipitation from model calibration for Bald Mountain Brook, 1984 water year.

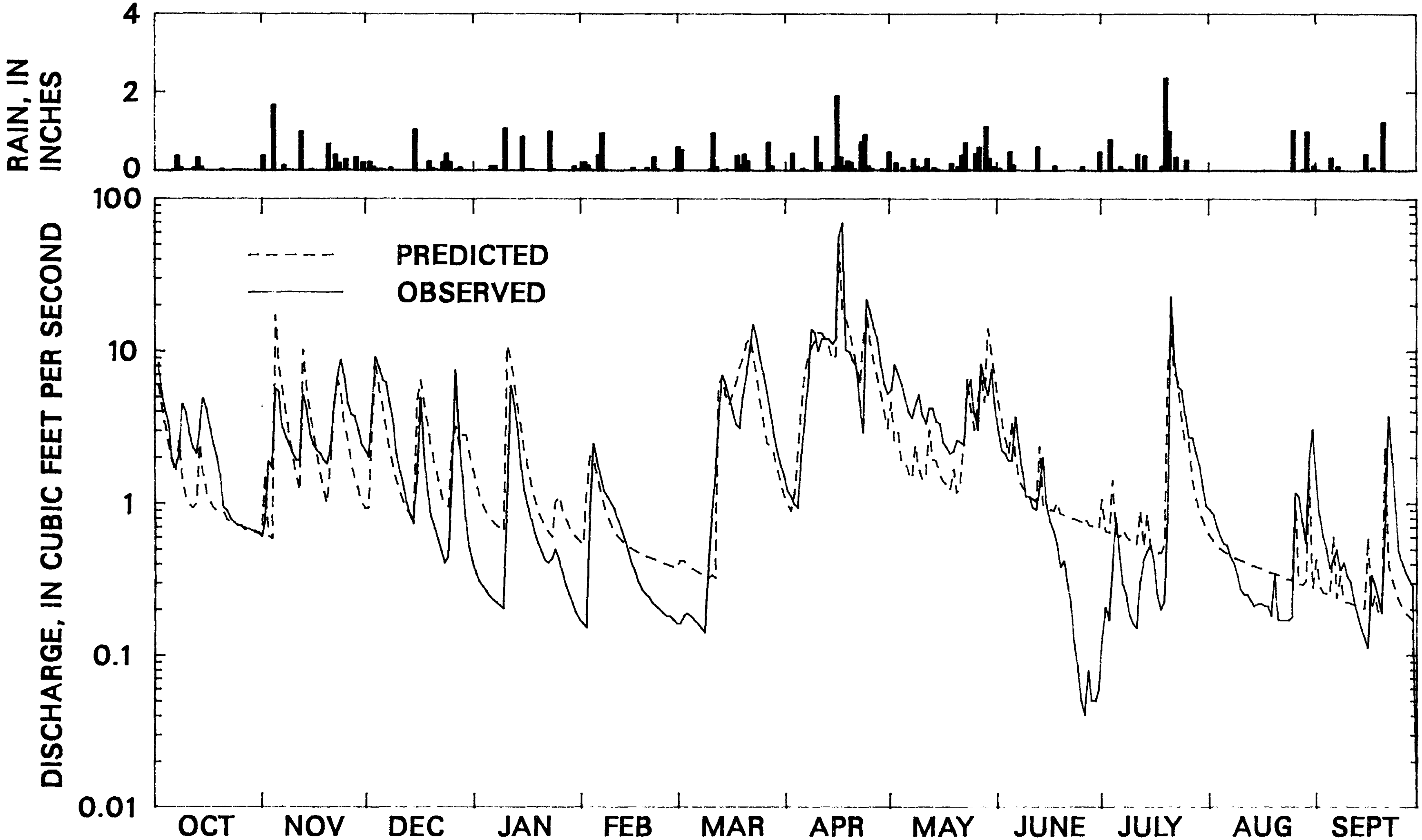

Figure 8.--Hydrographs of observed and predicted discharge and observed precipitation from model calibration for Bishop Mountain Brook, 1983 water year.

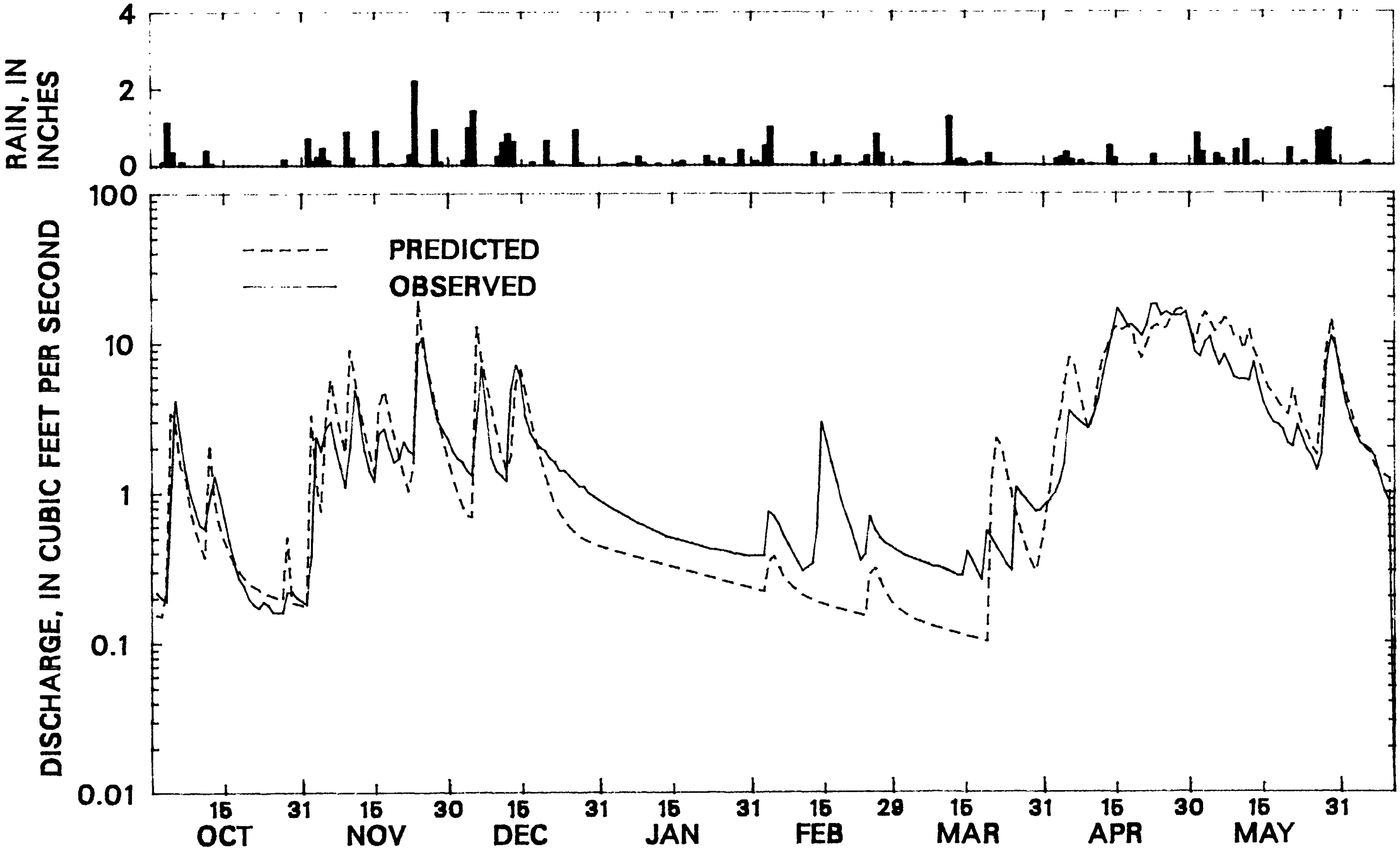

Figure 9.--Hydrographs of observed and predicted discharge and observed precipitation from model calibration for Bishop Mountain Brook, 1984 water year.

Table 15.--Quantity of water in each major model component for the calibration period

Model Component (in inches)	Bald Mountain Brook Water Year 1983	Bald Mountain Brook Water Year 1984[1/]	Bishop Mountain Brook Water Year 1983	Bishop Mountain Brook Water Year 1984[1/]
Observed precipitation	44.00	32.75	45.14	32.06
Net precipitation	41.92	32.28	42.47	31.22
Potential evapotranspiration	21.28	8.82	21.74	8.93
Actual evapotranspiration	13.81	4.93	13.66	4.63
Predicted runoff	28.82	26.32	31.12	25.58
Observed runoff	28.06	22.93	34.09	22.74
Ground-water reservoir inflow	6.43	5.73	6.54	5.77
Subsurface reservoir inflow	18.21	20.57	18.02	19.53
Subsurface to ground-water flow	.45	.50	.45	.47
Surface runoff	3.99	1.81	4.75	2.12
Subsurface flow	17.75	19.88	18.09	18.85
Ground-water flow	7.08	4.62	8.27	4.61

[1/] Data for 1984 water year represents only partial year, October 1 to June 12.

Verification Procedure

Verification of the calibrated PRMS models for the Bald Mountain Brook and Bishop Mountain Brook watersheds was accomplished by applying the models, with the fitted parameters from calibration fixed, to an independent data set from water years 1981 and 1982. Prior to verification model runs, some adjustments to measured model parameters were required. As noted in the section on watershed subdivision, timber harvesting took place in the fall of 1982 in HRU 3, 7, and 9 in the Bald Mountain Brook watershed and in HRU 2 in the Bishop Mountain Brook watershed. The model was calibrated using conditions as they existed after cutting was completed. To verify the model properly, cover density and predominant vegetative cover were changed to reflect conditions as they existed in the precutting 1981 and 1982 water years. The adjusted HRU characteristics for the precutting period are found in tables 6 and 7. Adjustments of the measurable characteristics, cover density and predominant vegetative cover, require concurrent adjustments of the parameters TRNCF, SNST, RNSTS, and RNSTW. Adjusted values for these parameters, used in model verification, are given in table 16.

Table 16.--Adjusted parameters used in model verification

	Bald Mountain Brook			Bishop Mountain Brook
Parameter	HRU 3	HRU 7	HRU 9	HRU 2
TRNCT	0.25	0.20	0.25	0.25
SNST	.10	.10	.10	.10
RNSTS	.10	.10	.10	.10
RNSTW	.07	.07	.07	.07

Hydrographs of observed and predicted discharge and observed precipitation from model verification for Bald Mountain and Bishop Mountain Brooks are shown in figures 10, 11, and 12. Visual graphical analyses of the plots indicate that the calibrated PRMS models for Bald Mountain and Bishop Mountain Brooks provide simulation results that compare favorably with observed data except during summer low-flow periods where model results are only fair. One additional period where the simulations depart from observed data is from February 3-13, 1982--a period of backwater from ice. Review of the records computation process and supportive meteorologic data for the period indicate that model results probably are more accurate than the estimates of streamflow for this period.

The predicted total discharge for the verification period was within 6.5 percent of the observed in the Bald Mountain Brook watershed and within 3.2 percent in the Bishop Mountain Brook watershed. Coefficients of determination for monthly total discharges for the verification period were 0.90 and 0.94 for Bald Mountain Brook and Bishop Mountain Brook watersheds, respectively. Coefficients of determination for the verification period were 0.71 and 0.84 for the Bald Mountain Brook and Bishop Mountain Brook watersheds, respectively. These statistical comparisons of observed and simulated results supported conclusions from the graphical analyses, indicating the calibrated PRMS models for Bald Mountain Brook and Bishop Mountain Brook watersheds provided reliable data during the verification period, except during summer low-flow periods where results are only fair. Based on these verification results, successful application of the PRMS model in the Bald Mountain area of northern Maine for watershed simulations was demonstrated to MDEP.

Example of Model Application

The successful daily discharge calibration and verification of the PRMS model for the Bald Mountain Brook and Bishop Mountain Brook watersheds allows simulations that involve variation of the watershed characteristics. Because of the distributed nature of the PRMS models, simulations can aid in evaluating the results of proposed or hypothetical changes in basin characteristics over individual HRU's or over the entire watersheds.

A hypothetical condition of clear-cut timber harvesting was evaluated in both the Bald Mountain Brook and Bishop Mountain Brook watersheds to demonstrate the potential utility of the PRMS model. In this application, one HRU at a time in each watershed was simulated as clear-cut until the entire watershed had been harvested. The clear-cutting was assumed to follow a numerical progression through each watershed starting with HRU 1 and finishing with HRU 10 in Bald Mountain Brook watershed and HRU 9 in Bishop Mountain Brook watershed. This analysis was applied to the data set used in the verification analysis, 1981 and 1982 water years.

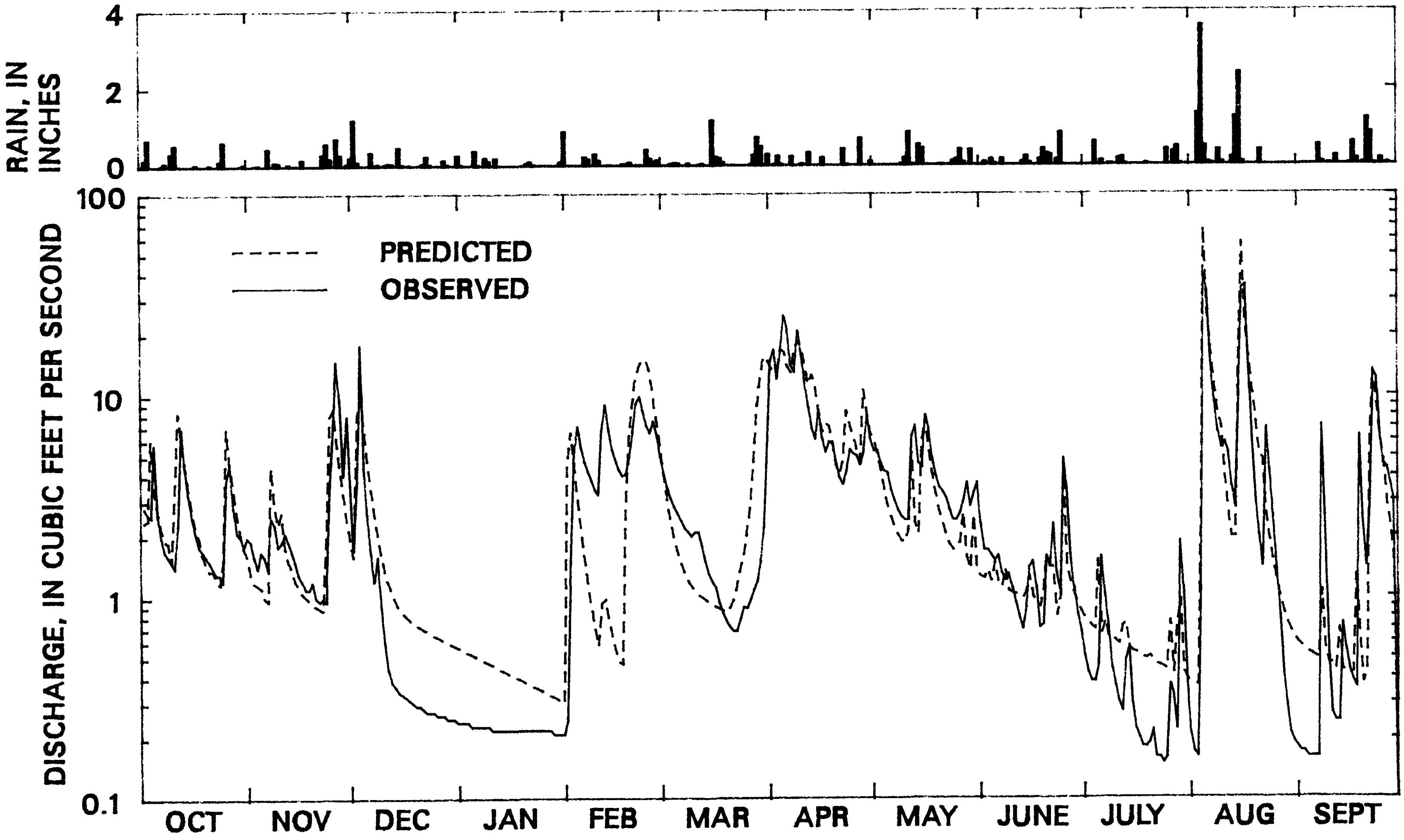

Figure 10.--Hydrographs of observed and predicted discharge and observed precipitation from model verification for Bald Mountain Brook, 1981 water year.

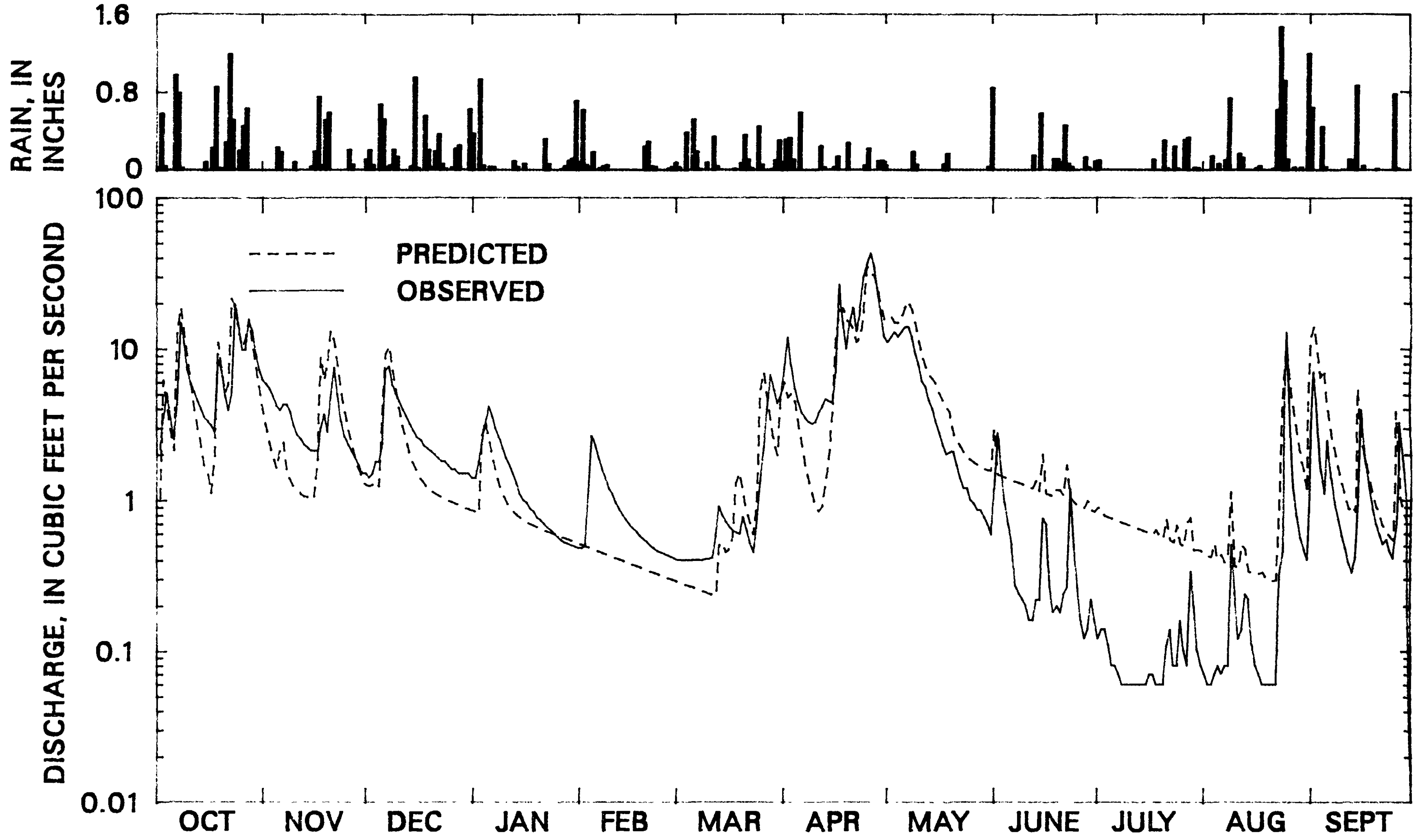

Figure 11.--Hydrographs of observed and predicted discharge and observed precipitation from model verification for Bald Mountain Brook, 1982 water year.

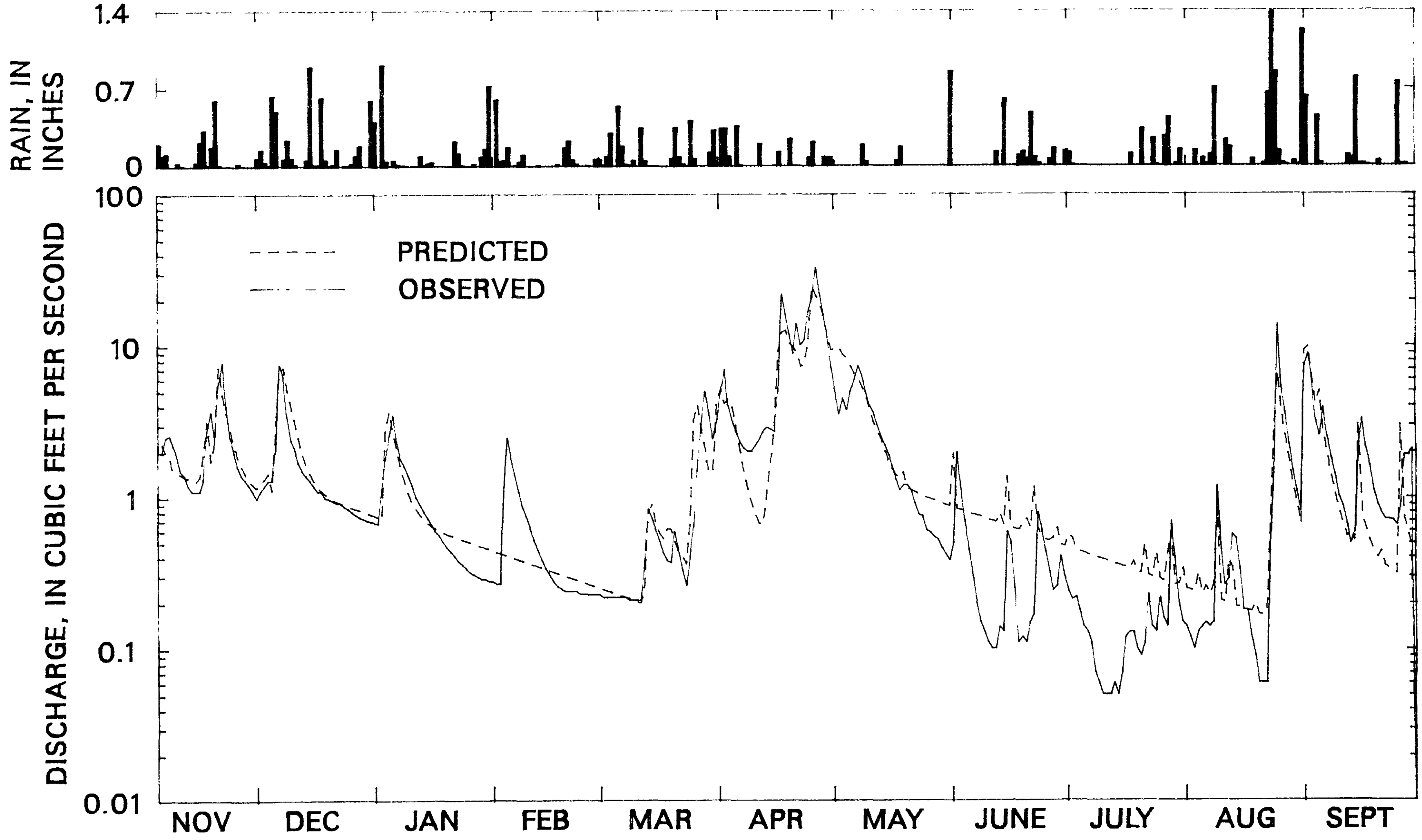

Figure 12.--Hydrographs of observed and predicted discharge and observed precipitation from model verification for Bishop Mountain Brook, 1982 water year.

In the hypothetical clear-cutting, it was assumed that with the completion of harvesting, the predominant vegetative cover on a HRU became brush. The cover density of summer vegetative was reduced to 0.25, and the cover density of winter vegetative was reduced to 0.15. The altered cover density values selected were not intended to represent any particular cutting operation but were selected at random by the author. As noted in the section on model verification, changes in vegetative cover density and type require changes in the parameters TRNCF, SNST, RNSTS, and RNSTW. Selection of these parameter values was based on results determined in the calibration modeling for a HRU that had recently experienced timber harvesting. In the hypothetical analysis, TRNCF was assigned a value of 0.65, and SNST, RNSTS, and RNSTW were all set equal to 0.05 on clear-cut HRU's.

To illustrate potential changes in discharge with the entire watersheds clear-cut, the final model simulation results (entire watershed clear-cut) were compared to verification period model results in the hydrographs shown in figures 13, 14 and 15. The quantity of water in each major component for the verification and simulation results are summarized in tables 17, 18, and 19.

In this example, clear-cutting caused snowmelt to occur earlier in the spring season, this caused an increase in snowmelt peaks early in the season and a decrease in snowmelt peaks later in the season. As noted in work at the Hubbard Brook experimental forest in New Hampshire, the change in snowmelt pattern indicates the timing of snowmelt is different in open and forested areas (Hornbeck, 1973).

The effect of clear-cutting on the magnitude of flood peaks is not as consistent. Summaries of observed clear-cutting effects indicate that increases in water yield may be expected; however, flood peaks may increase, decrease, or remain unchanged (Lull and Reinhart, 1972; Anderson and others, 1976). The spring snowmelt peak in the Bald Mountain Brook watershed increased in the clear-cut simulation for the 1981 water year. Snowmelt peaks in the 1982 water year for both Bald Mountain Brook and Bishop Mountain Brook watersheds remained essentially the same. In both water years, peaks for clear-cut conditions occurred earlier in the spring. Non-snowmelt peaks remained essentially the same for both watersheds. When only a small part of the watersheds were clear-cut, effects on downstream flood peaks were minimal. This agrees with the work summarized by Verry and others (1983).

These simulation results point out interesting trends. However, these results are based on hypothetical clear-cutting and are intended only to illustrate the potential utility of the calibrated and verified PRMS models for the Bald Mountain Brook and Bishop Mountain Brook watersheds.

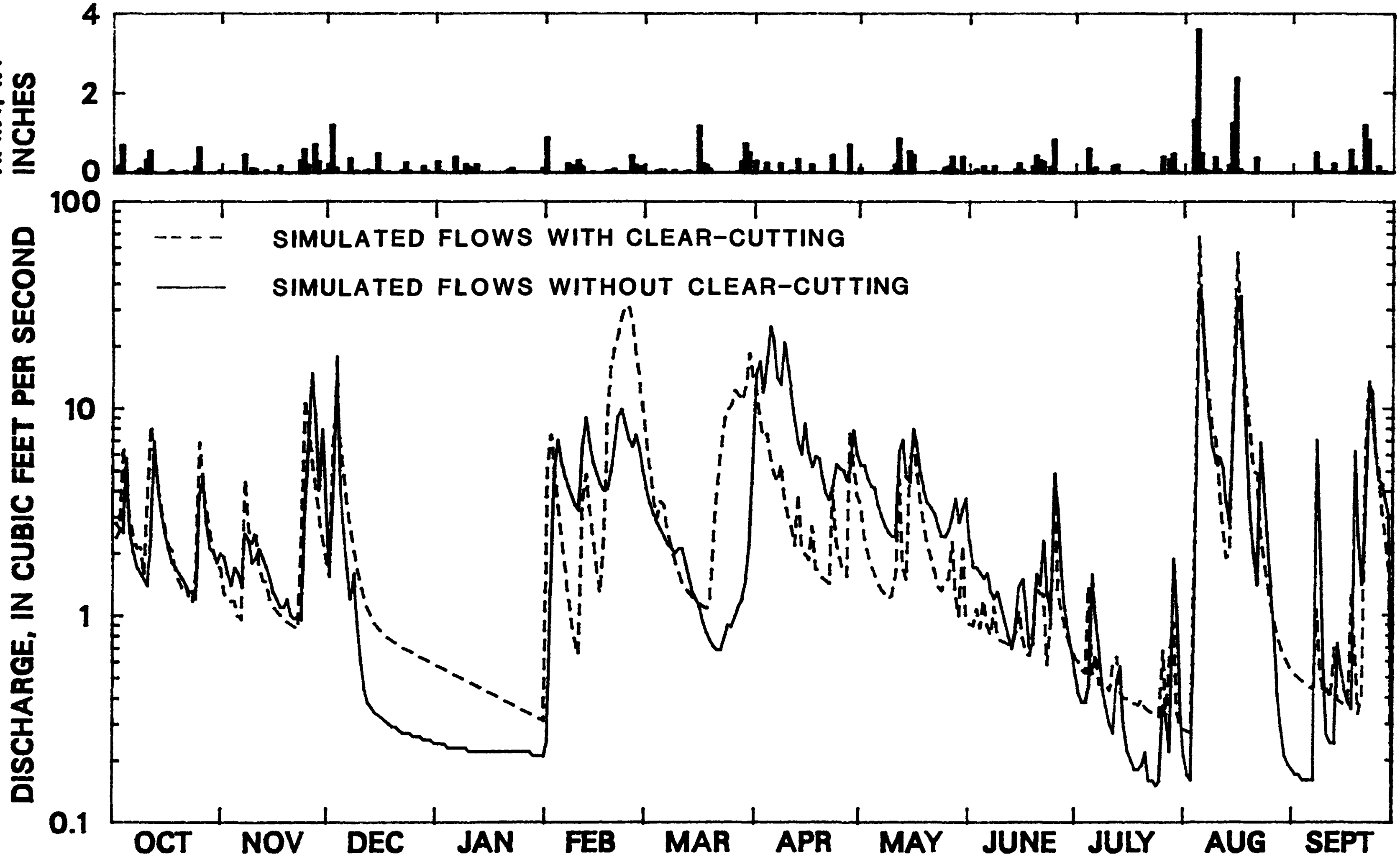

Figure 13.--Hydrographs showing changes in discharges computed using the precipitation-runoff modeling system revised basin characteristics for Bald Mountain Brook, 1981 water year.

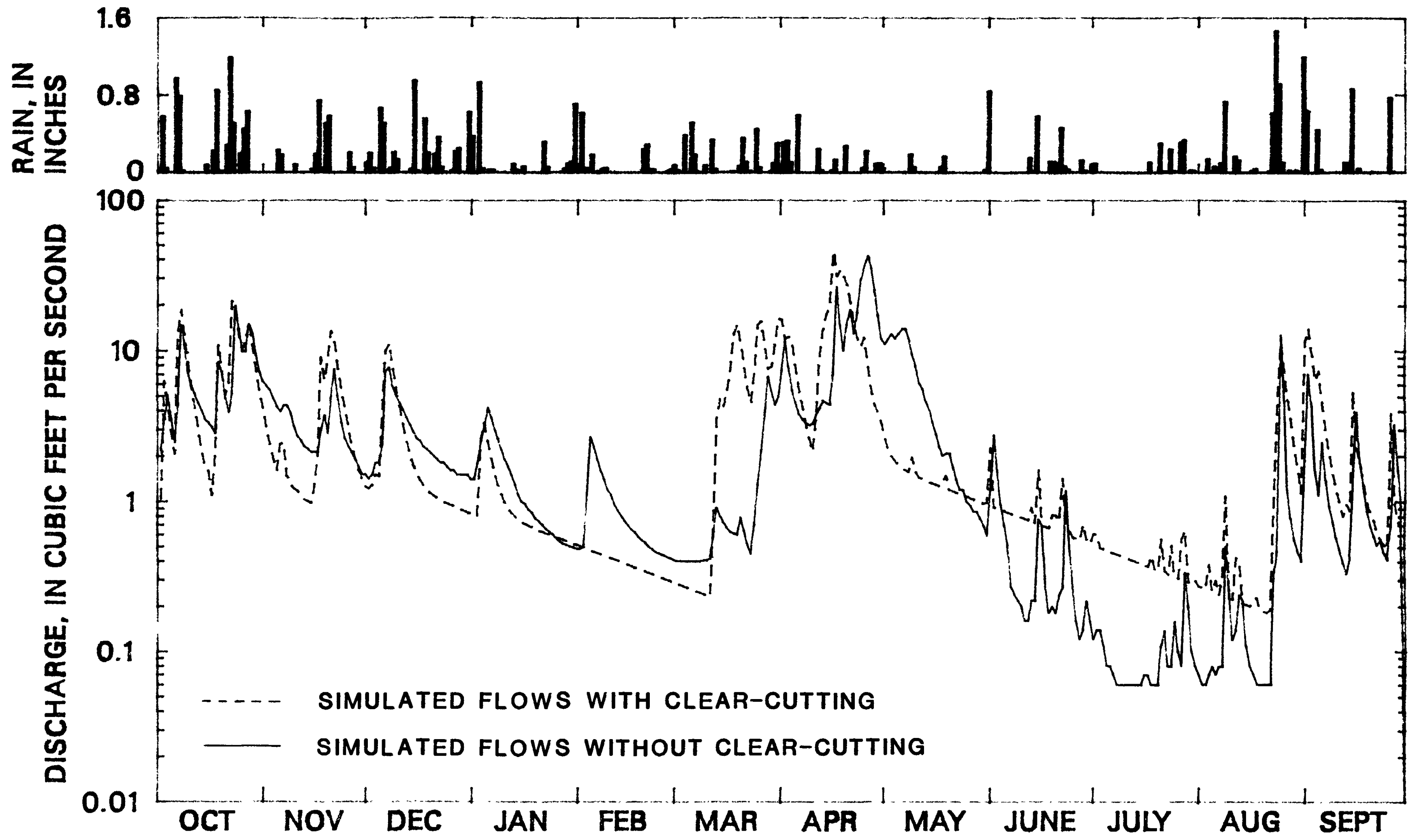

Figure 14.--Hydrographs showing changes in discharges computed using the precipitation-runoff modeling system revised basin characteristics for Bald Mountain Brook, 1982 water year.

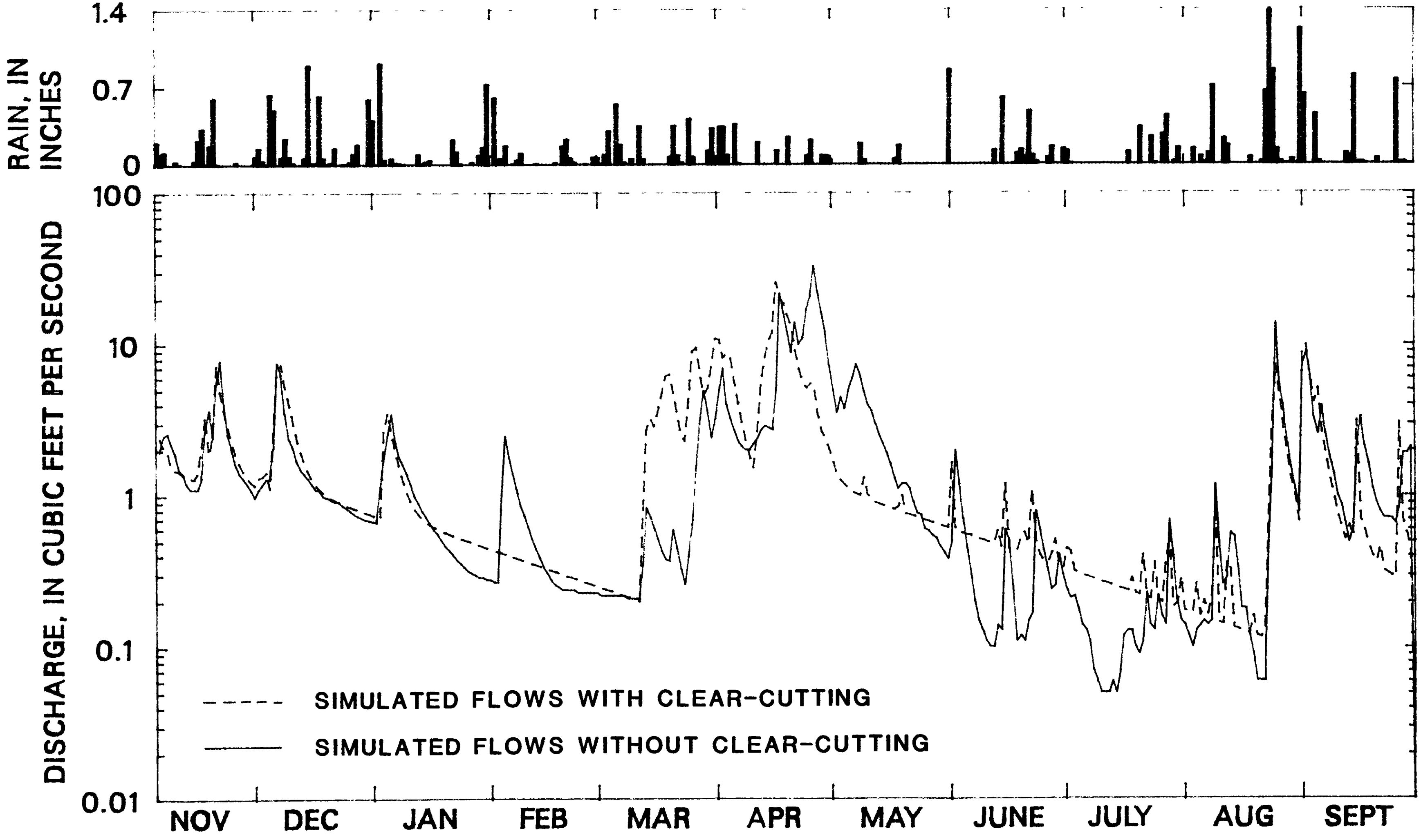

Figure 15.--Hydrographs showing changes in discharges computed using the precipitation-runoff modeling system revised basin characteristics for Bishop Mountain Brook, 1982 water year.

Table 17.--Quantity of water in each major model component for verification and simulated timber harvesting results, 1981 water year, Bald Mountain Brook.

Model Component	Final Verification Run Results	Simulation Results									
		Run 1 1/	Run 2 1/	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10 1/
Observed precipitation (in)	43.77	43.77	43.77	43.77	43.77	43.77	43.77	43.77	43.77	43.77	43.77
Net precipitation (in)	40.12	40.44	40.98	41.82	42.10	42.13	42.36	42.54	42.71	43.06	43.17
Potential evapotranspiration (in)	21.11	21.11	21.11	21.11	21.11	21.11	21.11	21.11	21.11	21.11	21.11
Actual evapotranspiration (in)	13.11	13.44	14.05	14.97	15.29	15.32	15.57	15.77	15.95	16.36	16.52
Predicted runoff (in)	27.60	27.59	27.53	27.48	27.45	27.45	27.43	27.42	27.41	27.36	27.32
Ground-water reservoir inflow (in)	5.94	5.88	5.78	5.62	5.56	5.55	5.50	5.48	5.47	5.39	5.30
Subsurface reservoir inflow (in)	17.10	17.13	17.11	17.00	16.94	16.93	16.91	16.90	16.90	16.88	16.84
Subsurface to ground-water flow (in)	0.42	0.42	0.42	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Surface runoff (in)	3.76	3.78	3.84	4.05	4.13	4.14	4.19	4.21	4.22	4.26	4.34
Subsurface flow (in)	16.59	16.62	16.60	16.49	16.43	16.43	16.40	16.40	16.39	16.37	16.34
Ground-water flow (in)	7.25	7.19	7.09	6.94	6.89	6.87	6.83	6.81	6.80	6.73	6.64

1/ Run 1 indicates HRU 1 has been clear-cut, Run 2 indicates HRU's 1 and 2 have been clear-cut, ..., Run 10 indicates the entire watershed has been clear-cut.

Table 18.--Quanity of water in each major model component for verification and simulated timber harvesting results, 1982 water year, Bald Mountain Brook.

Model Component	Final Verification Run Results	Simulation Results									
		Run 1 1/	Run 2 1/	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10 1/
Observed Precipitation (in)	39.36	39.36	39.36	39.36	39.36	39.36	39.36	39.36	39.36	39.36	39.36
Net precipitation (in)	36.42	36.68	37.14	37.84	38.07	38.10	38.29	38.44	38.58	38.87	38.97
Potential evapotranspiration (in)	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13
Actual evapotranspiration (in)	9.55	9.80	10.24	10.92	11.14	11.17	11.35	11.48	11.62	11.89	12.00
Predicted runoff (in)	27.00	27.01	27.02	27.06	27.07	27.07	27.08	27.10	27.11	27.12	27.12
Ground-water reservoir inflow (in)	6.23	6.14	6.05	5.93	5.89	5.88	5.87	5.85	5.85	5.81	5.80
Subsurface reservoir inflow (in)	18.46	18.46	18.51	18.54	18.55	18.55	18.54	18.55	18.55	18.57	18.59
Subsurface to ground-water flow (in)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Surface runoff (in)	2.50	2.59	2.65	2.77	2.81	2.82	2.85	2.87	2.88	2.92	2.91
Subsurface flow (in)	17.89	17.89	17.93	17.96	17.97	17.97	17.97	17.97	17.97	17.99	18.01
Groundwater flow (in)	6.61	6.53	6.44	6.32	6.29	6.27	6.26	6.25	6.25	6.21	6.20

1/ Run 1 indicates HRU 1 has been clear-cut, Run 2 indicates HRU's 1 and 2 have been clear-cut, ..., Run 10, indicates the entire watershed has been clear-cut.

Table 19.--Quantity of water in each major model component for verification and simulated timber harvesting results, Bishop Mountain Brook, 1982 water year.
[Results for 1982 water year represent only partial year November 5 to September 30.]

Model Component	Final Verification Run Results	Simulation Results								
		Run 1[1/]	Run 2[1/]	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9[1/]
Observed precipitation (in)	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34	30.34
Net precipitation (in)	27.75	28.06	28.40	28.64	29.04	29.17	29.24	29.74	29.96	30.03
Potential evapotranspiration (in)	19.44	19.44	19.44	19.44	19.44	19.44	19.44	19.44	19.44	19.44
Actual evapotranspiration (in)	9.22	9.51	9.84	10.07	10.44	10.56	10.65	11.14	11.36	11.44
Predicted runoff (in)	20.22	20.25	20.28	20.29	20.34	20.35	20.33	20.38	20.39	20.38
Ground-water reservoir inflow (in)	4.48	4.44	4.42	4.41	4.38	4.37	4.34	4.30	4.27	4.28
Subsurface reservoir inflow (in)	12.10	12.15	12.16	12.17	12.20	12.21	12.19	12.19	12.19	12.25
Subsurface to ground-water flow (in)	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Surface runoff (in)	1.78	1.80	1.83	1.84	1.88	1.89	1.92	1.99	2.02	1.95
Subsurface flow (in)	11.72	11.77	11.78	11.79	11.82	11.83	11.81	11.82	11.82	11.87
Groundwater flow (in)	6.72	6.68	6.66	6.66	6.64	6.63	6.60	6.57	6.55	6.56

1/ Run 1 indicates HRU 1 has been clear-cut, Run 2 indicates HRU's 1 and 2 have been clear-cut,...,
Run 9 indicates the entire watershed has been clear-cut.

SUMMARY

A massive copper-zinc ore body was discovered on the northwestern slopes of Bald Mountain, Aroostook County, Maine, in 1977. Potential environmental problems associated with development and extraction of the ore prompted a hydrologic study of the watersheds in the vicinity of the deposit. An intensive data-collection program was operated in the vicinity of Bald Mountain from June 1979 through June 1984 to allow description of existing surface-water quality and streamflow characteristics in the area and to provide the data necessary for more detailed studies.

Surface runoff in the watersheds near Bald Mountain was suitable for most uses. Only concentrations of iron exceeded drinking water standards established by the State of Maine. Dissolved solids were very low, as indicated by a mean specific conductance for all water samples of only 50 μs/cm. Suspended-sediment concentrations exceeded 100 mg/L in only 13 of 3,400 samples. Color of the water was high, with a mean of 48 platinum-cobalt units. Values of pH were near neutral, ranging from 5.9 to 7.4. Dissolved-oxygen concentrations were at or near saturation; the lowest value observed was 6.7 mg/L or 75 percent of saturation. Concentrations of phosphorus and nitrogen species averaged 0.012 mg/L for total phosphous (as phosphorus) and 0.12 mg/L for total nitrite plus nitrate (as nitrogen). Concentrations of total cadmium, total chromium, total copper, total lead, and total zinc were very low. The highest value measured for these trace metals was 120 μg/L for total zinc. Total iron concentrations as high as 8,300 μg/L were measured, well above the recommended limit of 300 μg/L.

Two of the watersheds most likely to be affected by mine development, Bald Mountain Brook and Bishop Mountain Brook watersheds, were selected for detailed study. In the two watersheds, use of the U.S. Geological Survey's PRMS model to simulate runoff processes was evaluated. Graphical and statistical evaluation of model calibration results indicated reliable calibration over the range of observed runoff, except for summer low-flow periods were model results are only fair. Graphical analyses of observed relative to predicted daily discharges during the verification period indicate favorable agreement, with the exception of summer low-flow periods. Predicted total discharge for the verification period was within 6.5 percent of observed total discharge in the Bald Mountain Brook watershed and within 3.2 percent on the Bishop Mountain Brook watershed. Coefficients of determination for the verification period were 0.71 and 0.84 for Bald Mountain Brook and Bishop Mountain Brook watersheds, respectively.

Sensitivity analysis for both watershed models indicate that SMAX was the most sensitive parameter, and SC1 was the next. Changes in the values of these two parameters have a greater effect on predicted flows in Bald Mountain Brook and Bishop Mountain Brook than changes in the other parameters evaluated.

Results from the daily mode calibration and verification of the PRMS model in the Bald Mountain Brook and Bishop Mountain Brook watersheds indicate that this model can be used successfully in the northeastern United States.

Application of the calibrated and verified PRMS model to a hypothetical clear-cut operation in the study watersheds provided an example of potential PRMS model simulation capabilities. Several trends of the type that might be useful in evaluating future mining proposals were noted in the hypothetical application in the Bald Mountain Brook and Bishop Mountain Brook watersheds. For example, snowmelt-runoff characteristics were drastically altered in the watersheds where earlier and sometimes greater peak runoffs were observed.

REFERENCES CITED

Anderson, H. W., Hoover, M. D., and Reinhart, K. G., 1976, Forest and water: Effects of forest management on floods, sedimentation and water supply: U.S. Department of Agriculture, Forest Service, General Technical Report PSW-18, 115 p.

Farnsworth, R. K., Thompson, E. S., and Peck, E. L., 1982, Evaporation atlas for the contiguous 48 United States: National Oceanic and Atmospheric Administration Technical Report NWS33, 26 p.

Fontaine, R. A., 1989, Hydrologic and meteorologic data for the Bald Mountain area, Aroostook County, Maine--June 1979 through June 1984: U.S. Geological Survey Open-File Report 85-174, 166 p.

Hornbeck, J. W., 1973, Stormflow from hardwood-forested and cleared watersheds in New Hampshire: Water Resources Research, v. 9, no. 2, p. 346-354.

Leavesley, G. H., and Striffler, W. D., 1978, A mountain watershed simulation model; In Colbec, S. C., and Roy, M., eds., Modeling of snow cover runoff, Hanover, New Hampshire, 1978, Proceedings: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, p. 379-386.

Leavesley, G. H., Lichty, R. W., Troutman, B. M., and Saindon, L. G., 1983, Precipitation-runoff modeling system: user's manual: U.S. Geological Survey Water-Resources Investigations 83-4238, 207 p.

Lorens, J. A., 1982, Computer programs for modeling flow and water quality of surface water systems: U. S. Geological Survey Open-File Report 82-430, 62 p.

Lull, H. W., and Reinhart, K. G., 1972, Forest and floods in the eastern United States: U.S. Department of Agriculture, Forest Service, Research Paper NE-226, 94 p.

Maine Department of Human Services, 1983, State of Maine rules relating to drinking water: Augusta, Maine, 51 p.

-----,1984, Rules relating to testing of private water systems for potentially hazardous contaminants: Augusta, Maine, 14 p.

Morrill, R. A., 1975, A technique for estimating the magnitude and frequency of floods in Maine: U.S. Geological Survey Open-File Report 75-292, 44 p.

Parker, G. W., 1978, Methods for determining selected flow characteristics for streams in Maine: U.S. Geological Survey Open-File Report 78-871, 31 p.

Philip, J. R., 1954, An infiltration equation with physical significance: Soil Science Society of America Proceedings, vol. 77, p. 153-157.

Scott, A. G., 1984, Analysis of characteristics of simulated flows from small surface-mined and undisturbed Applachian watersheds in the Tug Fork basin of Kentucky, Virginia, and West Virginia: U.S. Geological Survey Water-Resources Investigations Report 84-4451, 169 p.

Turkel, T., 1981, Going underground in search of Maine's mother lode of minerals: Maine Sunday Telegram January 11, 1981, P. 1-D.

U.S. Army, 1956, Snow hydrology: Portland, Oregon, U.S. Army Corps of Engineers, North Pacific Division, 437 p.

U.S. Geological Survey, 1981-84, Water resouces data for Maine, 1981-84: U.S. Geological Survey Water-Data Reports ME-81-1 to ME-84-1 (published annually.)

Verry, E. S., Lewis, J. R., and Brooks, K. N., 1983, Aspen clear-cutting increases snowmelt and storm flow peaks in north central Minnesota: Water Resources Bulletin, vol. 19, no. 1, p. 59-67.