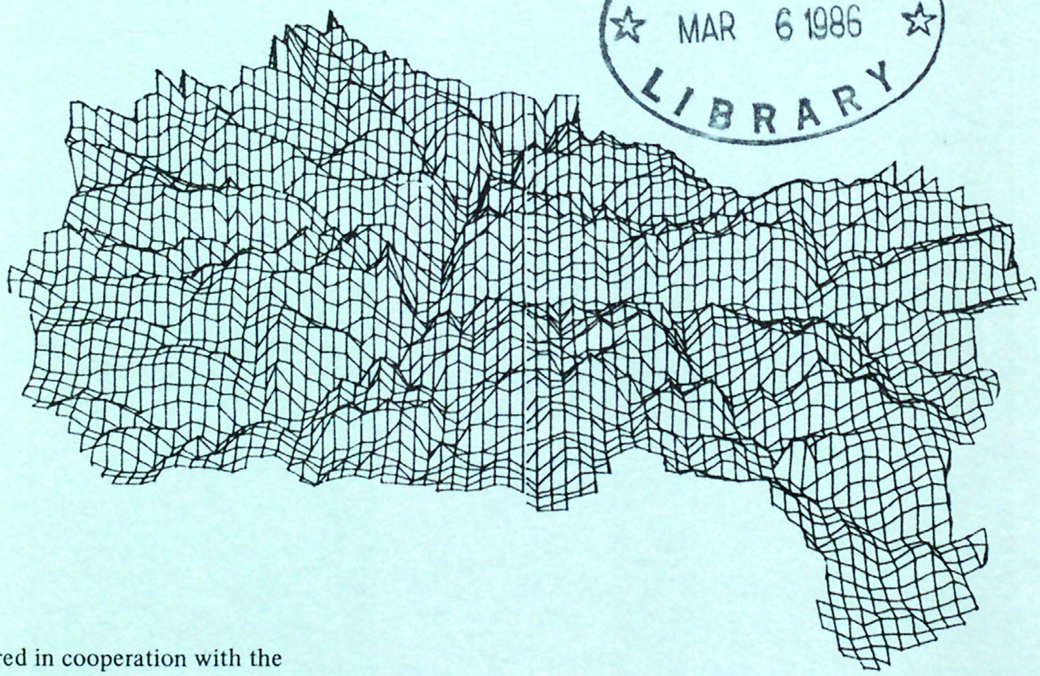
APPLICATION OF THE PRECIPITATION-RUNOFF MODEL IN THE WARRIOR COAL FIELD, ALABAMA

U.S. GEOLOGICAL SURVEY

Open-File Report 85-678



Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

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IN THE WARRIOR COAL FIELD, ALABAMA

By Robert E. Kidd and C. R. Bossong

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Tuscaloosa, Alabama

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS AND ABBREVIATIONS

INCH-POUND TO METRIC

Multiply Inch-Pound Units	By	To Obtain SI Unit
Inch (in.)	25.4	Millimeter (mm)
Inch per hour (in/h)	2.54	Centimeter per hour (cm/h)
Foot (ft)	0.3048	Meter (m)
Mile (mi)	1.609	Kilometer (km)
Foot per mile (ft/mi)	0.1894	Meter per kilometer (m/km)
Square mile (mi^2)	2.590	Square kilometer (km^2)
Mile per square mile (mi/mi^2)	0.622	Kilometer per square kilometer (km/km^2)
Acre	0.4047	Hectare (ha)
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)

Microsiemens per centimeter at 25 °C (uS/cm)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows: °C = (°F - 32) X 5/9.

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ABSTRACT

A deterministic precipitation-runoff model, the Precipitation Runoff Modeling System, was applied in two small basins located in the Warrior coal field, Alabama. Each basin has distinct geologic, hydrologic, and land use characteristics. Bear Creek basin (15.03 square miles) is undisturbed and underlain almost entirely by consolidated coal bearing rocks of Pennsylvanian age (Pottsville Formation) and is drained by an intermittent stream. Turkey Creek basin (6.16 square miles) contains a surface coal mine, is underlain by both the Pottsville Formation and unconsolidated clay, sand, and gravel deposits of Cretaceous age (Coker Formation). Aquifers in the Coker Formation sustain flow through extended rainless periods.

Preliminary daily and storm calibrations were developed for each basin. Initial parameter and variable values were determined with techniques recommended in the users manual (Leavesley and others, 1983) and through field reconnaissance. Parameters with meaningful sensitivity were identified and adjusted to match hydrograph shapes and compute realistic water year budgets. When the developed calibrations were applied to data exclusive of the calibration period as a verification exercise, results were obtained that were comparable to those for the calibration period.

The model calibrations included preliminary parameter values for the various categories of geology and land use in each basin. The parameter values for areas underlain by the Pottsville Formation in the Bear Creek basin were transferred directly to similar areas in the Turkey Creek basin, and these parameter values were held constant throughout the model calibration. Parameter values for all geologic and land use categories addressed in the two calibrations can probably be used in ungaged basins where similar conditions exist. The parameter transfer worked well as a good calibration was obtained for Turkey Creek basin.

INTRODUCTION

The U.S. Department of the Interior, as a part of a program to attain national energy goals, is responsible for the leasing of Federal coal reserves. The chief environmental issue addressed by this program is the impact of coal mining on water resources. The Surface Mining Control and Reclamation Act of 1977, Public Law 95-87, (U.S. Congress, 1977) requires an understanding of the hydrology in existing and proposed surface-mined areas in order to determine this impact. Hydrologic data for mine sites and adjacent areas are needed to satisfy requirements defined in the Act. The Act specifies that modeling techniques may be used to generate these data.

The U.S. Geological Survey (USGS), Water Resources Division and the U.S. Bureau of Land Management (BLM) began cooperative work in Alabama in 1977 to acquire a modeling capability that could be used to estimate impacts of coal mining on water resources.

Objectives

The objectives of this report are threefold and concern the use of the U.S. Geological Survey's Precipitation Runoff Modeling System (PRMS), a physically based distributed parameter precipitation-runoff model. The primary objective is to discuss the calibration and verification procedures used in different geologic-hydrologic areas in the Warrior coal field of Alabama. It is not the intent of the authors to quantitatively describe these procedures, but rather to discuss the general rationale which was used in their application. The secondary objectives are: (1) to demonstrate the results of the calibration, and (2) to discuss and demonstrate the transfer utility of the calibrations.

Previous Investigations

Miller and Causey (1958) described general geology and hydrology of Tuscaloosa County.

Paulson and others (1962) discussed geologic formations and their water-bearing characteristics, water-level fluctuations, and water quality in Tuscaloosa County.

Harkins and others (1980) presented information about sources of hydrologic information and existing hydrologic conditions in the southern end of the Eastern Coal Province which includes the Warrior coal field. Puente, and others (1980) presented hydrologic data collected from October 1976 through September 1978 in Bear, Blue, Yellow, and Turkey Creek basins in Tuscaloosa County.

Puente, and others (1982) assessed the hydrology of four potential Federal coal-lease tracts in Tuscaloosa and Fayette Counties. Puente and Newton (1982) described calibration of the PRMS digital model using one hydrologic response unit to simulate streamflow in selected basins in Tuscaloosa County. The modeling errors associated with simulated monthly mean discharges were attributed to model parameters that define soil-moisture accretion and depletion rates, subsurface and ground-water storage volumes, and routing coefficients.

Acknowledgments

Acknowledgment is made to Linda Saindon, Robert Lichty, and George Leavesley of the Precipitation-Runoff Modeling Group of U.S. Geological Survey, Water Resources Division, Central Region, for their excellent assistance and frequent counseling whenever difficulties were encountered. Acknowledgment is also made to Alan Lumb, U.S. Geological Survey, Water Resources Division, Branch of Surface water for his guidance.

AREAS OF STUDY

Physical Setting

Bear and Turkey Creek basins lie within the Warrior basin of the Cumberland Plateau. The Warrior basin is a large, shallow synclinal structure modified by several smaller synclines and anticlines, the Wiley Dome, and numerous north and northwest trending normal faults with limited displacement. The Warrior coal field (fig. 1) is the largest coal field in terms of area, production, and reserves in Alabama. The Warrior basin consists chiefly of a submaturely to maturely dissected upland developed largely on nearly flat-lying rocks (Johnston, 1933). Maximum relief is about 400 ft with numerous tributaries incised sharply into shale and sandstone that support ridges and steep slopes. Most basins are separated by sharp ridges. This is modified somewhat along southern and western boundaries of the coal field where unconsolidated sediments overlie the harder rocks. In these areas, hilltops and ridges tend to be less sharp and, in places, relatively flat.

Bear Creek basin is located in northern Tuscaloosa County, Ala. (fig. 1). The basin has a drainage area of 15.03 mi^2 (fig. 2). Total relief is about 380 ft and steepest slopes occur where streams are incised into the upland surface as much as 100 ft. The uplands have about 180 ft of relief and are generally hilly although relatively flat areas occur on some sub-basin divides and on the northern basin divide. The overland slope varies from 2 to 41 percent and averages 14 percent.

The main channel of Bear Creek has a sinuous shape and is 8.44 mi long. The average channel slope (Sc) is 0.5 percent. The slope varies from 0.2 percent, along the lower 70 percent of the reach, where the flood plain is up to 0.10 mi wide, to 1.5 percent in the headwater reach. Four major tributary channels, all with flood plains, each drain areas greater than 0.75 mi^2. The channel slope of a major tributary channel, Dry Branch, is 1.8 percent, roughly an order of magnitude greater than the main channel slope. However, profiles for both channels have similar shapes and they are notably steeper in their headwater reaches (fig. 3). Tributary A has a slope of 3.6 percent, and has a more uniform channel profile than the other channels. Riffles are common in all channels but pools generally occur only in the main and major tributary channels.

Turkey Creek basin, (fig. 4) located in central Tuscaloosa County (fig. 1), has an area of 6.08 mi^2. Maximum topographic relief is about 330 ft. The basin has a dendritic drainage pattern with streams incised as much as 80 ft. Upland areas of the basin have about 80 ft of relief with relatively flat areas on sub-basin divides. The overland slope varies from 1 to 37 percent. The average overland slope is 11 percent.

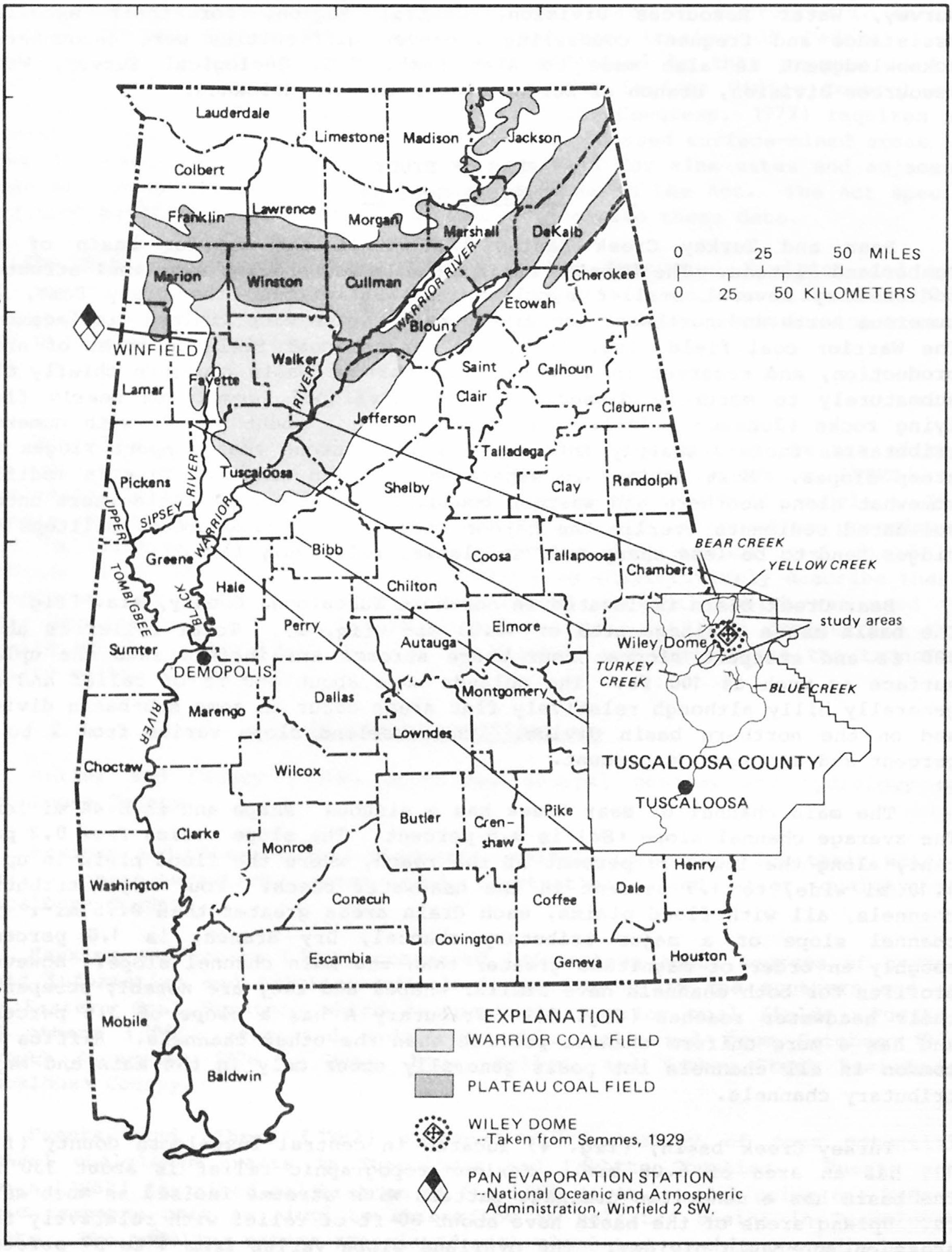

Figure 1. Location of the study areas, Wiley Dome and pan evaporation station.

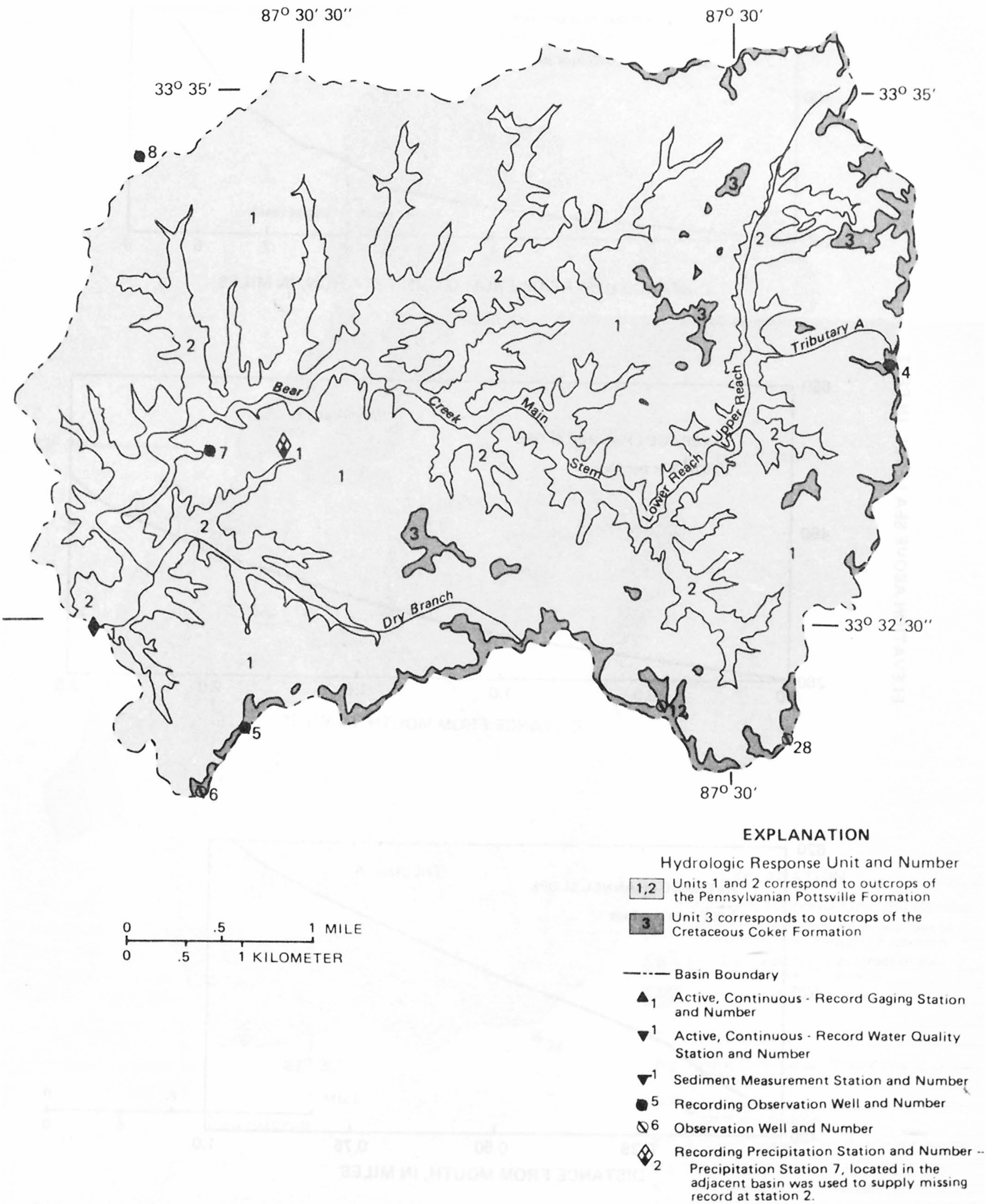

Figure 2. Geology, hydrologic response units and data collection sites in Bear Creek basin.

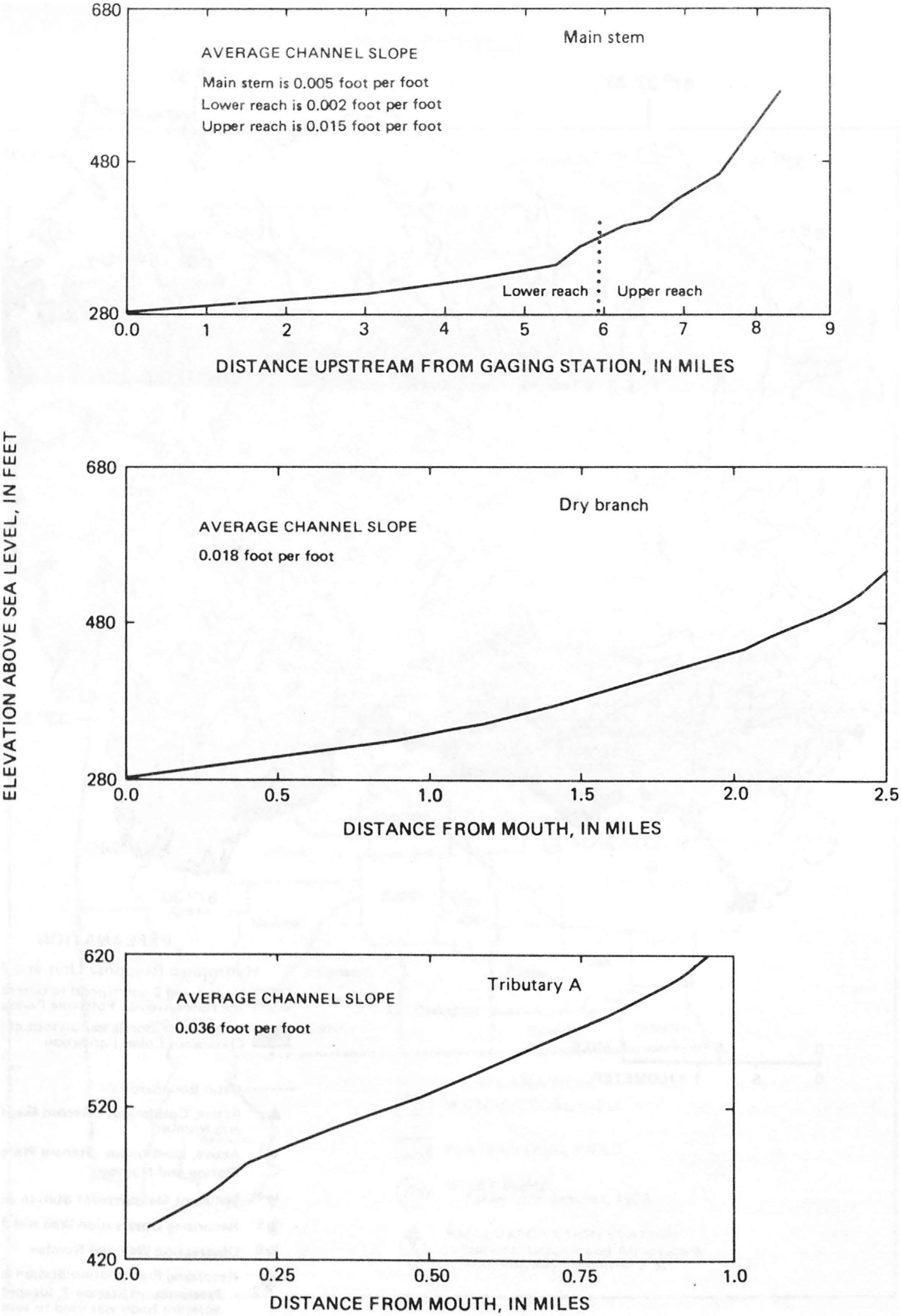

Figure 3. Channel profiles for the main stem and selected tributaries in Bear Creek basin. Channel locations are shown on figure 2.

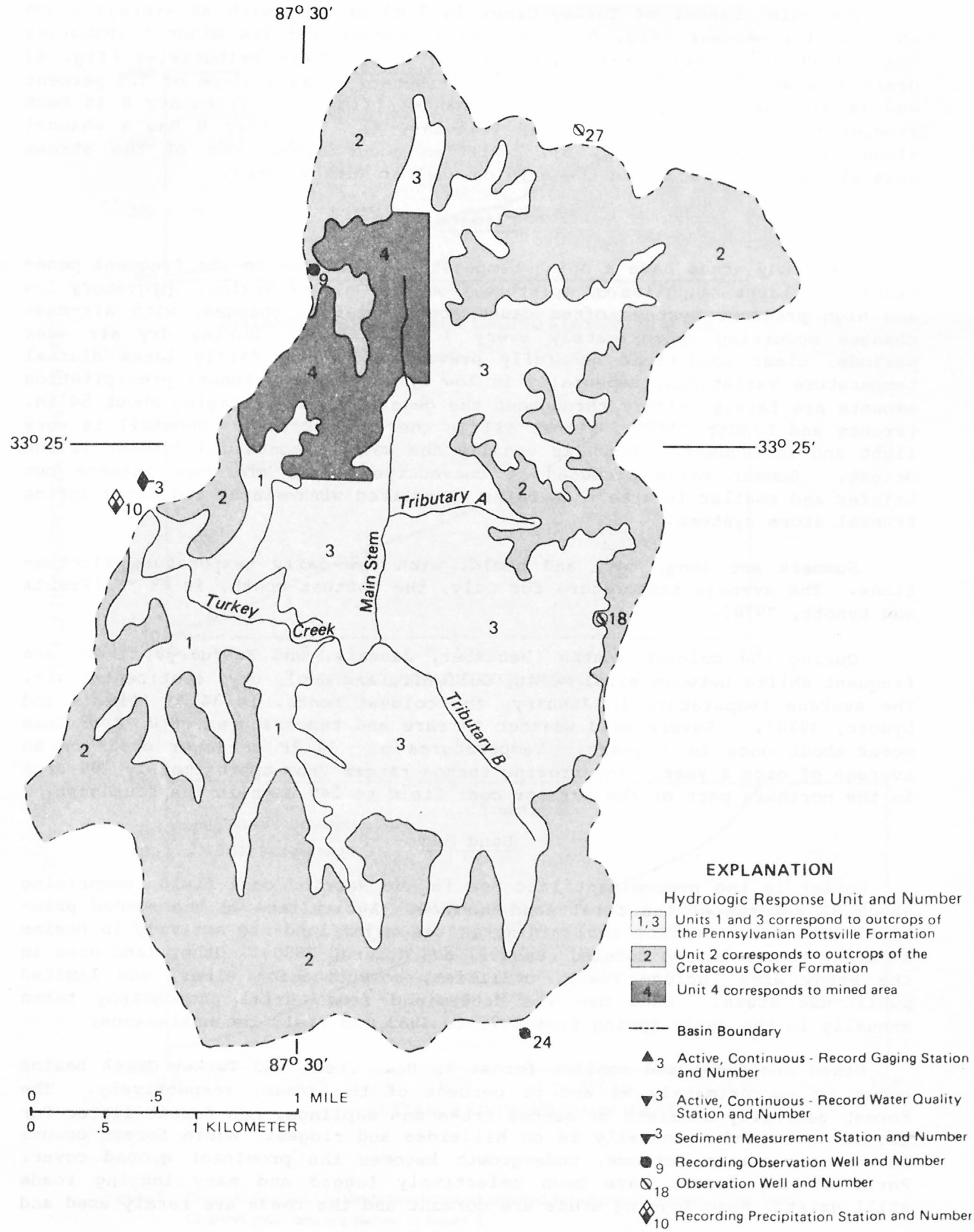

Figure 4. Geology, hydrologic response units and data collection sites in Turkey Creek basin.

The main channel of Turkey Creek is 3.81 mi long with an average slope (Sc) of 1.2 percent (fig. 5). The main channel and its minor tributaries drain 3.58 mi^2. Major tributaries A and B and their tributaries (fig. 4) drain 1.02 and 1.48 mi^2, respectively. Tributary A has a slope of 1.9 percent and is similar in shape to the main channel (fig. 5). Tributary B is much steeper than the main channel and Tributary A. Tributary B has a channel slope of 3.1 percent (fig. 5). Riffles occur along most of the stream channels and pools occur in the main channel of Turkey Creek.

Climate

The study areas have a moist temperate climate due to the frequent penetration of large supplies of moisture from the Gulf of Mexico. Migratory low and high pressure systems often cause abrupt weather changes, with air-mass changes occurring approximately every 3 to 5 days. During dry air mass periods, clear conditions generally prevail and cause fairly large diurnal temperature variations, especially in low lying areas. Annual precipitation amounts are fairly uniform throughout the general area, averaging about 54 in. (Frentz and Lynott, 1978), almost all in the form of rain. Snowfall is very light and infrequent. March is usually the wettest month and October is the driest. Summer rains produced by convective storms are more intense but briefer and smaller in area than rains associated with winter and early spring frontal storm systems.

Summers are long, hot, and humid, with few daily temperature fluctuations. The average temperature for July, the hottest month, is 69 °F (Frentz and Lynott, 1978).

During the coldest months (December, January, and February), there are frequent shifts between mild, moist, Gulf air, and cool, dry, continental air. The average temperature in January, the coldest month, is 34 °F (Frentz and Lynott, 1978). Severe cold weather is rare and temperatures of 0 °F or less occur about once in 7 years. Temperatures of 10 °F or lower occur on an average of once a year. The growing season ranges from approximately 200 days in the northern part of the Warrior coal field to 240 days in the southeast.

Land Use

Forest is the predominant land use in the Warrior coal field, comprising about 82 percent of the total land surface. Agriculture is the second principal land use. Surface coal mining is the major land-use activity in basins adjacent to the basins modeled (Puente, and others, 1980). Other land uses in the study area include roads, utilities, communication sites, and limited public-use areas. Land use was determined from aerial photography taken annually in the early spring from 1977 to 1983 and field reconnaissance.

Mixed deciduous and conifer forest in Bear Creek and Turkey Creek basins occur in approximately 95 and 90 percent of the areas, respectively. The forest generally consists of mature trees and saplings, has forest litter for ground cover and generally is on hillsides and ridges. Where forest occurs in or near stream bottoms, undergrowth becomes the prominent ground cover. Parts of the forest have been selectively logged and many logging roads still exist. Most logging areas are dormant and the roads are rarely used and

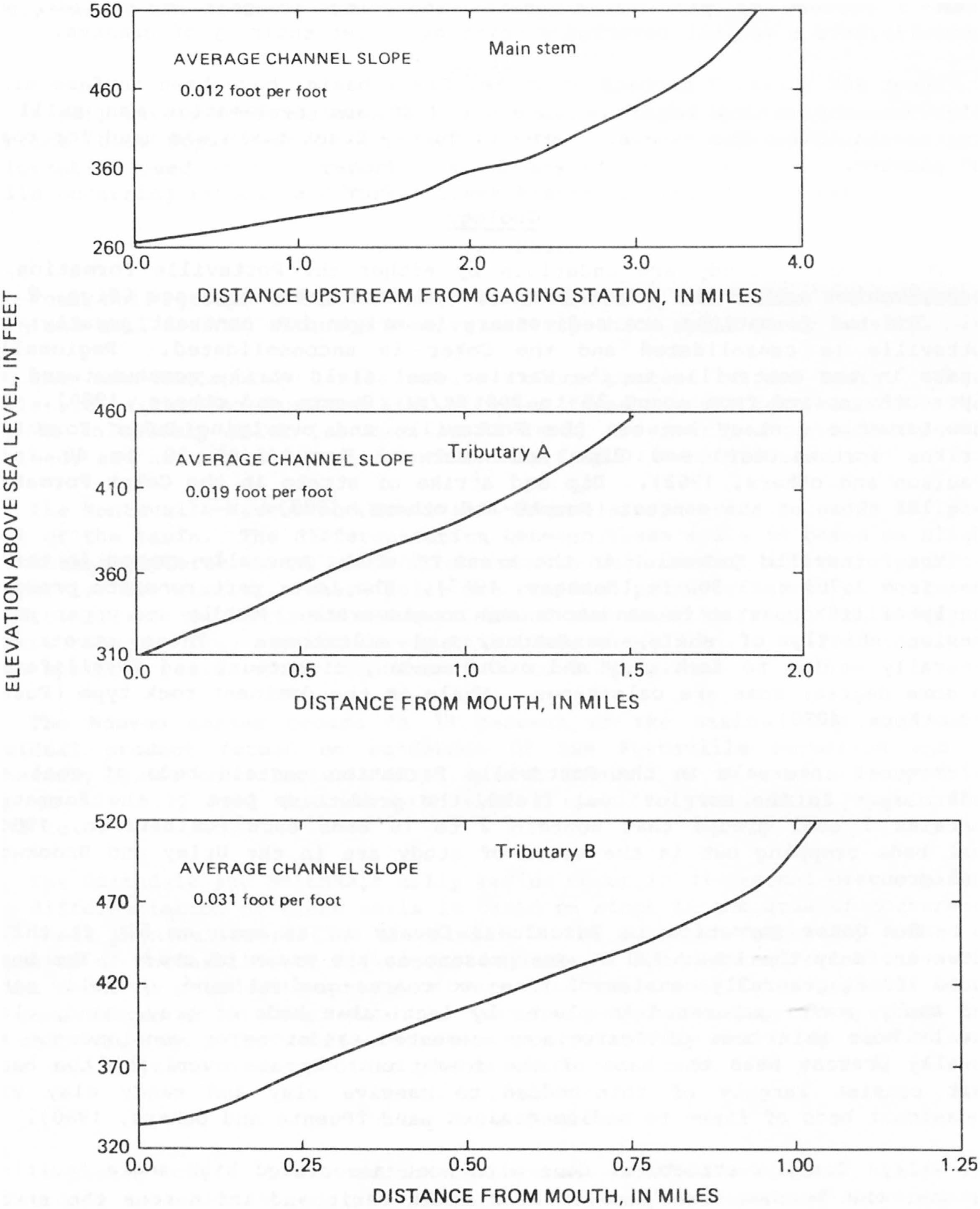

Figure 5. Channel profiles for the main stem and selected tributaries in Turkey Creek basin. Channel locations are shown in figure 4.

generally covered with forest litter. Approximately 1 percent of Bear Creek basin experienced active logging during the PRMS application period (January 1, 1978 to September 30, 1982). Areas cleared and now used for pasture occupy about 5 percent of Bear Creek basin, including domestic residences, and generally have a vegetal covering consisting almost entirely of grasses.

About 268 acres, 7 percent of Turkey Creek basin, have been surface mined (fig. 4). The mining began in November 1980 and reclamation was still in progress in 1984. The remaining area of Turkey Creek basin was used for roads and pasture.

Geology

The areas of study are underlain by either the Pottsville Formation of Pennsylvanian age or the Coker Formation of Late Cretaceous age (figs. 2 and 4). The two formations are sedimentary in origin but contrast greatly; the Pottsville is consolidated and the Coker is unconsolidated. Regionally, strata in the Pottsville in the Warrior coal field strike northwestward and dip southwestward from about 30 to 200 ft/mi (Puente and others, 1980). The unconformable contact between the Pottsville and overlying Coker Formation strikes northwestward and dips southwestward from about 30 to 40 ft/mi (Paulson and others, 1962). Dip and strike of strata in the Coker Formation parallel those of the contact (Puente and others, 1980).

The Pottsville Formation in the areas of study generally ranges in thickness from 2,700 to 3,300 ft (Metzger, 1965). The lower part consists predominantly of orthoquartzitic sandstone and conglomerate. Middle and upper parts consist chiefly of shale, sandstone, and siltstone. These strata are generally medium to dark gray and carbonaceous, micaceous, and fossiliferous to some degree; some are calcareous. Shale is the dominant rock type (Puente and others, 1980).

Several intervals in the Pottsville Formation contain beds of coal and underclay. In the Warrior coal field, the productive part of the formation contains 7 coal groups that contain 2 to 10 beds each (Culbertson, 1964). Coal beds cropping out in the areas of study are in the Utley and Brookwood coal groups.

The Coker Formation in Tuscaloosa County is as much as 500 ft thick; however, only the lower 120 ft are present in the areas of study. The basal 25 to 100 ft generally consist of fine- to coarse-grained sand, gravelly sand, and sandy gravel separated in places by lenticular beds of gray, sandy clay. One or more thin beds of ferruginous cemented sandstone or conglomerate are usually present near the base of the formation. Strata overlying the basal unit consist largely of thin-bedded to massive clay and sandy clay with occasional beds of fine- to medium-grained sand (Puente and others, 1980).

Wiley Dome, a structural dome with some associated high angle faulting, is near the southeastern part of Bear Creek basin and influences the strike and dip of Pottsville strata within the basin (fig. 1).

Geology of the study areas differ in that most of Bear Creek basin is underlain by the Pottsville Formation and most of Turkey Creek basin is underlain by the Coker Formation (figs. 2 and 4). Detailed descriptions of the geology and the occurrences and distributions of the coal resources in the two study basins are given in Puente and others (1980).

Soils

A soil survey of Tuscaloosa County conducted by the U.S. Soil Conservation Service (U.S. Department of Agriculture, 1981) is the primary source of soil information used in this report. A summary of selected soil properties for soils occurring in Bear and Turkey Creek basins is presented in table 1.

Bear Creek Basin

Four soil groups occur in Bear Creek basin. The soils are generally thin and well drained although some relatively thick soils occur locally.

The Iuka-Mantachie series occurs in one percent of the basin. These soils are formed on sand and silt alluvium found along stream bottoms. They may be relatively thick (as much as 72 in.), are poorly to moderately well drained, and have specific yields that vary from 0.10 to 0.20 in./in.

The Montevallo-Nauvoo and Montevallo-Nauvoo steep series occur in 69 percent of the basin. The differentiation between these soils is based on slight percentage differences of Montevallo soils in each series but their physical properties are similar. These soils are residual products formed on shale and sandstone from the Pottsville Formation and are found on steep hillsides and narrow ridges. They are relatively thin (less than 35 in.), well drained, and have specific yields which vary from 0.09 to 0.20 in./in.

The Nauvoo series occurs in 19 percent of the basin. The soil is a residual product formed on sandstone of the Pottsville Formation and is generally found on relatively flat upland areas. It is a relatively thick (up to 60 in.), well drained soil with a specific yield which varies from 0.13 to 0.17 in./in.

The Smithdale and Smithdale hilly series occur in 11 percent of the basin. The differentiation of these soils is based on slope in the area of occurrence and their physical properties are similar. The soils are generally formed on deposits of unconsolidated Cretaceous deposits of sand (Coker Formation). The soils occur as residual products on very thin veneers of Coker deposits found on some ridges or on Coker material that has moved downslope from ridges due to mass wasting. The soils themselves are relatively thick (up to 72 in.), well drained, and have specific yields which vary from 0.14 to 0.17 in./in.

Turkey Creek Basin

In Turkey Creek basin Smithdale-Luverne, Smithdale-Luverne hilly, and Palmerdale soil series occur in addition to the soils described above except the Nauvoo series. The occurrence of Iuka-Mantachie, Montevallo-Nauvoo steep, Smithdale, and Smithdale hilly soils in the basin is similar to their occurrence in Bear Creek basin; the part of the basin that these soils occupy is listed in table 1. The remaining soils are described below.

Table 1.--Properties of soil series in Bear and Turkey Creek basins
(Modified from U.S. Department of Agriculture, 1981)

Soil series	Depth to bedrock (inches)	Slope (percent)	Physical description	Permeability (inches/hour)	Specific yield (inch/inch)	Parent material	Part of basin (percent) Bear Creek	Part of basin (percent) Turkey Creek
Iuka-Mantachie	<72	0-2	Silt loam	0.6-2.0	0.10-0.20	Alluvium	1	1
Montevallo-Nauvoo and Montevallo-Nauvoo steep	<35	15-45	Clay loam	0.6-6.0	0.09-0.20	Shale and sandstone	69	26
Nauvoo	<60	4-10	Sandy loam	0.6-6.0	0.13-0.17	Sandstone	19	0
Palmerdale	<80	6-45	Gravelly loam	2.0-6.0	0.04-0.10	Spoil	0	7
Smithdale and Smithdale hilly	<72	6-25	Sandy loam	2.0-6.0	0.14-0.17	Sand	11	41
Smithdale-Luverne Smithdale-Luverne hilly	<72	10-35	Sandy loam	0.2-6.0	0.06-0.18	Sand	0	25

Palmerdale soils occur in 7 percent of the basin. This soil is formed on spoil material produced when coal, overlain by deposits of the Coker Formation, is surface mined. U.S. Department of Agriculture (1981) soil maps do not indicate Palmerdale soils in the basin because the maps were prepared before surface mining occurred and their presence is inferred by the authors. The soil is thick (up to 80 in.), excessively drained, and has specific yields that vary from 0.04 to 0.10 in./in (U.S. Department of Agriculture, 1981).

The Smithdale-Luverne and Smithdale-Luverne hilly series occur in 25 percent of the basin. Differentiation between these soils is based on slight differences in the percentage of Smithdale soils and their physical properties are similar. The soils are generally formed on fine grained sands from the Coker Formation. The soils are found on hillsides and in areas where the Coker has moved downslope from outcrops due to mass wasting. The soils may be relatively thick (up to 72 in.), are well drained, and have specific yields that vary from 0.06 to 0.18 in./in.

Hydrology

The Warrior coal field is in the Black Warrior and Upper Tombigbee River basins with the latter draining only the westernmost edge of the area. Land surface in these major basins is dissected by tributaries forming numerous sub-basins. The Appalachian Plateau Physiographic Province has the lowest drainage density, 3.0 to 4.0 mi/mi^2, in the United States (Chow, 1964). Low drainage density is favored in regions of highly permeable subsoil materials under dense vegetative cover (Chow, 1964). The Pottsville and Coker Formation have diverse water-bearing characteristics. Most indurated rocks in the Pottsville are relatively impermeable whereas unconsolidated sand and gravel in the Coker is permeable.

Surface Water

Streamflow characteristics are determined by climatic, physiographic and geologic conditions, and the stream-regulating activities of man. In a broad area where conditions determining streamflow characteristics are similar, basins may have similar low-, median-, and flood-flow characteristics. Many streams in the coal mining regions of Alabama do not have well-sustained flows. This is characteristic of basins underlain by soil or rocks that have a limited capacity for water storage. Streamflow recedes rapidly from sharply concentrated flood peaks to low flows, or even to no flow between storms. The median annual 7-day low flows (2- and 10-year recurrence intervals) approach or reach zero in all but the southern and western edges of the Warrior coal field.

The average discharge for streams in the area, based on records for several sites, ranges from 1.31 to 1.62 (ft^3/s)/mi^2. Most sub-basins draining coal mines have drainage areas ranging in size from 1 to 5 mi^2. The peak discharge for areas of this size during a flood with a 2-year recurrence interval generally would range from 280 to 800 (ft^3/s)/mi^2, and from 580 to 2,000 (ft^3/s)/mi^2 during a flood with a 25-year recurrence interval (Olin and Bingham, 1977).

Streamflow hydrographs reflect seasonal variations in precipitation and evapotranspiration in Bear and Turkey Creek basins. Greatest discharges usually occur from November through April when precipitation increases and evapotranspiration decreases. Observed discharges for Bear Creek and Turkey Creek are shown in figures 6 and 7, respectively. Differences in streamflow characteristics of the two streams result from variations in the geology of the basins. Bear Creek basin is underlain primarily by thin soils and the relatively impermeable Pottsville Formation; whereas, in Turkey Creek basin thicker soils and the more permeable Coker Formation covers 47 percent of the basin. The greater storage capacity of the rocks and soil in Turkey Creek basin is indicated by sustained flow throughout the year as compared to Bear Creek. Bear Creek has periods of no flow each year even though its drainage area is about three times that of Turkey Creek.

Water in streams unaffected by man's activities in the Warrior coal field is generally of good chemical quality. Adverse effects on the quality of water resulting from coal mining have been significant only in tributaries draining mined areas. The most severe and long-term degradation of water quality is greatest in the immediate vicinity of mining. Dissolved-solids concentration decreases progressively as water moves away from mined areas, and, in the Black Warrior and Sipsey Rivers, is dissipated to a large degree by large volumes of streamflow from unmined areas.

Ground Water

Quantitative data are not available to evaluate the hydraulic characteristics of the Pottsville or Coker Formations in the basins studied. The descriptions of the occurrence, storage, and movement of ground water in the respective basins are based on geology, well inventories, test wells drilled in 1978, and field examinations.

The primary source of water in the Pottsville Formation is recharge from the overlying soil. Soils formed on the Pottsville Formation are thin but have very high porosity and permeability relative to the indurated bedrock they overlie. Consequently, most water in the soil zone, which is not held by capillary forces, percolates to the soil-bedrock interface and then moves along its gradient. The water which moves through the soil zone will be referred to as subsurface flow in this report; it is conceptually similar to interflow.

Perched, confined, and unconfined conditions occur in aquifers in the Pottsville Formation (fig. 8). Water which percolates to the bedrock and does not run down the soil-bedrock interface has little opportunity to enter primary porosity available in the tightly cemented strata but will enter secondary porosity features such as fractures. The number, size, and interconnection of most fractures decreases with depth and the fractures often end abruptly when they encounter competent strata such as sandstone. Perched water tables occur at these levels. Perched water moves along the gradient of the competent layer to discharge points. Water which does not encounter perched zones percolates to deeper confined or unconfined aquifers.

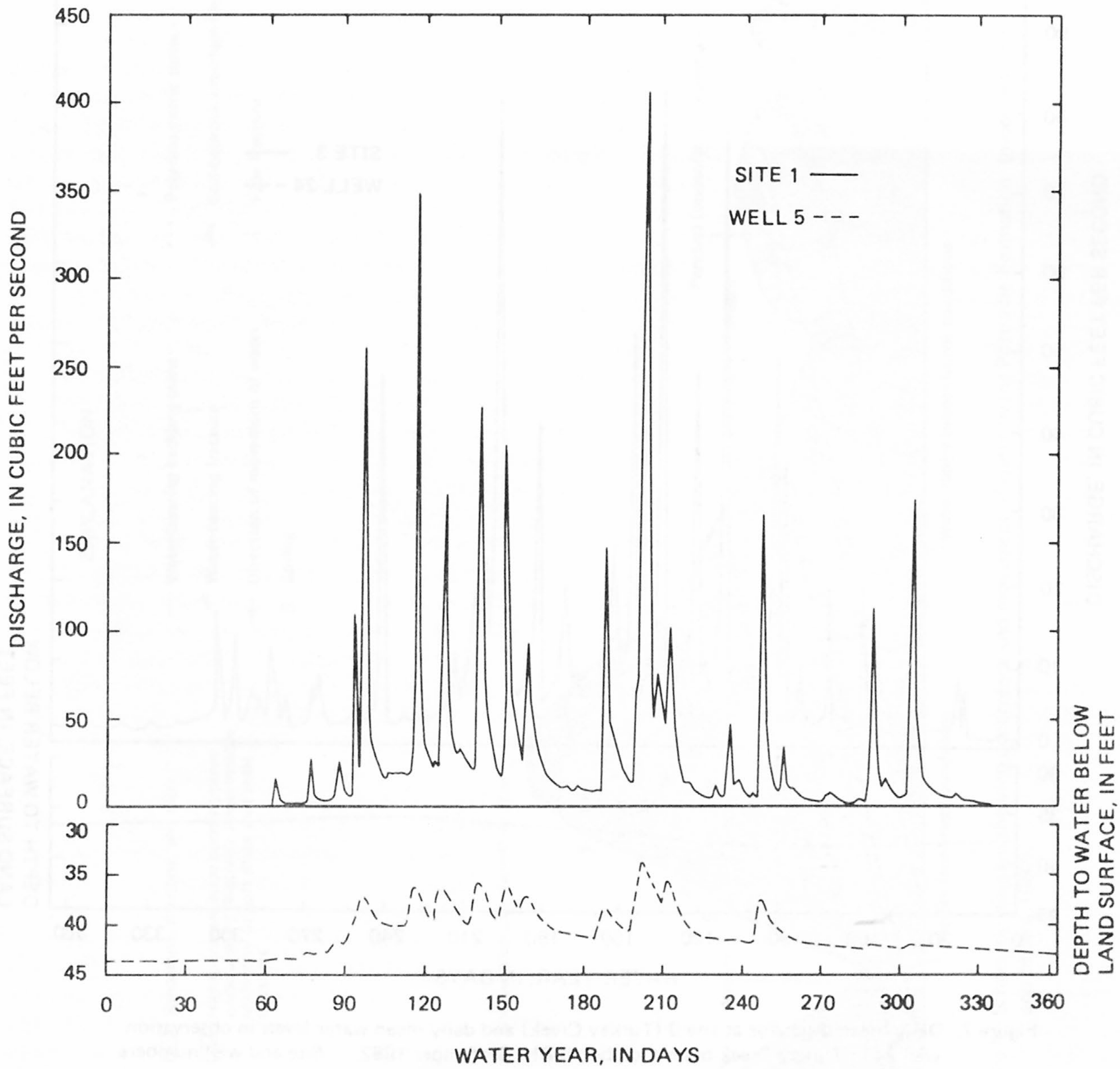

Figure 6. Daily mean discharge at site 1 (Bear Creek) and daily mean water levels in observation well 5 in Bear Creek basin October 1981 - September 1982. Site and well numbers correspond to those on figure 2.

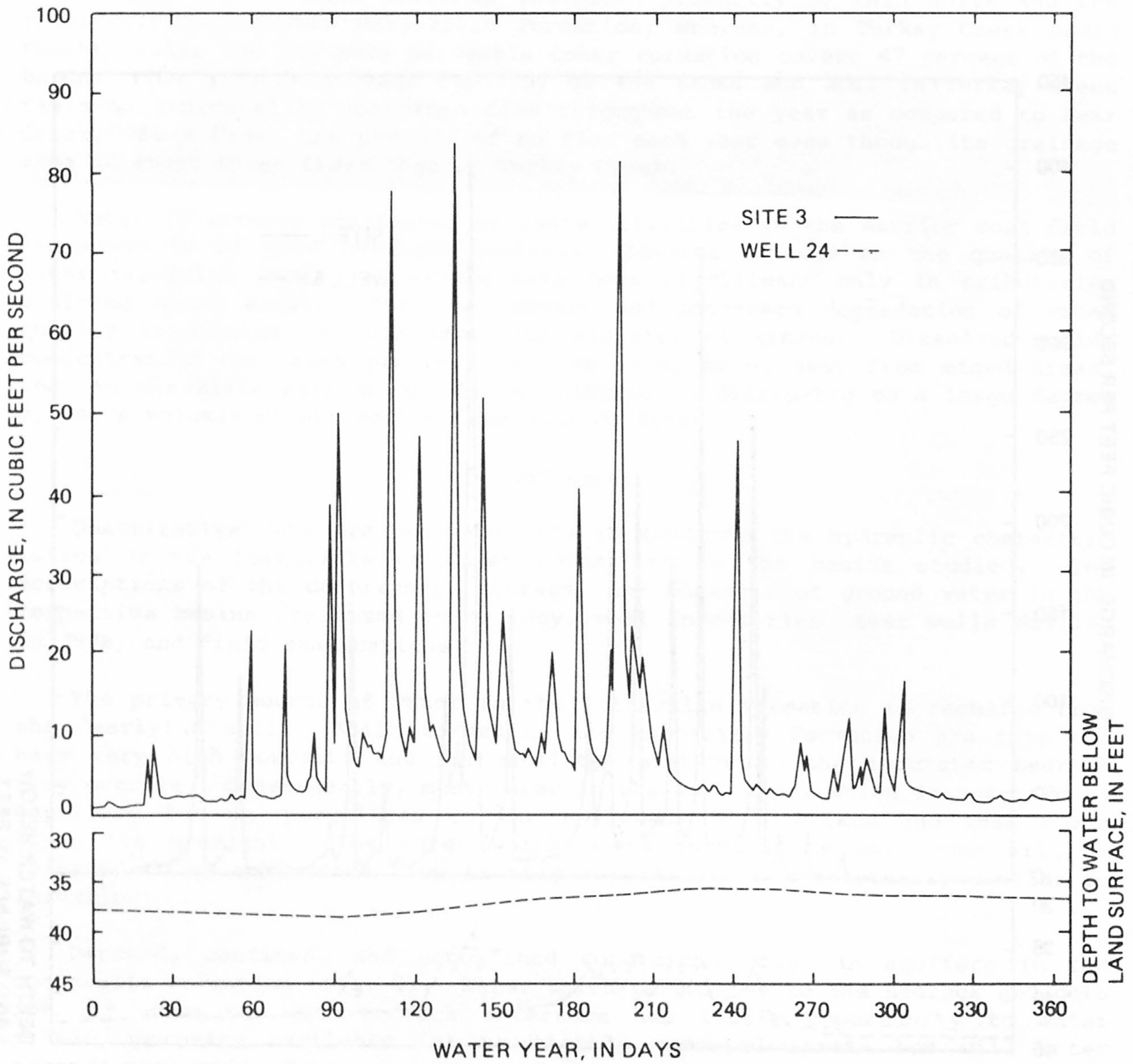

Figure 7. Daily mean discharge at site 3 (Turkey Creek) and daily mean water levels in observation well 24 in Turkey Creek basin October 1981 - September 1982. Site and well numbers correspond to those on figure 4.

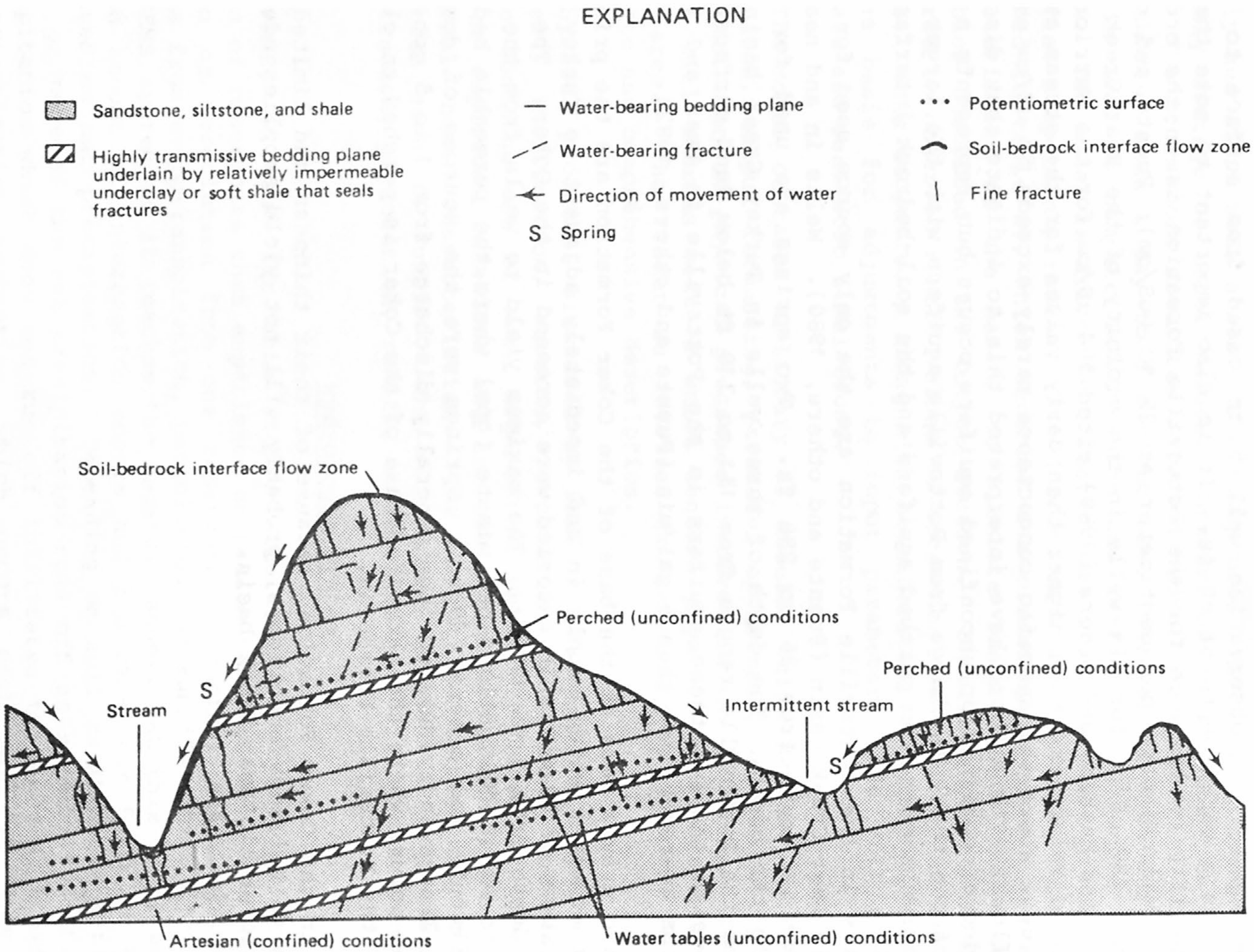

Figure 8. Schematic diagram showing occurrence and movement of water in the Pottsville Formation (modified from Puente and others, 1980).

Ground-water level and specific conductance records from Pottsville basins suggest that there are two distinct types of discharge from Pottsville aquifers. The lack of sustaining flow in the Bear Creek basin could be interpreted to indicate that the Pottsville aquifers discharge small volumes of water to the stream. A cursory inspection of ground-water levels from site 5 (observation well 5, fig. 6) indicates a considerable water-level fluctuation and suggests that a commensurate volume of water is moving through some of the Pottsville aquifers. Observation well 5 is cased from surface to 32 ft below and has a total depth of 60 ft. It is also important to note that the average specific conductance for the Pottsville Formation is on the order of 200 to 500 microsiemens per centimeter at 25 °C (uS/cm); Puente and others (1980) cited 220 uS/cm for six wells in the vicinity of the Bear Creek basin during 1977 and Harkins and others (1980) cited 504 uS/cm for the Warrior coal field. These values are much higher than daily values for the stream at site 1 (Bear Creek) where the specific conductance rarely exceeds 50 uS/cm even at very low flows. The authors have interpreted this to indicate that discharge from the deeper confined or unconfined aquifers occurs but represents a small fraction of the total discharge from Pottsville aquifers with the larger fraction coming primarily from perched aquifers and the soil-bedrock interface.

Aquifers in the Pottsville Formation are the only source used for water supplies in Bear Creek basin (Puente and others, 1980). Wells in and near the basin range in depth from 26 to 286 ft. Two springs are used for water supplies in the basin. The depth of three wells in Turkey Creek basin producing from the Pottsville ranges from 131 to 318 ft below land surface. The yield to wells tapping these aquifers in the Pottsville in Bear and Turkey Creek basins averages less than 5 gal/min (Puente and others, 1982).

Sand and gravel beds at the base of the Coker Formation are the principal sources of domestic water supply in and immediately adjacent to Turkey Creek basin. Sixteen of 20 wells inventoried were screened in the Coker. The wells ranged in depth from 9 to 100 ft. The maximum yield to wells from the Coker Formation is about 100 gallons per minute (gpm) where the permeable beds are thickest (Puente and others, 1980). Springs were the sources of domestic supplies. Eleven individual springs generally discharge from 1 to 5 gpm. The spring line occurs where the saturated base of the Coker is perched on clay at the top of the Pottsville Formation.

Sands in the Coker Formation, because of their thinness and limited area of outcrop on hilltops and ridges, probably will not yield supplies adequate for domestic use in Bear Creek basin.

DESCRIPTION OF PRECIPITATION-RUNOFF MODEL

The model discussed in this report is the Precipitation Runoff Modeling System (PRMS) and was developed by the U.S. Geological Survey (Leavesley and others, 1983). PRMS is a modular, physically based, distributed parameter system designed to simulate runoff, sediment yields, and general hydrologic conditions within a drainage basin. The model can simulate basin hydrology on a daily and storm mode scale. The daily mode simulates hydrologic components as daily average or total values. Streamflow is computed as a mean daily flow. The storm mode simulates selected hydrologic components at time intervals shorter than a day to a minimum time interval of 1 minute. The storm mode is used to compute infiltration and surface water runoff for selected storms. The model is driven by climatic data which describe precipitation and potential evapotranspiration. The driving data are used with input parameters (defined in table 2), which describe the climatic, physical, and hydrologic characteristics of the basin, to simulate basin runoff and other output variables described in the Output section. Simulated runoff values may be compared to observed runoff values to determine the accuracy of the simulated values. This comparison, along with consideration of other output variables is the basis for adjustments to input parameters that will produce more accurate and realistic simulations.

The model contains a library of modules which perform data management operations, output formatting, parameter optimization, sensitivity analysis, and simulation of physical processes involved in the hydrologic cycle. This report will address modules which concern physical processes active in the study area. The reader is referred to Leavesley and others, 1983, for a complete and comprehensive description.

Physical processes simulated by PRMS modules include evapotranspiration, snowmelt, infiltration, erosion, percolation, and runoff phenomena. Each module contains one or more algorithims which are based on known physical laws or empirical relations and include parameters which can be related to measurable basin characteristics. The algorithims continuously update model variables such as runoff. The algorithims related to evapotranspiration, infiltration, percolation, runoff, and erosion are briefly discussed below.

Hydrologic System

PRMS, as used for this study, simulates the hydrologic system as a series of reservoirs that experience accretion of water due to either precipitation or percolation from one reservoir to another and depletion due to losses from evapotranspiration, percolation, or runoff. Precipitation enters the PRMS system as it reaches the vegetal canopy. At this point a user specified amount of interception occurs and the remainder falls to the ground surfaces as net precipitation. Depending on soil moisture conditions, all, some, or none of the net precipitation runs off as surface runoff. Any net precipitation which does not run off infiltrates to the soil moisture zone. Evapotranspiration accounting, which occurs each day, is done for soil moisture and intercepted water. Water in the soil moisture zone may percolate further to the ground-water and (or) the subsurface reservoirs when a user specified threshold volume has been achieved. Water percolating from the soil

Table 2.--Selected parameters with definitions

Parameter*	Definition**	Associated Process
	Parameters associated with each hydrologic response unit	
DRCOR	Rainfall amount correction factor (elevation)	Net rainfall
DRN	Soil moisture redistribution factor	Unit infiltration
EN	Sediment transport coefficient	Erosion
HC	Sediment detachment coefficient	Erosion
IMPERV	Percent impervious area	Daily surface runoff
ISOIL	General soil type	Actual evapotranspiration
KF	Sediment detachment coefficient	Erosion
KM	Sediment transport coefficient	Erosion
KR	Sediment detachment coefficient	Erosion
KSAT	Saturated hydraulic conductivity soil	Unit infiltration
PSP	Combined effect of soil moisture deficit and capillary potential	Unit infiltration
REMX	Maximum capacity of upper soil zone	Actual evapotranspiration
RETIP	Maximum retention storage on impervious area	Daily surface runoff
RGF	Soil moisture deficit/capillary potential	Unit infiltration
RNSTS	Rainfall storage of summer vegetation	Net rainfall
RNSTW	Rainfall storage of winter vegetation	Net rainfall
SEP	Maximum daily recharge (soil moisture zone to ground-water reservoir)	Percolation
SC1	Contributing area computation coefficient	Daily surface runoff
SCN	Contributing area computation coefficient	Daily surface runoff
SCX	Maximum value for contributing area	Daily surface runoff
SMAX	Maximum capacity of soil moisture zone	Percolation
	Parameters associated with each subsurface reservoir	
RCF	Linear flow routing coefficient	Subsurface flow
RCP	Flow routing coefficient	Subsurface flow
RESMX	RSEP coefficient	Percolation
REXP	RSEP coefficient	Percolation
RSEP	Recharge rate (subsurface reservoir to ground-water flow reservoir)	Percolation
	Parameters associated with each ground-water reservoir	
GSNK	Seepage rate to ground-water sink reservoir	Percolation
RCB	Flow routing coefficient	Ground-water flow
	Parameters associated with overland flow planes and channel segments	
ALPHA	Kinematic wave routing coefficient	Unit flow routing
EXPM	Kinematic wave routing coefficient	Unit flow routing
FRN	Roughness	Unit flow routing
	Climatic parameters	
EVC	Monthly evaporation coefficients	Potential evapotranspiration

* Includes major parameters used in study area.

** Condensed definitions.

moisture zone first goes to the ground-water reservoir until a user specified daily maximum has been satisfied; any water exceeding this daily value percolates to the subsurface reservoir. Water in the subsurface reservoir also may percolate to the ground-water reservoir if the user specifies a seepage or percolation rate. Water in these reservoirs is routed to channels to become part of the total daily runoff. Water may also percolate below the ground-water reservoir which is conceptually no longer available to runoff accounting in the basin if the user specifies a rate. The algorithims involved in these processes are described below and the relations of individual reservoirs to each other and to runoff are schematically diagramed in figure 9.

Evapotranspiration

PRMS has the capability to compute daily potential evapotranspiration several different ways. A relatively simple method of computing daily potential evapotranspiration (PET) involving daily pan evaporation data was selected for use in the study area. Daily PET is calculated as the product of daily pan evaporation and user defined monthly pan coefficients. PET is used with relations developed by Zahner (1967) to determine actual evapotranspiration (AET). Zahner's relations compute the percentage of PET which occurs as AET as a function of the ratio of available soil moisture values to field capacity for three general soil types: sand, loam, or clay. AET losses deplete soil moisture.

Infiltration and Percolation

Daily infiltration volumes are calculated as the remainder between net precipitation and surface runoff (SRO). SRO is computed according to a contributing area concept. Infiltration in the storm mode is calculated according to a modified version of the Green-AMPT equation (Leavesley and others, 1983) which calculates infiltration as a function of hydraulic conductivity, capillary suction, and current soil moisture.

After infiltration, water may percolate into and out of the soil moisture zone. The soil moisture zone has a user defined maximum water holding capacity (SMAX) which controls movement of water out of this zone. This capacity is equal to the difference between field capacity and wilting point and may also be considered as the amount of water available for percolation and evapotranspiration. When the current volume of available soil moisture (SMAV) is less than SMAX, water may not percolate further and depletion occurs only as a result of actual evapo-transpiration (AET). When SMAV is equal to SMAX any additional infiltrating water percolates into the ground-water reservoir (GW) or the subsurface reservoir (SSR). Water enters the ground-water reservoir according to a user defined daily volume (SEP) which is satisfied whenever possible. Once this volume has been routed to the ground-water reservoir any additional water available from the soil moisture zone enters the subsurface reservoir.

A considerable amount of flexibility is afforded the user to control movement of water out of the subsurface reservoir. Subsurface flow (SSF), which is conceptually similar to interflow, may be routed to channels according to user

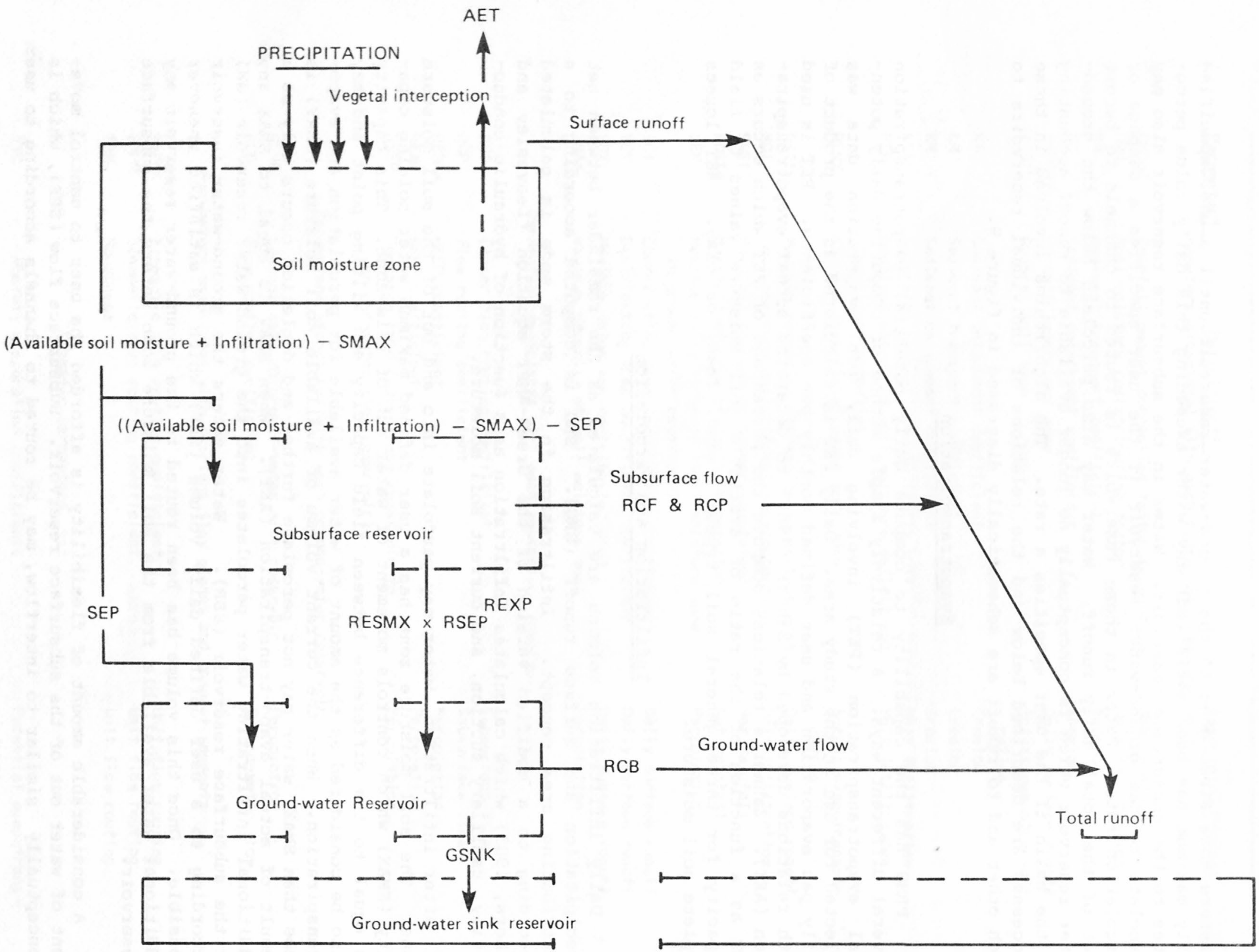

Figure 9. Schematic diagram of the Precipitation Runoff Modeling System hydrologic system.
(abbreviations correspond to those defined in table 2)

selected linear or non-linear relations. Water from the subsurface reservoir may also percolate or seep to the ground-water reservoir according to a user defined seepage rate (RSEP). If the user desires, the RSEP algorithim may be modified by two coefficients (RESMX, REXP) which control the volume of water available for seepage.

Depletion of ground-water storage occurs in two ways. Depletion may occur as base flow or as percolation to a ground-water sink (SNK) according to a user defined rate (GSNK).

Runoff

Surface runoff (SRO) in the study area occurs on rainfall days and is not influenced by snowmelt. Daily mode surface runoff is calculated using a contributing area percentage (CAP) concept (Dickenson and Whitely, 1970). Contributing area percentage is the PRMS computed area of the basin which will contribute to SRO on each rainfall day. The upper limit is user definable and the actual value is a function of soil moisture and rainfall amount. Once the contributing area percentage has been determined, surface runoff is calculated as the product of the contributing area percentage and net daily precipitation minus any user definable surface detention storage (RETIP).

The storm mode computes surface runoff with a more comprehensive technique at a short time step (5 minutes or less depending on the recording interval for rainfall data). The volume of surface runoff or rainfall excess (RE), is computed as net precipitation less infiltration. Rainfall excess is routed to channels as overland flow and channel flow is then routed to the basin outlet. PRMS uses the kinematic wave method to route both overland and channel flow. The reader is referred to Leavesley and others (1983) or to Dawdy and others (1978) for a description of this method.

Two additional components of runoff are evaluated by PRMS. They are: flow from the subsurface reservoir (RAS) and flow from the ground-water reservoir (BAS). Subsurface flow is conceptually similar to interflow and represents the relatively rapid discharge of water to streams from temporary perched water storage above the water table. Subsurface flow and surface runoff are sometimes collectively referred to as direct runoff. Subsurface flow is routed out of the subsurface reservoir according to a linear or non-linear function of storage in the subsurface reservoir. Ground-water flow is conceptually similar to baseflow and is routed out of the ground-water reservoir as a linear function of storage in that reservoir. User input consists of estimates of two parameters for subsurface reservoir (RCF, RCP) and one for ground-water flow (RCB).

Partitioning

The distributed nature of PRMS allows the user to account for spatial and temporal variation of climatic, hydrologic, and physical characteristics by partitioning or sub-dividing the basin into hydrologic response units (HRU's). HRU delineation may be based on elevation, geology, land use, slope, soil type, vegetation or any factor which the user feels will significantly affect hydrologic response and is addressed by input parameters. The maximum number of HRU's allowed is 50 and a subsurface reservoir, ground-water reservoir, and ground-water sink may be defined for each one. Total basin response is determined by summing individual HRU response on a unit-area basis.

When the storm mode is used the basin must be further subdivided or segmented into overland flow planes and channel segments to route surface runoff. Upland erosion calculations are done at the overland flow plane level. A HRU can be equal to an overland flow plane or subdivided into several overland flow planes. Each overland flow plane has a user specified width and must be adjacent to a channel segment of user specified length. The overland flow plane channel and segment configuration is constructed to approximate the distribution of contributing drainage area and the drainage network in the basin. The maximum number of combined overland flow planes and channel segments is 100.

Output

Output from PRMS includes a summary of parameter values and basin characteristics input by the user. In addition, several different levels of tabular output can be specified. In the daily mode these may be (1) simple reports of observed and simulated daily runoff or (2) detailed reports of daily status for climatic and hydrologic variables which include daily, monthly, and (or) annual summaries of climatic processes, reservoir dynamics, and runoff components for the entire basin or per HRU. The user can also specify plots of observed and simulated runoff.

In the storm mode standard output is a tabular listing of observed, routed, and simulated runoff volumes, observed and simulated peak runoff rates, and sediment yield for each storm. Optional listed and plotted output at a specified time step of inflow, outflow and suspended sediment concentrations for specified overland flow planes and channel segments may also be requested.

DATA COLLECTION

Hydrologic, climatic and basin characteristics data are used by the PRMS model to simulate the basin hydrologic system. Daily and storm period streamflow records were used in modeling Bear and Turkey Creek basins. A summary of data collection activities in the study basins is presented in table 3.

Bear Creek Basin

A gaging station, site 1 on figure 2, was located on Bear Creek near Samantha, Ala. (station no. 02463900). Instrumentation included a stilling well with a water-stage recorder, a water temperature and specific conductance automatic monitor and an automatic pumping sediment sampler. Surface-water samples for laboratory analysis were collected at various times each year from 1976 through 1983.

Table 3.--Summary of data collection network

[Site numbers correspond to those on figures 2 and 4; C, continuous; D, daily; M, monthly; F, floods; O, observer; R, random]

Site number	Name	USGS station number	Period of record	Data type and sampling frequency: Streamflow	Water quality	Suspended sediment	Water level	Precipitation (minutes)
			Bear Creek Basin					
1	Bear Creek gage near Samantha	02463900	Oct. 1976-Sept. 1983	C	C	D		
2	Griffin rain gage	333323087323601	Dec. 1977-Sept. 1983					5
7	Bagwell rain gage	333259087280101	May 1978-Sept. 1983					5
4	Observation well 4	333344087291001	Oct. 1979-Sept. 1983		R	C		
5	Observation well 5	333204087324601	Oct. 1979-Sept. 1983		R	C		
6	Observation well 6	333144087330401	Oct. 1979-Sept. 1983		R	M		
7	Observation well 7	333322087335701	Apr. 1979-July 1982		R	C		
8	Observation well 8	333451087331501	Oct. 1979-Sept. 1983		R	C		
12	Observation well 12	333206087302801	Oct. 1979-Sept. 1983		R	M		
28	Observation well 28	333157087294501	Oct. 1979-Sept. 1983		R	M		
			Turkey Creek Basin					
3	Turkey Creek gage below Hwy 69 near Tuscaloosa	02464146	Feb. 1981-Sept. 1983	C,D	C,D	D,O		
10	Turkey Creek rain gage	02464146	Feb. 1981-Sept. 1983					5
9	Observation well 9	332524087295901	Oct. 1976-Sept. 1983		R		M,C	
18	Observation well 18	332425087284501	Oct. 1976-Sept. 1983		R		M	
27	Observation well 27	332604087290201	Oct. 1976-Sept. 1983		R		M	

Climatic data used to drive the model consist of precipitation and pan-evaporation data. Precipitation data, recorded at five-minute intervals, were collected at Griffin and Bagwell rain gages (sites 2 and 7, respectively, in figure 2) in Bear Creek basin. Precipitation data from Griffin rain gage was used as the primary source and Bagwell rain gage used for missing record.

Daily pan-evaporation data were collected by the National Weather Service (NWS) (U.S. Dept. of Commerce, 1976-83) at Winfield, Ala., which is located about 32 mi northwest of the Bear Creek basin (fig. 1). Pan-evaporation data from Winfield were used in modeling Bear and Turkey Creek basins. Missing records were estimated using NWS pan-evaporation data from Demopolis, Ala., located about 68 mi southwest of Turkey Creek basin.

Eight observation wells were drilled in or near Bear Creek basin (fig. 2). Beginning October 1978, continuous water level recorders operated on three observation wells and monthly tape down measurements were made on five. Water samples for laboratory analysis were collected from the wells in October 1979, June 1982, and September 1983.

Turkey Creek Basin

A gaging station on Turkey Creek was located below State Highway 69 near Tuscaloosa, Ala. (station no. 02464146). Equipment included graphic and digital water-stage recorders driven by a servo-manometer, water temperature and specific conductance automatic monitor, and an automatic pumping sediment sampler. Surface-water samples for laboratory analysis were collected at various times each year in 1981, 1982, and 1983. Turkey Creek basin was modeled using precipitation data from two rain gages at the Turkey Creek gage with data from Griffin rain gage used for missing record.

Four observation wells were drilled in or near Turkey Creek basin (fig. 4). Beginning October 1979, a continuous water level recorder operated on one well and monthly tape down measurements were made on three. Water samples for laboratory analyses were collected from the wells in October 1979, June 1982, and September 1983.

CALIBRATION AND VERIFICATION

Bear Creek

Data for the period of January 1, 1978 to September 30, 1982 were used for calibration and verification. Calibration years were the 1979 and 1980 water years. Calibrated parameter values obtained for these years were applied to the remaining years to evaluate the model's performance outside the calibration period.

Partitioning

Geology, soil type, and overland slope were the principal factors used to define three hydrologic response units (HRU's) in the Bear Creek basin (fig. 2). The largest of the HRU's covers 74 percent of the basin (7,139 acres) and is referred to as Forested Pottsville HRU. This HRU includes all forested Pottsville areas in the the basin, which are not unusually steep, as well as some small acreages of timbered and cleared Pottsville areas. The spatial distribution of this HRU is essentially all upland in the basin where the Pottsville Formation is at or near the surface. Montevallo-Nauvoo and Nauvoo soils are prevalent in these areas.

The second HRU covers 22 percent of the basin (2,036 acres) where valleys are incised into the Pottsville Formation. Montevallo-Nauvoo steep and Iuka-Mantachie soils are prevalent in these areas.

The third HRU covers 4 percent of the basin (410 acres) and is referred to as Coker. The spatial distribution of this HRU is limited to areas where soils are derived from the Coker Formation and includes areas where Coker material has moved downslope due to mass wasting. Smithdale and Smithdale hilly soils are prevalent in this area.

The basin was further partitioned into flow planes, channel segments, and junctions to accommodate unit mode simulations. One flow plane was delineated for each HRU. Flow planes for the Forested Pottsville and the Coker HRU's were linked with 1,000 ft channels in seven different channel segment configurations to represent minor tributary channels which drain from 25 to 350 acres. These channel segments were linked with a network of 3,000 ft channels and Steep Pottsville flow planes in a configuration which closely approximates the distribution of contributing area.

Initial Parameter and Variable Values

Initial values for most parameters and variables were calculated using techniques provided in the users manual (Leavesley and others, 1983), from data extracted from topographic maps, streamflow records, climatologic reports, soil surveys, and from field reconnaissance to determine initial values for most parameters (table 4). Certain parameters, primarily coefficients, but also vegetal interception, contributing area, and seepage or recharge parameters, were not defined by existing data for the study area and initial values were estimated. In addition, existing data did not allow adequate definition of unit infiltration parameters and initial estimates were recommended (A. M. Lumb, U.S. Geological Survey, written commun., 1983).

Initial values for soil moisture storage as well as subsurface and ground water reservoir storage were estimated from field reconnaissance.

Calibration

Calibration efforts were undertaken for the 1979 and 1980 water years after initial simulations had been completed. Precipitation record from the Griffin rain gage (USGS station) and pan evaporation from the Winfield 2 SW (NOAA station) were used in the calibration. The locations of these stations are indicated in figures 2 and 1, respectively; station numbers are given in table 3. Precipitation for the two sites for the calibration period was high relative to the long term average annual precipitation for the area, 71.67 and

Table 4.--Initial and final parameter values for Bear Creek basin

Parameter[1]	Units	Parameter values[2] Initial	Final	Source of initial estimates
		Parameters associated with each hydrologic response unit		
DRCOR	Coefficient	1.00	1.00	Users manual
DRN	Coefficient	1.00	1.00	Recommended
IMPERV	Coefficient	0.00	0.00	Topographic and reconnaissance
ISOIL	Dimensionless	sand(1)	sand(1)	Published soil survey[3]
KSAT	Inches/hour	1.00	1.4,2.7,3.4	Recommended
PSP	Inches	0.10	0.23,0.23,0.10	Recommended
REMX	Inches	2.0	2.0,2.0,3.0	Estimated
RETIP	Inches	0.00	0.00	Topographic maps and reconnaissance
RGF	Coefficient	8.00	55.0,55.0,12.0	Recommended
RNSTS	Inches	0.15	0.10	Estimated
RNSTW	Inches	0.10	0.07	Estimated
SEP	Inches/day	0.01	0.05,0.99	Estimated
SCI	Coefficient	0.30	0.30	Estimated
SCN	Coefficient	0.0003	0.0003	Estimated
SCX	Coefficient	0.60	0.09,0.06,0.06	Estimated
SMAX	Inches	3.50,2.50,8.64	3.50,6.90,8.64	Published soil survey[3]
		Parameters associated with each subsurface reservoir		
RCF	Coefficient	0.85	0.17,0.17,0.45	Users manual and streamflow records
RCP	Coefficient	0.10	0.09,0.09,0.001	Users manual and streamflow records
RESMX	Coefficient	1.00	3.5,2.5,1.0	Estimated
REXP	Coefficient	1.00	1.0	Estimated
RSEP	Inches/day	0.00	0.13,0.13,0.00	Estimated
		Parameters associated with each ground-water reservoir		
GSNK	Acre/inches	0.00	0.0,0.0,0.003	Estimated
RCB	Coefficient	0.13	0.12,0.12,0.003	Users manual
		Parameters associated with overland flow planes and channel segments		
ALPHA	Coefficient	0.06-2.23	0.06-2.23	Users manual and topographic maps
EXPM	Coefficient	1.67	1.59	Users manual and topographic maps
FRN	Coefficient	0.04-0.4	0.04-0.4	Reconnaissance
		Climatic parameters		
EVC	Coefficient	0.13-1.0	0.52-0.94	Published climatologic data[3]

1/ Abbreviations defined in table 2.

2/ Distributed parameter values listed by hydrologic response unit.

3/ U.S. Department of Agriculture, 1981.

72.01 in. versus 52.58 in. (U.S. Department of Commerce, 1968). The maximum precipitation of record occurred during the 1979 water year. However, in spite of relatively high precipitation amounts, several days of no flow occurred during each water year and characteristic diverse climatic conditions prevailed during the calibration period.

Daily Calibration

A four phase approach was used in the daily calibration. The first phase involved adjusting selected parameters to obtain a reasonable match between observed and simulated hydrographs of daily flow. Phase two concentrated on matching simulated and observed annual runoff volumes as well as adjusting initial reservoir storages and the third phase involved adjusting the simulated water budget. Phase four was used to make final adjustments.

Simulated hydrographs of daily flow were adjusted so that recessions approached or closely matched those for observed data in the first phase. Subsurface (RCP) and ground-water (RCB) flow coefficients were identified as parameters which effectively control the slopes of hydrograph recessions. These were adjusted with the Rosenbrock Optimization option of PRMS which attempts to minimize an objective function of absolute or squared differences between daily simulated and observed runoff for a user specified period and by trial and error adjustment. Trial and error adjustment was favored over the Rosenbrock technique because the period of recession was generally too short to allow effective optimization.

After trial and error adjustment of flow routing coefficients, simulated recessions closely matched observed recessions when available soil moisture storage was at or near field capacity (SMAV approaching SMAX). When available soil moisture storage was not at or near field capacity, two general types of departure were noted. First, when entering periods of no flow, simulated recessions would often be significantly steeper than the observed; and second, when approaching periods of flow after periods of no flow, simulated hydrographs would often have the same shape as observed hydrographs but would often reflect greater or lesser volumes. These phenomena indicate incorrect volumes in the subsurface and ground-water reservoirs and reflect errors in parameters that control these volumes which were adjusted in phase two.

Phase two began with adjustments to initial storage volumes in the soil moisture zone (SMAV) and the ground-water reservoir (GWS) which affect the annual volume, but more importantly, control the match of the initial simulation period and may be thought of as initialization. Both subsurface and ground-water flow were considered during this phase of calibration. SMAV was adjusted to obtain a good match for the initial storm flow of the simulation period (January 5, 1978). GWS was adjusted to obtain a reasonable match for the initial ground-water recession (early February 1978).

After initialization the simulated annual runoff volume was adjusted to approach the observed volume. Pan evaporation coefficients (EVC) and precipitation interception coefficients (RNSTS and RNSTW) were selected as the controlling parameters for these adjustments. Additional parameters which control simulated annual volume such as the ground-water sink parameter (GSNK) or the surface rentention parameter (RETIP) were not considered for use at this point. The final simulated annual volumes are approximately 3 and 5 in. less, respectfully, than the observed for both calibration years. Some of this error can probably be attributed to the accuracy of discharge records during April 1979 and precipitation records during October 1979 and September 1980.

A general discussion of the range and distribution for pan coefficients in NOAA publications (U.S. Department of Commerce, 1982) was used to determine the initial values for monthly pan coefficients. The initial values were adjusted until a reasonable match between simulated and observed annual volumes was obtained. The amount of simulated potential evapotranspiration was not allowed to vary significantly from the annual free water surface values published by NOAA (U.S. Department of Commerce, 1982) during the adjustment processes.

Precipitation interception storage capacities were initially set at 0.15 and 0.10 in. per day for summer and winter months, respectively. The initial values were adjusted so that the annual interception was approximately 10 percent of the annual precipitation.

The initial storage volume adjustments made during the first part of phase two produced a good match for the initial simulation period. In addition, it was necessary to adjust additional parameters which control recharge to subsurface and ground water reservoirs to maintain a good match throughout the simulation period. SMAV must equal SMAX for water to percolate from the soil moisture zone to the subsurface and ground-water reservoirs. The value selected for SMAX is critical with respect to the timing and volume of recharge to these reservoirs and it was adjusted next.

Initial values computed for SMAX were 3.5 and 8.6 in. for Pottsville and Coker response units, respectively. These values produced simulated results which were consistently high when periods of flow were entered after periods of no flow. It was assumed that there was an error in the SMAX value for the Forested Pottsville response unit not only because it is the largest and most influential, but also because of its soil characteristics. The initial value for SMAX computed for this response unit was 3.5 in. and did not consider Nauvoo soils. A new value of 4.7 in. was computed based on an area-weighted consideration of the Nauvoo soils. Simulated results were improved considerably when the new value was used.

The simulated water budget was evaluated with respect to the magnitude of individual hydrograph components; surface, subsurface, and ground-water flow in phase three. The simulated hydrograph components consisted primarily (greater than 80 percent) of subsurface and ground-water flow; surface runoff occurred only on storm days and rarely exceeded 25 percent of the storm runoff. Field reconnaissance during storms supported low figures for surface runoff and no attempts to adjust this relation were made.

Specific conductance records from the Bear Creek site and ground-water level records from wells nearby were used to evaluate the relation between the subsurface and ground-water flow volumes. The average specific conductance for six wells penetrating the Pottsville Formation in the vicinity of the Bear Creek basin sampled during 1977 was 220 uS/cm (Puente and others, 1980). The average for the Pottsville Formation in the Warrior coal field has been reported as 504 uS/cm by Harkins and others (1980). Daily values for mean specific conductance at the Bear Creek site vary from 20 to 76 uS/cm during the calibration period and normally exceeded 50 uS/cm only during periods of low flow. The relatively low values for specific conductance at this site indicate that correspondingly low volumes of water from the Pottsville Formation are being discharged to the stream. The simulated water budget, via the SEP parameter, was adjusted accordingly to reflect this. However, daily values for water levels of wells in the Pottsville Formation in the basin show considerable fluctuation in response to rainfall and indicate that rapid recharge and discharge of ground water occurs in response to storms. This reflects greater horizontal than vertical permeability in the Pottsville Formation due to bedding plane fractures which deteriorate with depth and are most prevalent near the surface at the contact with the overlying soil. The RSEP, RESMX, and REXP parameters were used to route water from the subsurface reservoir to the ground-water reservoir and reflect this phenomena in the simulated results.

At this point in the calibration, simulated and observed hydrographs compared favorably and final adjustments to the calibration were made. Values for the Coker response unit were replaced with those developed in the Turkey Creek calibration. Substituted values agreed closely with the original, except for GSNK which was previously zero, and had a negligible effect on the simulated results because of the relatively small size of the Coker response unit. Although the simulated and observed hydrographs generally agreed, there were still several types of consistent departure. Departures were of three general types: first, simulated volumes during periods when soils were unsaturated were generally high; second, volumes during many parts of the year showed slight departures; and third, simulated recessions during late spring often continued to recede below observed flows. Corrections for the first two types were made by adjusting the maximum value for the soil moisture zone (SMAX) and pan evaporation coefficients (EVC) respectively. Previously calculated values for these parameters were adjusted to obtain the best fit. The value for SMAX in the Forested Pottsville response unit had to be raised significantly to obtain satisfactory results. Values for EVC were also modified, but only slightly, to obtain a more satisfactory fit. Adjustments to the EVC values were made primarily to affect the distribution of potential evapotranspiration through the year and not the annual volume.

The third type of departure, in which the simulated recession continued beyond the observed, was prevalent from March to May during the 1980 water year. It was assumed that the observed record leveled out during these periods because of perched water discharge. When subsurface flow coefficients (RCF and RCP) or ground-water flow parameters (SEP and RCB) were adjusted to correct for this problem, a good match for the problem period was obtained; however, the increases in simulated flow to correct this error were sustained throughout the year causing simulated flow during periods of no observed flow. Additional approaches to this problem, such as creating a new response unit and adjusting the RSEP, RESMX, and REXP parameters, also produced results which introduced sustained flow in dry periods when the problem was solved. Adjusting EVC to compensate for the sustained flows was unsuccessful; probably because PRMS evapotranspiration losses occur in the soil moisture zone and do not directly affect the volumes in the subsurface or ground-water flow reservoirs. Manipulating the GSNK parameter to reduce base flows was also unsuccessful. The problem of simulated recessions continuing beyond the observed is present in the calibration and may be related to unaccounted evapotranspiration of subsurface and ground-water storage by riparian vegetation.

The final values for parameters for Bear Creek basin are listed in table 4. A summary of observed data and simulated results for the calibration period is listed in table 5 and plots of observed and simulated daily flows for the same period are in figure 10. The plots of simulated daily runoff generally show good agreement with the observed data except for the departures noted above and a few periods in which either the driving precipitation data was estimated due to missing record or the observed data was estimated due to the magnitude of the storm. Simulated annual volumes, listed in table 5, differ by 7.1 and 11.1 percent for the 1979 and 1980 water years, respectively. While these values agree closely, it is important to note, especially with respect to the estimated record which is present in the observed data, that they are, at best, only a general indication of the integrity of the calibration because they give no indication of day to day departure. Monthly volumes give a better indication of the calibration accuracy.

The simulated and observed monthly volumes in table 5 give a better picture of the accuracy of the calibration. These figures generally reflect some of the problems encountered in the calibration process. This is especially true with respect to the tendency to oversimulate runoff during the transition from dry to wet conditions; the simulated volumes for October, November, December, and September are usually greater than the observed. Monthly totals also indicate two periods where the accuracy of the observed record may be a contributing factor. Observed record for the flood of April 12, 1979, which was computed using a rating curve that was extended based on a slope-conveyance study. During the flood, approximately 9.55 in. of rain were observed at two rain gages in the basin and 10.50 in. were observed at another gage approximately 20 mi to the southeast, yet greater than 13 in. of runoff are indicated by the computed record. Subsequent measurements at high stages have placed the computed record for this storm under consideration for revision. Observed precipitation (1.37 in.) record for the March 17, 1980, flood is low, compared to surrounding rain gages (3.73 in. at Bagwell rain gage), and is probably not representative of the total precipitation for the basin. Also, the observed precipitation at the beginning (October 3, 1979) and end (September 26 and 27, 1980) of the 1980 water year do not seem representative of the actual precipitation for the entire basin.

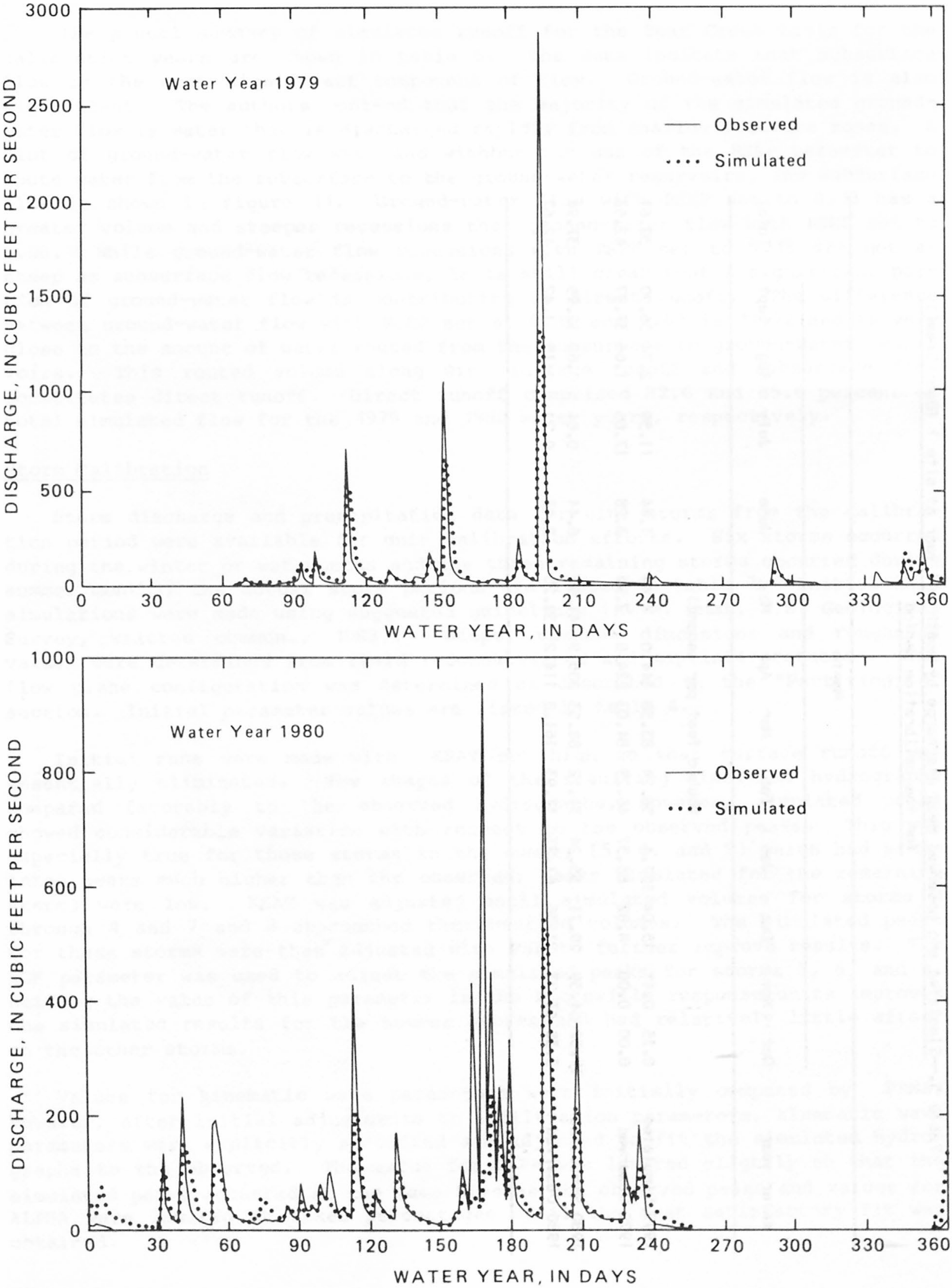

Figure 10. Hydrographs of observed and simulated daily mean discharge at Site 1 (Bear Creek) for the calibration period (water years 1979-1980).

Table 5.--Simulated and observed mean discharge by month and year at site 1 (Bear Creek) for the calibration period

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total
	Month												
	(Cubic feet per second)												
1979 Simulated	0.15	0.17	15.04	107.4	50.24	83.58	144.0	4.44	1.44	11.59	2.74	56.90	39.61
1979 Observed	0.00	0.00	4.82	86.57	46.29	84.03	224.8	7.95	3.28	17.66	1.66	37.87	42.63
1980 Simulated	19.52	61.59	29.71	55.24	34.12	88.53	105.9	41.96	6.44	0.64	0.60	12.99	37.94
1980 Observed	3.38	63.93	21.36	67.23	37.93	161.8	114.2	39.20	2.45	0.21	0.15	1.42	42.67

The annual summary of simulated runoff for the Bear Creek basin for the calibration years are shown in table 6. The data indicate that subsurface flow is the most significant component of flow. Ground-water flow is also significant. The authors contend that the majority of the simulated ground-water flow is water that is discharged rapidly from shallow fracture zones. A plot of ground-water flow with and without the use of the RSEP parameter to route water from the subsurface to the ground-water reservoirs, and subsurface flow is shown in figure 11. Ground-water flow with RSEP set to 0.13 has a greater volume and steeper recessions than ground-water flow with RSEP set to 0.00. While ground-water flow recessions with RSEP set to 0.13 are not as steep as subsurface flow recessions, it is still clear that a significant portion of ground-water flow is contributing to direct runoff. The difference between ground-water flow with RSEP set at 0.13 and 0.00 is 13.72 and is very close to the amount of water routed from the subsurface to ground-water reservoirs. This routed volume along with surface runoff and subsurface flow constitutes direct runoff. Direct runoff comprised 82.6 and 85.6 percent of total simulated flow for the 1979 and 1980 water years, respectively.

Storm Calibration

Storm discharge and precipitation data for nine storms from the calibration period were available for unit calibration efforts. Six storms occurred during the winter or wet months and the three remaining storms occurred during summer months; the actual storm periods are listed in table 7. Initial unit simulations were made using suggested guidelines (A. M. Lumb, U.S. Geological Survey, written commun., 1983). Slope, channel dimensions and roughness values were determined from field reconnaissance and map interpretation. The flow plane configuration was determined as described in the "Partitioning" section. Initial parameter values are listed in table 4.

Initial runs were made with KSAT set high so that surface runoff was essentially eliminated. The shapes of the resulting simulated hydrographs compared favorably to the observed hydrographs, however, simulated peaks showed considerable variation with respect to the observed peaks. This was especially true for those storms in the summer (5, 6, and 9) which had simulated peaks much higher than the observed; peaks simulated for the remaining storms were low. KSAT was adjusted until simulated volumes for storms 1 through 4 and 7 and 8 approached the observed volumes. The simulated peaks for these storms were then adjusted with PSP to further improve results. The RGF parameter was used to adjust the simulated peaks for storms 5, 6, and 9. Raising the value of this parameter in the Pottsville response units improved the simulated results for the summer storms and had relatively little affect on the other storms.

Values for kinematic wave parameters were initially computed by PRMS; however, after initial adjustments to infiltration parameters, kinematic wave parameters were explicitly specified and adjusted to fit the simulated hydrographs to the observed. The value for EXPM was lowered slightly so that the simulated peaks occurred at the same time as the observed peaks and values for ALPHA were lowered at fixed percentages until the most satisfactory fit was obtained.

Table 6.--Annual summary of simulated runoff and observed precipitation by water year for the Bear Creek calibration period

Water year	Precip-itation	Inter-ception	Potential evapotrans-piration	Actual evapotrans-piration	Surface runoff	Subsurface flow	Subsurface to ground water transfer	Ground water flow	Ground water sink	Total discharge
					(Inches)					
1979	71.67	5.88	39.27	26.09	4.48	19.25	10.26	11.92	0.21	35.71
1980	72.01	6.46	44.37	29.03	2.29	15.23	13.85	16.71	0.43	34.26

Table 7.--Simulated and observed storm statistics for Bear Creek for the calibration period

Storm number	Beginning date mo-day-yr	Ending date mo-day-yr	Observed Precipitation (inches)	Observed runoff (inches)	Simulated flow (inches)	Observed peak (cubic feet per second)	Simulated peak (cubic feet per second)
1	1- 6-79	1- 8-79	1.53	0.71	0.71	321	184
2	1-19-79	1-21-79	5.32	3.45	3.30	1210	788
3	2-23-79	2-26-79	2.39	1.22	1.34	426	297
4	3- 3-79	3- 4-79	5.17	4.59	3.50	3010	3346
5	9- 1-79	9- 2-79	3.01	.18	.19	234	295
6	9-13-79	9-14-79	3.37	.60	.68	424	423
7	3- 7-80	3- 9-80	1.12	.58	.43	141	108
8	3-27-80	3-29-80	2.15	1.34	1.18	583	806
9	6-19-80	6-20-80	1.21	.02	.04	8	30

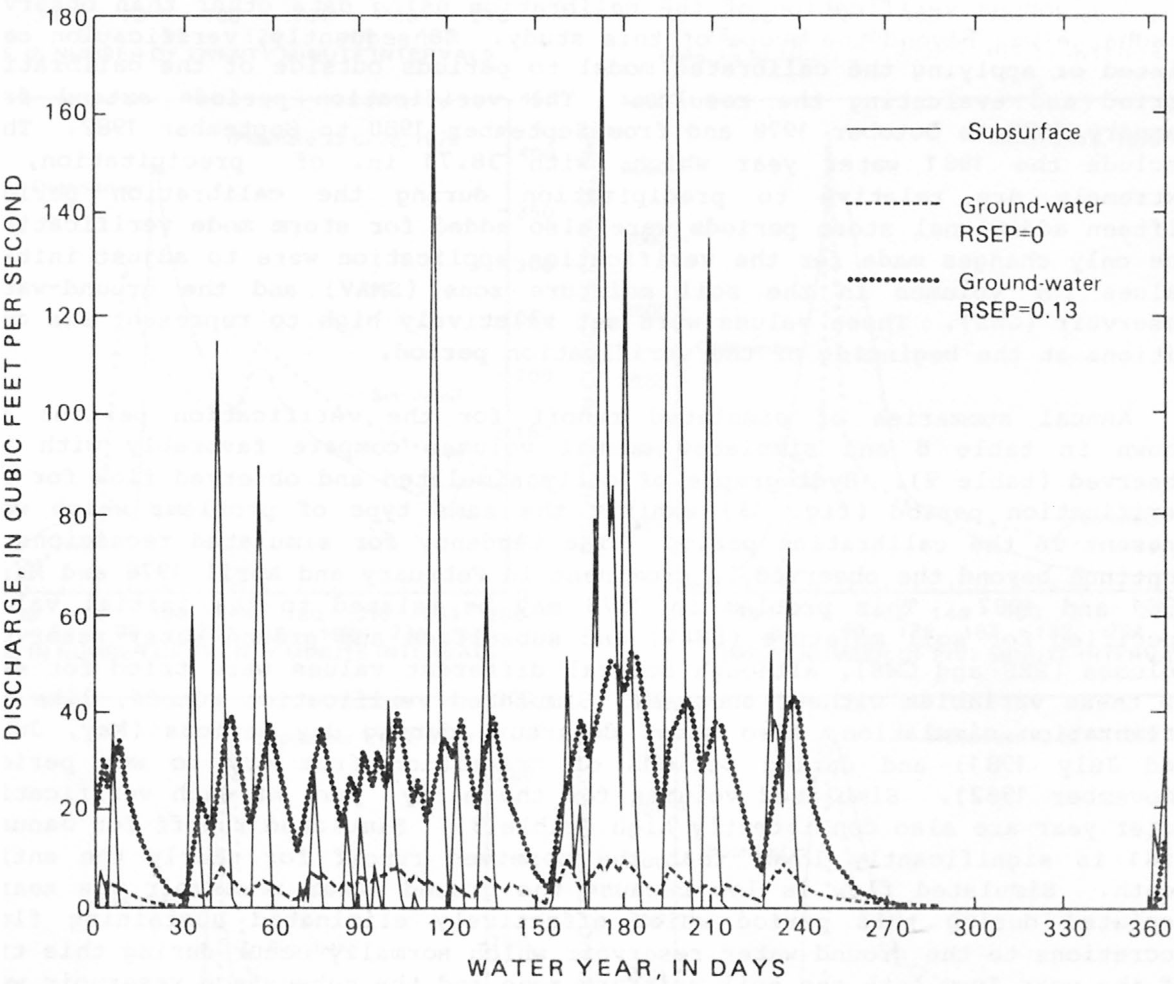

Figure 11. Simulated ground-water and subsurface flow at Bear Creek, water year 1980.

The storm calibration produces simulated storm hydrographs which approximate the observed record. A summary of the simulated storm statistics is given in table 7 and simulated and observed storm hydrographs are shown in figure 12. Simulated hydrographs are markedly more peaked than the observed for most storms. The peaked parts of the simulated hydrographs represent surface runoff and it is possible that this problem is related to the routing configuration although this was not determined during this study. Simulated annual volumes were not affected significantly when unit simulations were included with daily simulation because of the relatively small number of storms used.

Verification

A rigorous verification of the calibration using data other than observed discharge was beyond the scope of this study. Consequently, verification consisted of applying the calibrated model to periods outside of the calibration period and evaluating the results. The verification periods extend from January 1978 to October 1978 and from September 1980 to September 1982. They include the 1981 water year which, with 38.71 in. of precipitation, is extremely dry relative to precipitation during the calibration period. Fifteen additional storm periods were also added for storm mode verification. The only changes made for the verification application were to adjust initial values for volumes in the soil moisture zone (SMAV) and the ground-water reservoir (GWS). These values were set relatively high to represent the conditions at the beginning of the verification period.

Annual summaries of simulated runoff for the verification periods are shown in table 8 and simulated annual volumes compare favorably with the observed (table 9). Hydrographs of daily simulated and observed flow for the verification period (fig. 13) exhibit the same type of problems which were present in the calibration period. The tendency for simulated recessions to continue beyond the observed is prominent in February and April 1978 and March 1981 and 1982. This problem in 1978 may be related to the initial values specified for soil moisture (SMAV) and subsurface and ground water reservoir volumes (RES and GWS), although several different values were tried for each of these variables without success. Simulated verification runoff, like the calibration simulation, also shows departure during dry periods (May, June, and July 1981) and during periods of transition from dry to wet periods (November 1982). Simulated volumes for the early part of each verification water year are also consistently high (table 9). Simulated runoff for January 1981 is significantly lower than the observed runoff for nearly the entire month. Simulated flow is low because the ground water reservoir was nearly depleted during this period which effectively eliminated sustaining flow. Accretions to the ground water reservoir which normally occur during this time of the year from both the soil moisture zone and the subsurface reservoir were virtually nonexistent due to lack of rainfall. Adjusting EVC to lower the actual evapotranspiration was the only successful means of correcting this problem; however, such an adjustment destroyed existing relations for the rest of the verification period.

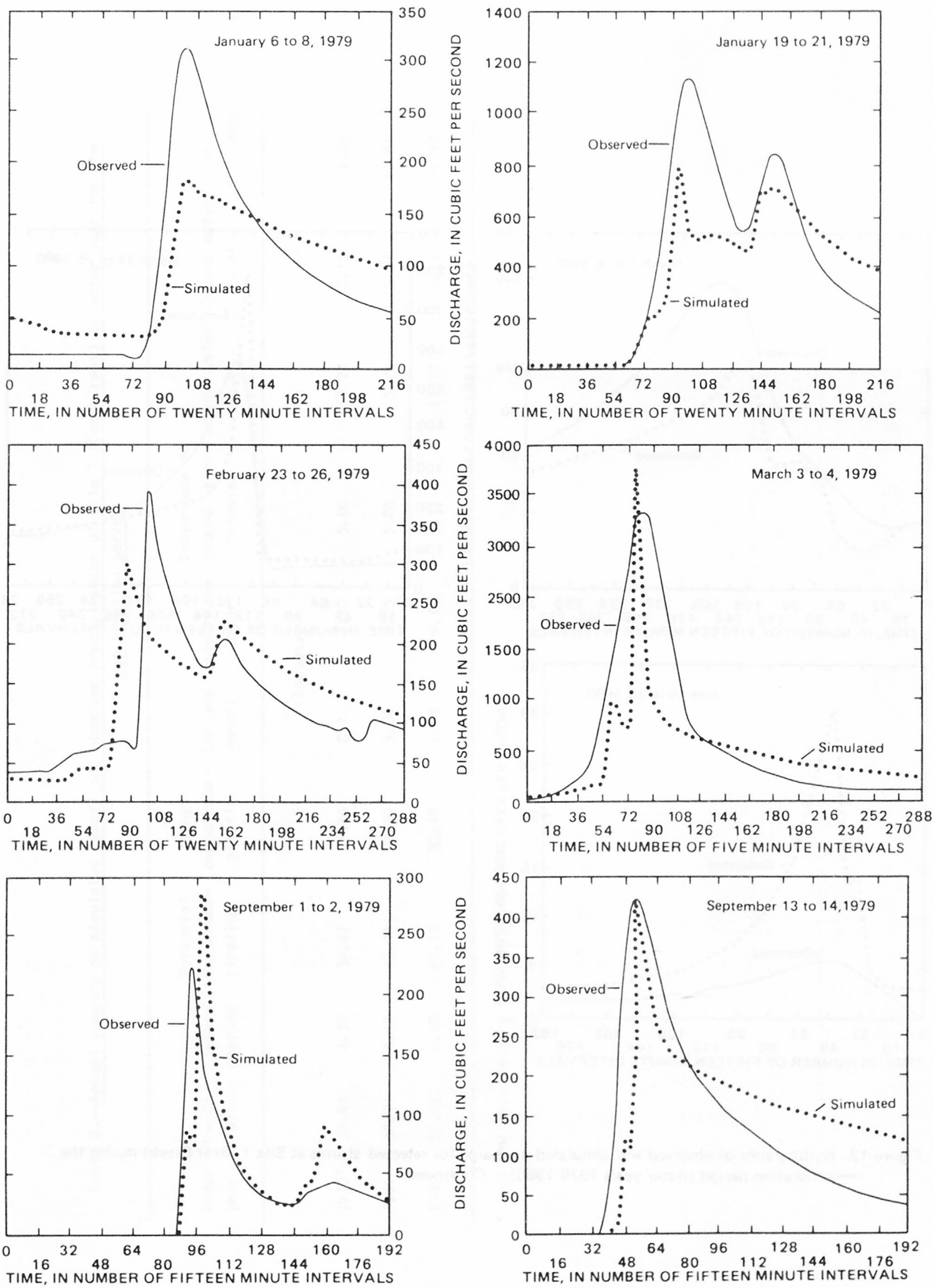

Figure 12. Hydrographs of observed and simulated discharge for selected storms at Site 1 (Bear Creek) during the calibration period (water years 1979 - 1980).

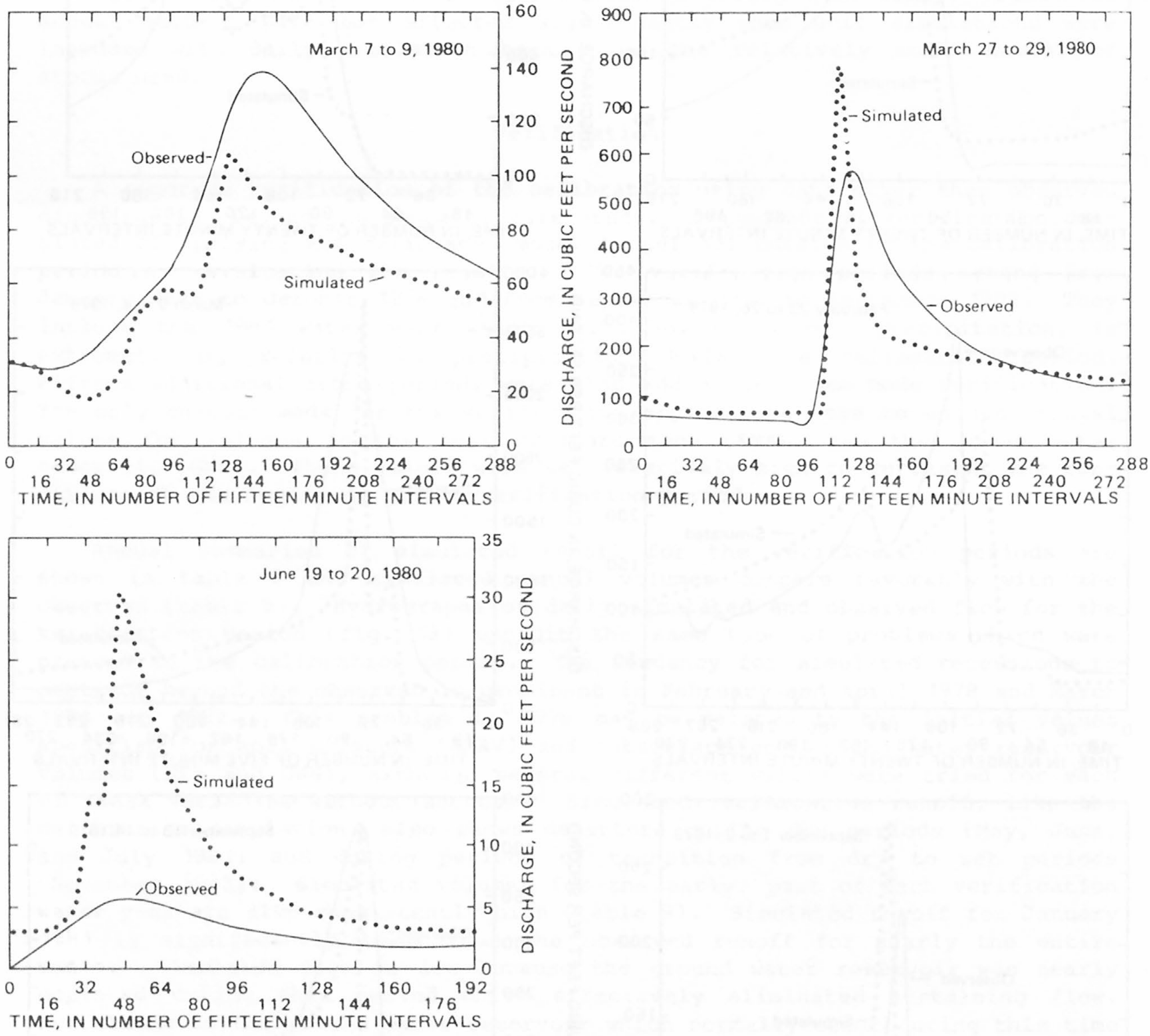

Figure 12. Hydrographs of observed and simulated discharge for selected storms at Site 1 (Bear Creek) during the calibration period (water years 1979-1980). -- Continued.

Table 8.--Annual summary of simulated runoff and observed precipitation at site 1 (Bear Creek) by water year for the verification period

Water year	Precip- itation	Inter- ception	Potential evapotrans- piration	Actual evapotrans- piration	Surface runoff	Subsurface flow	Subsurface to ground water transfer	Ground water flow	Ground water sink	Total discharge
					(Inches)					
1978*	35.95	4.35	34.47	23.36	0.71	4.12	5.90	7.25	0.15	12.08
1981	38.71	4.17	42.93	28.20	1.00	5.25	5.08	6.29	0.21	12.55
1882	61.85	6.45	47.12	32.49	1.54	9.19	9.51	11.13	0.18	21.87

* Includes only January through September

Table 9.--Simulated and observed mean discharge by month and year at site 1 (Bear Creek) for the verification period

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Mean
	(Cubic feet per second)												
1978 Simulated	0.000	0.000	0.000	38.60	16.11	43.58	2.01	31.15	27.35	1.20	0.37	0.18	13.42
1978 Observed	.000	.000	.000	43.39	14.83	44.46	8.06	33.50	16.56	1.06	.46	.00	13.60
1981 Simulated	19.60	26.48	15.45	1.20	39.44	34.91	30.94	.87	.34	.29	.24	.11	13.94
1981 Observed	2.10	17.36	10.75	7.26	41.25	53.67	29.68	1.67	.88	.59	.06	.00	13.56
1982 Simulated	.18	.09	9.30	72.36	67.50	22.40	48.26	16.89	19.11	18.50	19.37	.49	24.29
1982 Observed	.01	.10	9.11	53.39	64.11	24.77	74.70	14.35	18.09	15.65	13.81	.25	23.71

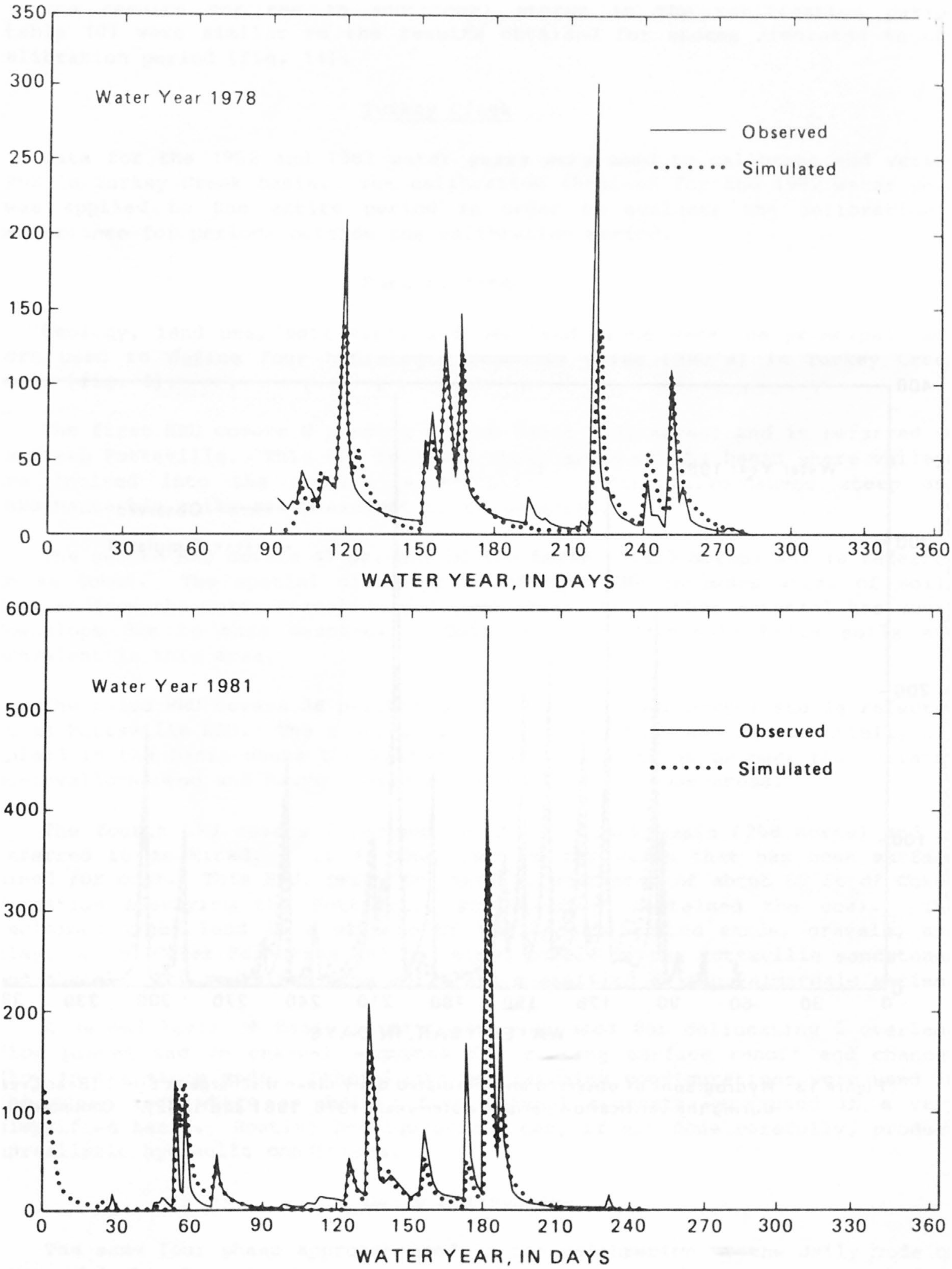

Figure 13. Hydrographs of observed and simulated daily mean discharge at Site 1 (Bear Creek) during the verification period (water years 1978, 1981 and 1982).

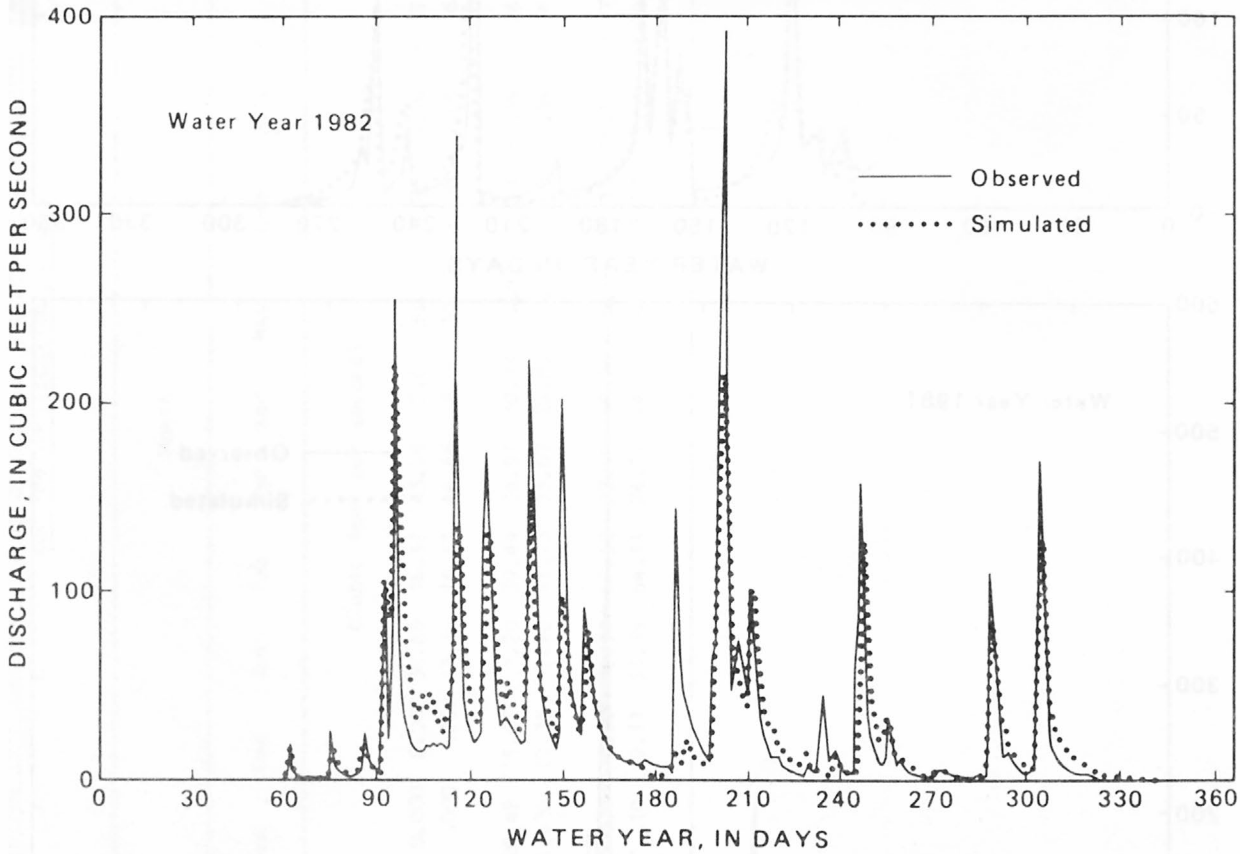

Figure 13. Hydrographs of observed and simulated daily mean discharge at Site 1 (Bear Creek) during the verification period (water years 1978, 1981 and 1982). -- Continued.

The results for the 15 additional storms in the verification period (table 10) were similar to the results obtained for storms simulated in the calibration period (fig. 14).

Turkey Creek

Data for the 1982 and 1983 water years were used to calibrate and verify PRMS in Turkey Creek basin. The calibration obtained for the 1982 water year was applied to the entire period in order to evaluate the calibration's performance for periods outside the calibration period.

Partitioning

Geology, land use, soil type, and overland slope were the principal factors used to define four hydrologic response units (HRU's) in Turkey Creek basin (fig. 4).

The first HRU covers 8 percent of the basin (322 acres) and is referred to as Steep Pottsville. This HRU includes steep areas of the basin where valleys are incised into the Pottsville Formation. Montevallo-Nauvoo steep and Iuka-Mantachie soils are prevalent in these areas.

The second HRU covers 47 percent of the basin (1,832 acres) and is referred to as Coker. The spatial distribution of this HRU includes areas of soils derived from the Coker Formation and some areas where Coker material has moved downslope due to mass wasting. Smithdale and Smithdale hilly soils are prevalent in this area.

The third HRU covers 38 percent of the basin (1,472 acres) and is referred to as Pottsville HRU. The spatial distribution of this HRU is essentially all upland in the basin where the Pottsville Formation is at or near the surface. Montevallo-Nauvoo and Nauvoo soils are prevalent in these areas.

The fourth HRU covers 7 percent of Turkey Creek basin (268 acres) and is referred to as Mined. It is that part of the basin that has been surface mined for coal. This HRU, prior to mining, consisted of about 60 ft of Coker Formation overlying the Pottsville strata which contained the coal. The reclaimed mined land is a mixture of the unconsolidated sands, gravels, and clays of the Coker Formation and the mined rubble of the Pottsville sandstones and shales. The reclaimed mine soils are classified as the Palmerdale series.

A second level of basin partitioning was used for delineating 5 overland flow planes and 28 channel segments for routing surface runoff and channel flow in the storm mode. Other basin partitioning configurations were used in the storm mode where as few as five channel segments were used in a very simplified basin. Routing configurations can, if not done carefully, produce unrealistic hydraulic conditions.

Daily Calibration

The same four phase approach used in the calibration of the daily mode of the model for Bear Creek basin was used for Turkey Creek basin. The four phases are: (1) hydrograph match, (2) annual volume match, (3) water budget analysis, and (4) final adjustments.

Table 10.--Simulated and observed storm statistics for Bear Creek verification

Storm number	Beginning date mo-day-yr	Ending date mo-day-yr	Observed Precipitation (inches)	Observed runoff (inches)	Simulated runoff (inches)	Observed peak (cubic feet per second)	Simulated peak (cubic feet per second)
1	2-28-78	2-28-78	1.37	0.15	0.08	99	60
2	3- 7-78	3- 8-78	1.25	.48	.41	144	119
3	3-14-78	3-14-78	.96	.34	.28	205	275
4	2-10-81	2-11-81	2.29	.96	.68	438	236
5	3-21-81	3-23-81	1.53	.68	.23	292	122
6	3-29-81	3-30-81	3.23	1.54	.92	1320	1313
7	4- 4-81	4- 5-81	1.11	.60	.40	280	163
8	11-30-81	12- 1-81	2.04	.04	.05	38	79
9	12-31-81	1- 1-82	1.75	.38	.49	257	285
10	1- 3-82	1- 4-82	2.03	1.09	1.09	589	463
11	3- 6-82	3- 7-82	1.31	.33	.29	100	90
12	4-19-82	4-21-82	2.74	2.19	1.30	571	262
13	5-17-82	5-18-82	1.67	.05	.07	43	44
14	6- 3-82	6- 4-82	2.59	.41	.29	234	215
15	6-12-82	6-13-82	1.75	.11	.12	63	75

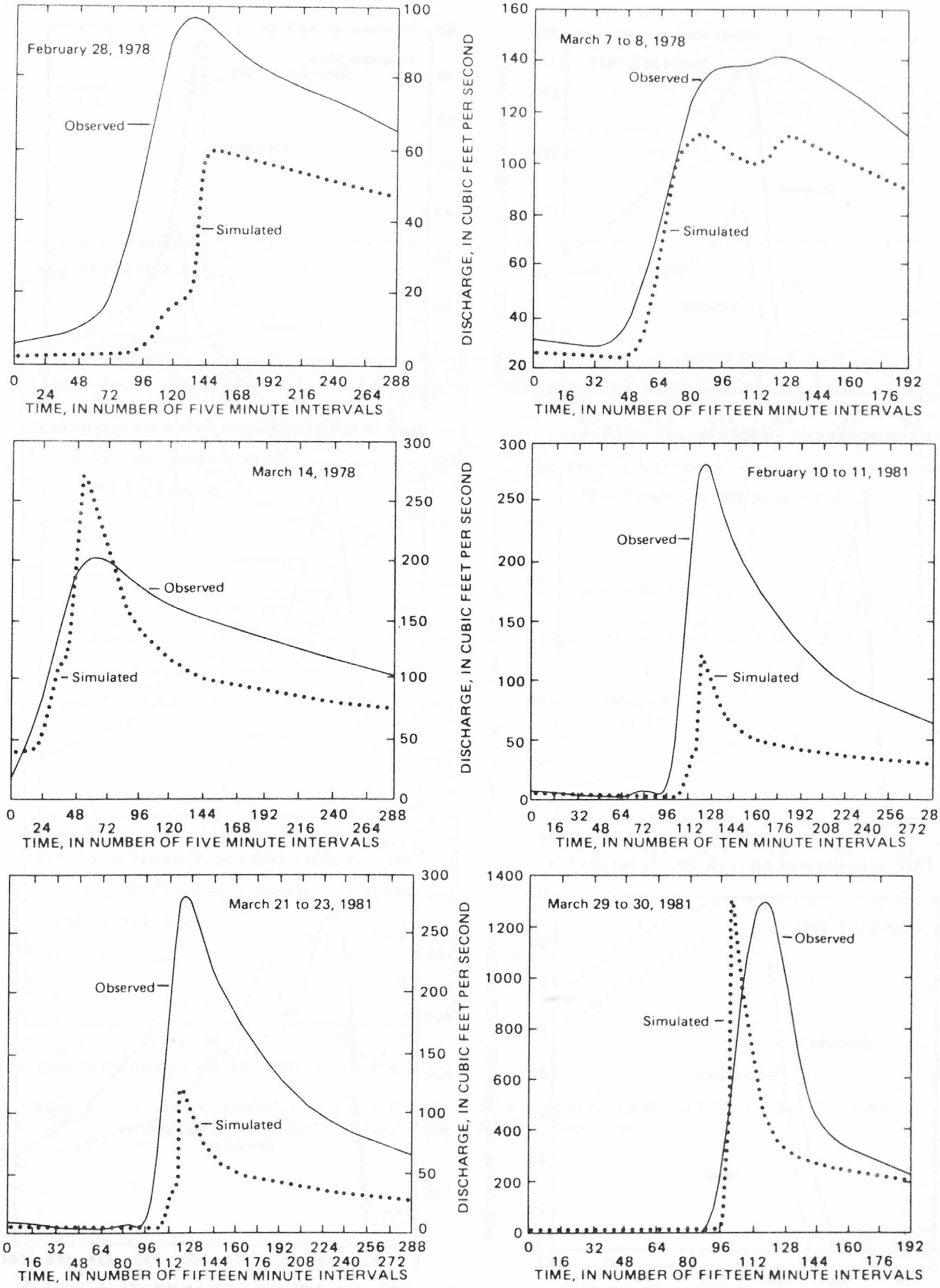

Figure 14. Hydrographs of observed and simulated discharge for selected storms at Site 1 (Bear Creek) during the verification period (water years 1978, 1981, and 1982).

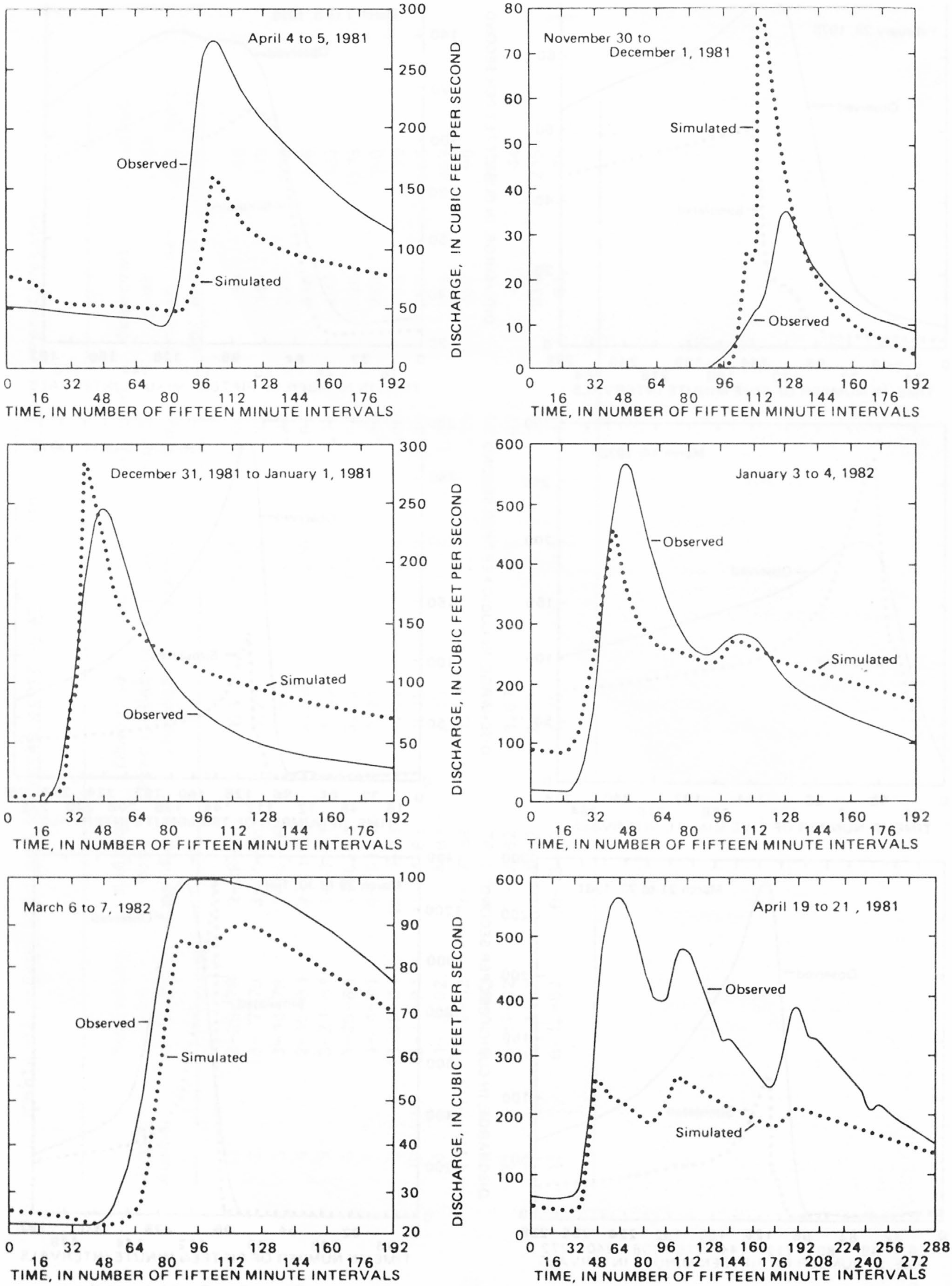

Figure 14. Hydrographs of observed and simulated discharge for selected storms at Site 1 (Bear Creek) during the verification period (water years 1978, 1981, and 1982). -- Continued.

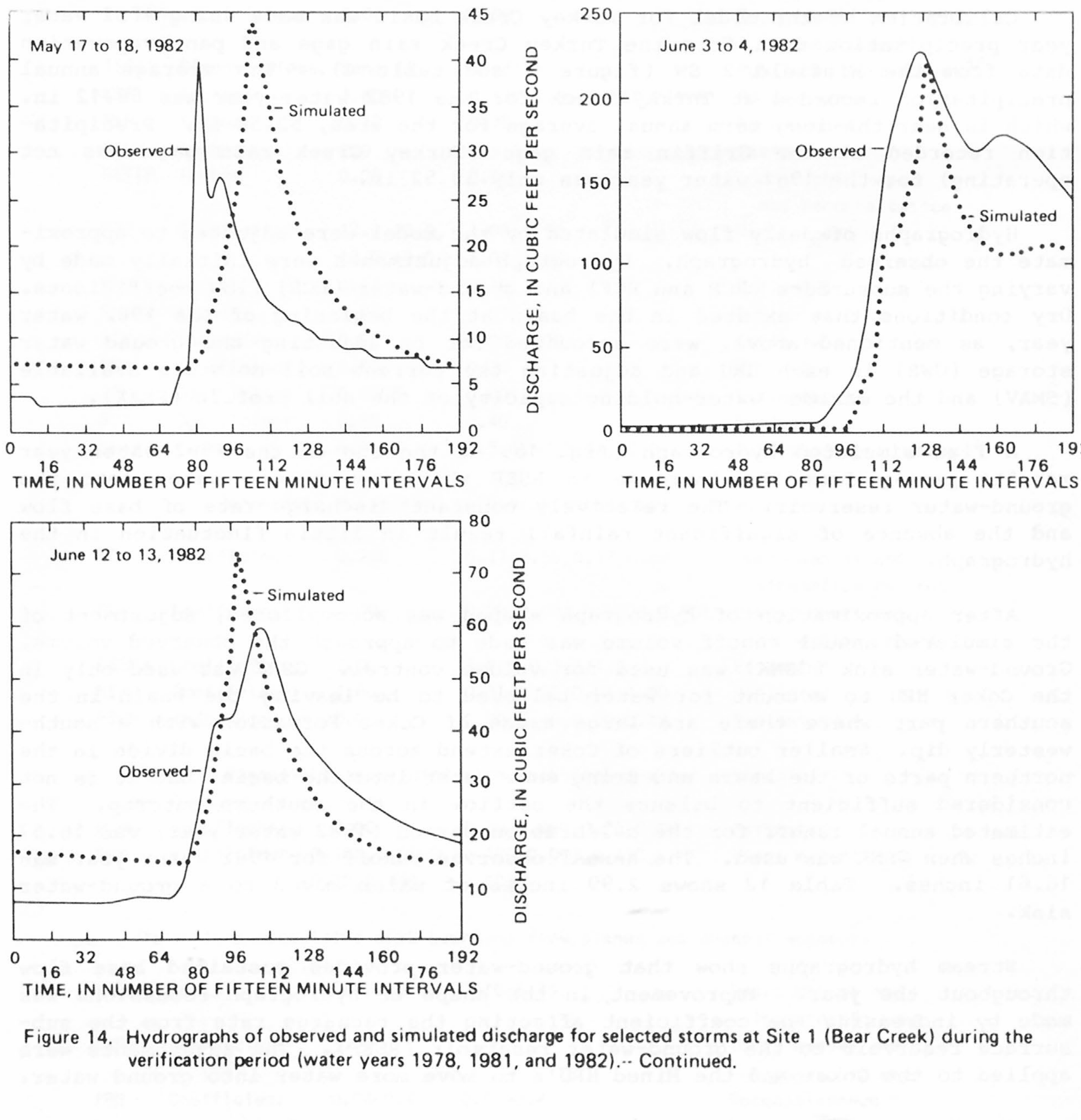

Figure 14. Hydrographs of observed and simulated discharge for selected storms at Site 1 (Bear Creek) during the verification period (water years 1978, 1981, and 1982).-- Continued.

Data were taken from topographic maps, streamflow records, climatological reports, soil surveys, and from field reconnaissance to determine initial values for many parameters. Many of the initial values for coefficients and some of the variables used in the Pottsville and Steep Pottsville HRU's in Turkey Creek basin were transferred from the calibration of the Bear Creek basin. Initial values and parameters had to be determined for the Coker, and Mined HRU's. Initial and final values and parameters are given in table 11.

Calibration of the model for Turkey Creek basin was made using 1982 water year precipitation data from the Turkey Creek rain gage and pan evaporation data from the Winfield 2 SW (figure 1 and table 4). The average annual precipitation recorded at Turkey Creek for the 1982 water year was 58.12 in. which is near the long term annual average for the area, 52.58 in. Precipitation recorded at the Griffin rain gage (Turkey Creek rain gage was not operating) for the 1981 water year was only 39.52 in.

Hydrographs of daily flow simulated by the model were adjusted to approximate the observed hydrograph. Hydrograph adjustments were initially made by varying the subsurface (RCP and RCF) and ground-water (RCB) flow coefficients. Dry conditions that existed in the basin at the beginning of the 1982 water year, as mentioned above, were accounted for by adjusting the ground water storage (GWS) in each HRU and adjusting the current soil moisture available (SMAV) and the maximum water-holding capacity of the soil profile (SMAX).

A flat simulated hydrograph (fig. 15) at the end of the 1982 water year results partly from the increase in RSEP which moved more water into the ground-water reservoir. The relatively constant discharge rate of base flow and the absence of significant rainfall result in little fluctuation in the hydrograph.

After approximation of hydrograph shapes was accomplished, adjustment of the simulated annual runoff volume was made to approach the observed volume. Ground-water sink (GSNK) was used for volume control. GSNK was used only in the Coker HRU to account for water believed to be leaving the basin in the southern part where there are large areas of Coker Formation with a southwesterly dip. Smaller outliers of Coker extend across the basin divide in the northern parts of the basin and bring some water into the basin, but it is not considered sufficient to balance the outflow in the southern outcrop. The estimated annual runoff for the calibration period (1982 water year) was 16.57 inches when GSNK was used. The annual observed runoff for 1982 water year was 16.61 inches. Table 12 shows 2.99 inches of water moved to a ground-water sink.

Stream hydrographs show that ground-water provides sustained base flow throughout the year. Improvement in the shape of hydrograph recessions was made by increasing the coefficient affecting the recharge rate from the subsurface reservoir to the ground-water reservoir (RSEP). The adjustments were applied to the Coker and the Mined HRU's to move more water into ground water.

The "Final Adjustment" phase was used to make trade-offs between simulated volumes and hydrograph shapes with more weight being given to hydrograph

Table 11.--Initial and final parameter values for Turkey Creek basin

Parameter[1/]	Units	Parameter Values[2/] Initial	Final	Source of initial estimates
Parameters associated with each hydrologic response unit				
DRCOR	Coefficient	1.00	1.00	Users manual
DRN	Coefficient	1.00	1.00	Recommended
IMPERV	Coefficient	0.00	0.00	Topographic and reconnaissance
ISOIL	Dimensionless	Sand(1)	Sand(1)	Published soil survey[3/]
KSAT	Inches/hour	1.00	0.130,1.86,0.360,2.190	Recommended
PSP	Inches	0.10	0.10	Recommended
REMX	Inches	2.0	1.5	Estimated
RETIP	Inches	0.00	0.00	Topographic maps and reconnaissance
RGF	Coefficient	12.0,10.0, 10.0,10.0	1.00,1.00, 1.01,1.00	Recommended
RNSTS	Inches	0.12	0.10	Estimated
RNSTW	Inches	0.07	0.05	Estimated
SEP	Inches/day	0.01	0.09-1.99	Estimated
SCI	Coefficient	0.30	0.20	Estimated
SCN	Coefficient	0.0003	0.0012	Estimated
SCX	Coefficient	0.60	0.40	Estimated
SMAX	Inches	6.0	3.5,6.90,8.64,12.0	Published soil survey[3/]
Parameters associated with each subsurface reservoir				
RCF	Coefficient	0.200	0.17,0.59,0.17,0.59	Users manual and streamflow records
RCP	Coefficient	0.00	0.09,0.001,0.0900,0.001	Users manual and streamflow records
RESMX	Coefficient	1.00	3.5,1.0,3.5,1.0	Estimated
REXP	Coefficient	1.00	0.01,1.00,0.01,1.00	Estimated
RSEP	Inches/day	0.00	0.00,0.49,0.00,0.49	Estimated
Parameters associated with each ground-water reservoir				
GSNK	Acre/inches	0.00	0.00,0.002,0.00,0.00	Estimated
RCB	Coefficient	0.100,0.0100, 0.10,0.130	0.120,0.003,0.130, 0.0030	Users manual
Parameters associated with overland flow planes and channel segments				
ALPHA	Coefficient	0.06-2.23	1.18-6.45	Users manual and topographic maps
EXPM	Coefficient	1.67	2.50	Users manual and topographic maps
FRN	Coefficient	0.04-0.4	0.04-0.4	Reconnaissance
Climatic parameters				
EVC	Coefficient	0.13-1.0	0.52-0.94	Published climatologic data[3/]

1/ Abbreviations defined in table 2.

2/ Distributed parameter values listed by hydrologic response unit.

3/ U.S. Department of Agriculture, 1981.

shape. Continued recessions were corrected only slightly by adjusting the subsurface flow coefficients (RCF and RCP) and ground-water parameters (SEP and RCB).

Final values for variables and parameters used in the calibration of Turkey Creek basin are given in table 11. A summary of observed and simulated results for the calibration period are listed in table 12. Plots of the simulated and observed daily flows are shown in figure 15. Simulated annual volume differs from the observed by less than 10 percent. Simulated and observed monthly volumes are presented in table 13.

Verification

Verification of the daily mode model calibration for Turkey Creek basin consisted of model application to the 1983 water year. The calibration period was included to remove any initialization or start up error that might occur in estimating the amount of water present in the system at the beginning of the 1983 water year. Precipitation for the 1983 water year was 76.82 in., which is 23.24 in. above the long term annual average for the area. As mentioned above, the beginning of the calibration period was following the very dry (39.52 in.) 1981 water year. No changes in model parameters or variables were made for the verification period. The simulated annual volume differs from the observed by 12 percent for the 1983 water year. Figure 16 and tables 14 and 15 present the results of the daily verification.

Storm Mode Calibration

Initial storm simulations were made using parameter values determined in the Bear Creek basin calibration as shown in table 4. The simulated hydrographs showed no storm peaks due to the absence of surface runoff. Simulated storm volumes differed from the observed by about an order of magnitude in each storm and the simulated outflow for each storm was less than half the observed. KSAT was decreased to increase surface runoff and storm outflow. PSP and RGF were decreased (all storms occur in wet periods) to get a close fit on the storm peaks. Values for kinematic wave parameters were computed by PRMS and adjusted slightly to fit the simulated hydrograph. Final values (table 11) for KSAT and RGF are much lower than the initial values. Use of the lower values to simulate the observed hydrograph shapes and volumes in wet periods may not be effective in dry conditions when moisture deficits would probably require PSP and RGF to be higher as in the Bear Creek calibration. The routing configuration probably accounts for most of the differences in simulated and observed peaks and volumes. Repartitioning of the basin helped decrease the volume of water staying in the channel segments after a storm, but a significant amount stayed in the channel and flowed out the following day. The lower KSAT values were used after excessive runoff occurred if one (the smallest) flow plane was set to contribute all precipitation excess to outflow with no routing and after changes in the basin segmentation to try to increase surface runoff from the channel segments were not successful.

Final storm calibration for Turkey Creek basin simulates storm hydrographs, peaks and volumes as shown in table 16 and figure 17. It should be noted that storm data were not available in the summer and fall when dry conditions occur.

Table 12.--Annual summary of simulated runoff and observed precipitation at site 3 (Turkey Creek) for the calibration period

Water year	Precip-itation	Inter-ception	Potential evapotrans-piration	Actual evapotrans-piration	Surface runoff	Subsurface flow	Subsurface to ground water transfer	Ground water flow	Ground water sink	Total discharge
	(Inches)									
1982	58.12	7.64	42.20	31.59	3.50	6.80	0.42	6.27	2.99	16.57

Table 13.--Simulated and observed mean discharge by month at site 3 (Turkey Creek) for the calibration period

Water year	Month												Mean
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
	(Cubic feet per second)												
1982 Simulated	1.96	1.53	5.29	18.74	21.90	9.95	13.57	5.11	4.48	3.54	2.41	1.88	7.43
1982 Observed	1.85	2.02	5.50	14.79	19.15	10.70	18.36	4.69	5.00	4.08	2.94	1.39	7.45

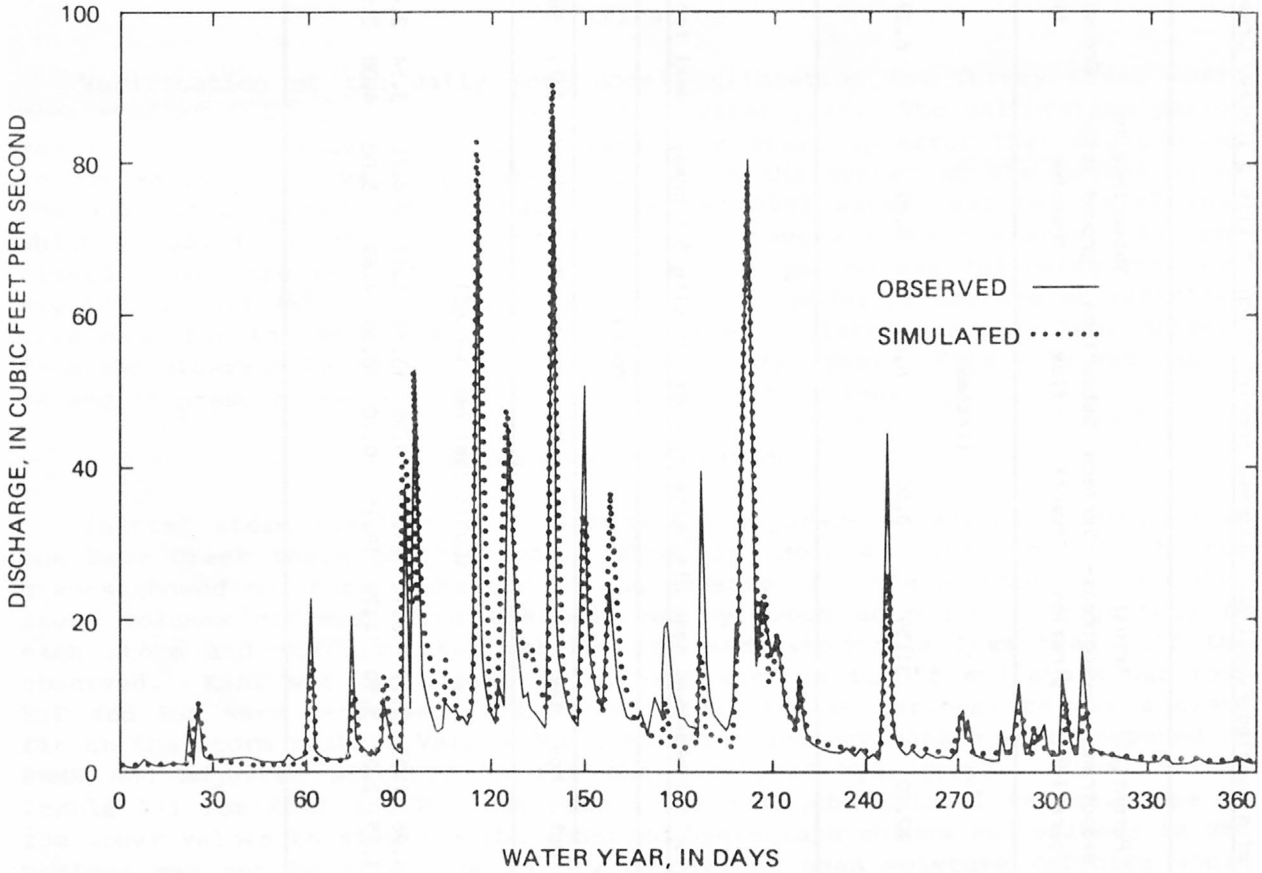

Figure 15. Annual hydrograph of daily observed and simulated discharge at Turkey Creek for the verification period (water year 1982).

Table 14.--Annual summary of simulated runoff and observed precipitation at site 3 (Turkey Creek) for the verification period

Water year	Precip-itation	Inter-ception	Potential evapotrans-piration	Actual evapotrans-piration	Surface runoff	Subsurface flow	Subsurface to ground water transfer	Ground-water flow	Ground-water sink	Total discharge
					(Inches)					
1983	73.48	7.82	41.77	25.96	5.23	16.13	1.21	10.13	4.78	31.50

Table 15.--Simulated and observed mean discharge by month at site 3 (Turkey Creek) for the verification period

Water year	Month												Mean
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
						(Cubic feet per second)							
1983 Simulated	2.94	6.74	28.93	12.87	36.01	20.77	16.81	27.36	6.61	4.49	3.84	3.64	14.14
1983 Observed	3.18	5.28	29.60	12.91	36.69	22.70	31.97	36.96	6.75	3.27	2.25	3.30	16.12

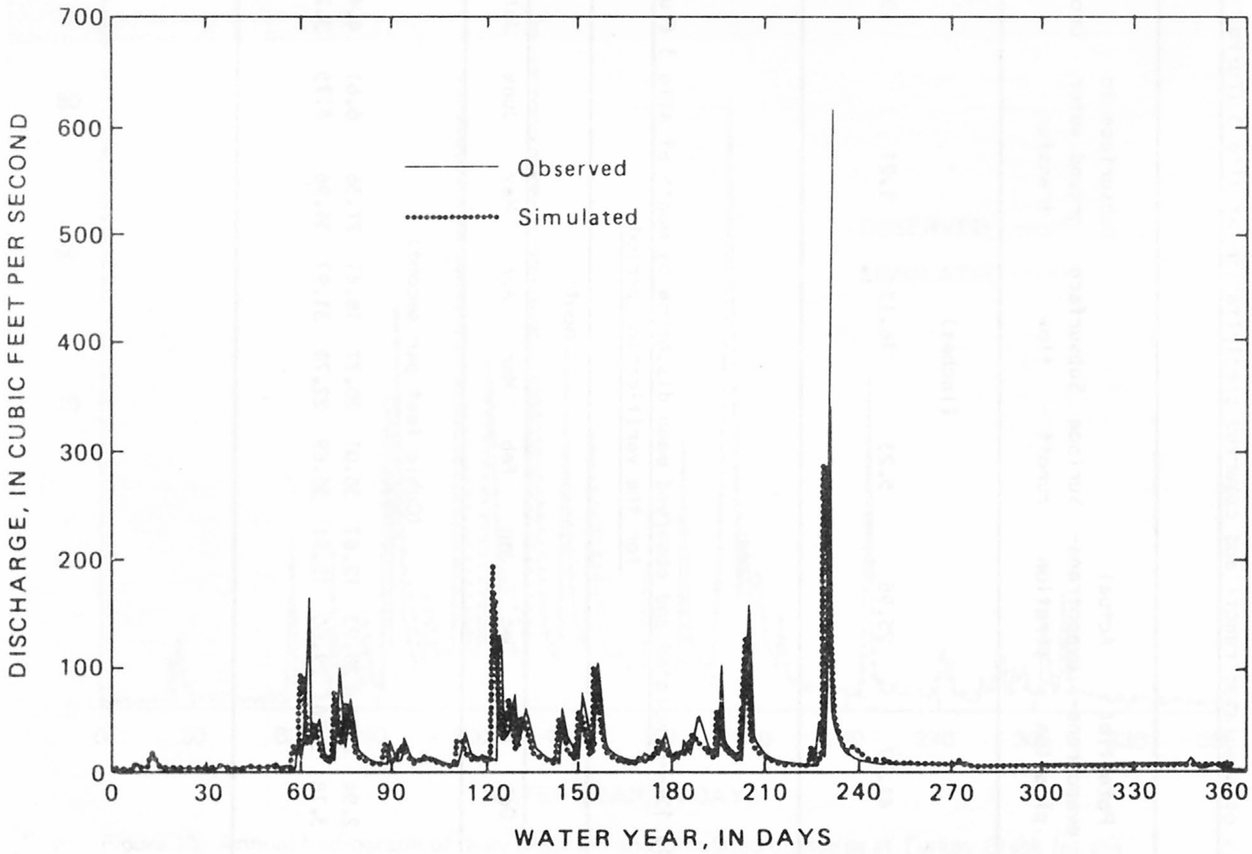

Figure 16. Annual hydrograph of daily observed and simulated discharge at Turkey Creek for the verification period (water year 1983).

Significant Calibration Parameters

Several key calibration parameters could be identified at the conclusion of the calibration process for both basins. While a large number of PRMS parameters effected the simulations, these key parameters had significant effects on the overall accuracy of the calibrations. They effected the match between observed and simulated volumes and recessions and also the distribution of simulated flow to the three components of total simulated flow (surface, subsurface, and ground-water runoff). Most of the final values for these parameters were fitted, to some extent, with a trial and error process. Values of the parameters were systematically varied during fitting until the appropriate effect to the simulated hydrograph was achieved.

The SMAX, EVC, and GSNK parameters are all capable of influencing the simulated volume significantly. SMAX affects runoff volumes when antecedent soil moisture is low. If SMAX is set too low, runoff volumes will be too high; if it is set too high, runoff volumes will be low. Initial values for SMAX were computed based on specific yields calculated by the Soil Conservation Service. These initial values were adjusted to obtain the best fit between observed and simulated runoff during periods of low antecedent soil moisture.

The EVC parameter is capable of affecting significant control on annual simulated runoff volumes. A considerable range of values were used throughout the calibration process. The final values used conform closely to the range of pan coefficients calculated by the National Oceanic and Atmospheric Administration (U.S. Department of Commerce, 1982). While these values did not produce the best results with respect to the match of annual simulated and observed runoff volumes, they did produce the best results with respect to published values for annual free water surface evaporation (U.S. Department of Commerce, 1982).

The GSNK parameter can also have a dramatic affect on the simulated volume of runoff. It allows water in the ground-water flow reservoir to "sink" to a conceptually lower reservoir which is isolated from runoff processes in the basin. The GSNK parameter was used only when warranted by geologic and hydrologic conditions such as those described in the Turkey Creek basin.

The subsurface (RCF and RCP) and ground-water (RCB) flow coefficients are powerful calibration parameters. Initial values for these parameters were calculated from hydrographs of observed daily flow. The initial calculated values represented a value integrating the recessions from the various response units in the basin. The initial values for subsurface flow coefficients were modified to represent the perceived contribution for each response unit. Values were (1) raised in response units with steep slopes or relatively high values for soil permeability and were (2) lowered for response units with moderate slopes or relatively low soil permeability.

Values for the ground-water flow coefficient were treated similarly and adjusted on the basis of water-level hydrographs and field reconnaissance.

Table 16.--Simulated and observed storm statistics for site 3 (Turkey Creek)

Storm number	Beginning date mo-day-yr	Ending date mo-day-yr	Observed precipitation (inches)	Observed runoff (inches)	Simulated runoff (inches)	Observed peak (cubic feet per second)	Simulated peak (cubic feet per second)
1	1-22-82	1-24-82	1.49	0.65	0.78	204	171
2	2-15-82	2-17-82	2.07	0.72	0.90	210	175
3	3- 5-83	3- 7-83	2.54	1.15	1.30	263	235
4	4-22-83	4-24-83	3.40	1.48	1.32	393	193

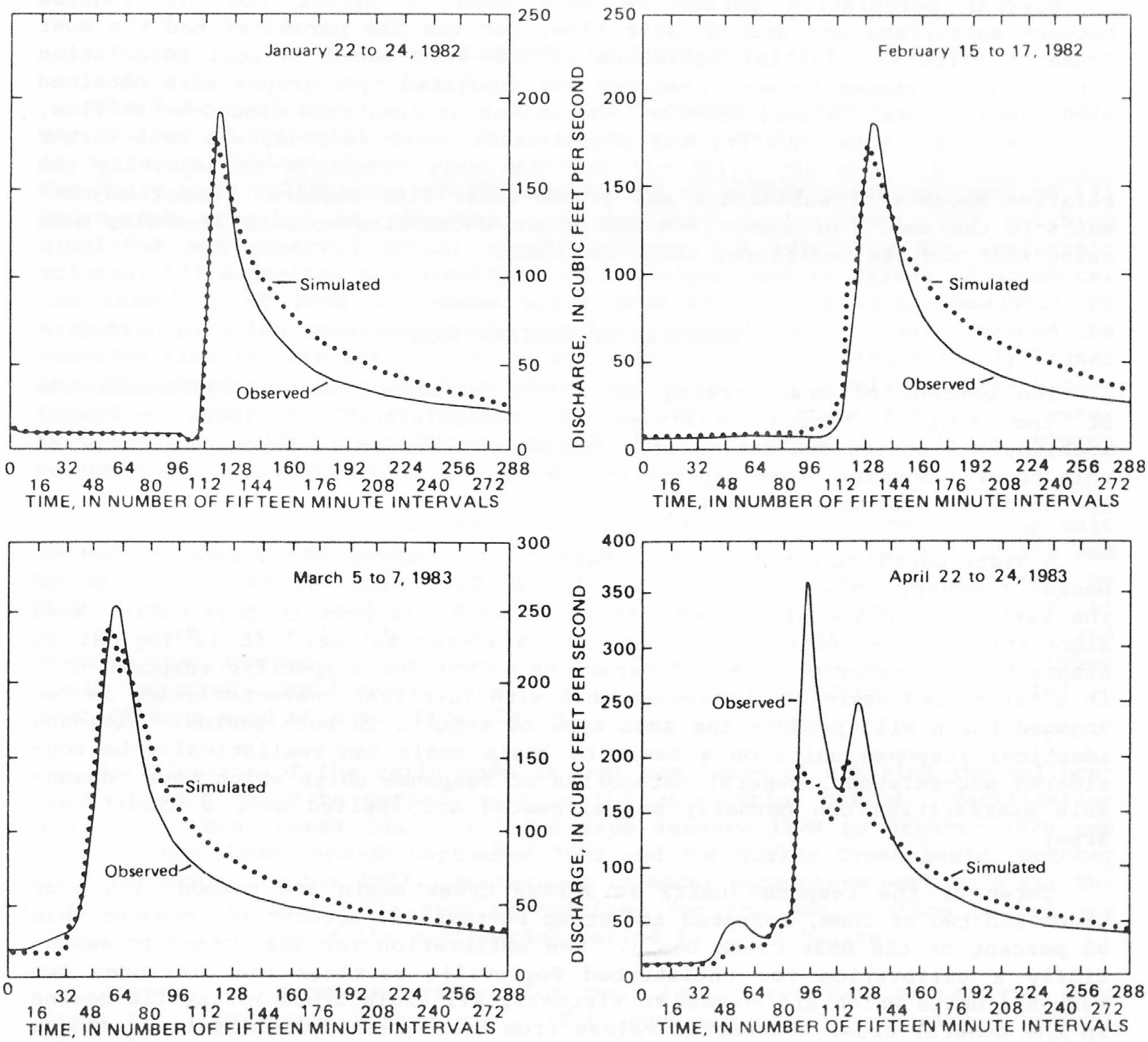

Figure 17. Hydrographs of observed and simulated discharge for selected storms at Site 10 (Turkey Creek), water years 1982-1983.

Response units which were known to store and transmit water at rates which sustain streamflow through rainless periods were assigned coefficient values calculated from the sustaining, or late summer, part of the hydrograph. Values for response units which were known to store and transmit water at relatively quick rates were calculated from spring recessions.

Several percolation parameters were used to affect the distribution between subsurface and ground-water flow, but the SEP parameter had the most dramatic affects. Initial estimates of SEP were based on soil percolation rates. Good matches between observed and simulated hydrographs were obtained with these initial values; however, the amount of simulated ground-water flow, based on stream water quality and ground-water level records, was much larger than expected. The SEP parameter was extremely effective in adjusting the relative amounts of subsurface and ground-water flow volumes. Minor adjustments to the amount of subsurface and ground-water flow volumes were also made using RSEP and its modifiers, RESMX and REXP.

TRANSFER OF CALIBRATIONS

The concept of transferring calibrated parameter values represents one of the most lucrative utilities of deterministic precipitation-runoff modeling. A strict evaluation of calibration transfer is beyond the scope of this report, however, some aspects of the concept which became apparent during the study are discussed below.

A distributed calibration for a basin will simulate runoff from the entire basin; however, this integrated result is determined through evaluation of the various user specified response units with respect to physically based algorithims driven with unique sets of parameter values. It is logical to assume that transfer of a set of parameter values for a specific response unit in a calibrated basin to a response unit with identical characteristics in an ungaged basin will produce the same type of results in both basins. Although identical response units on a basin to basin scale can realistically be considered non-existent, general categories of response units which have reasonable similarities can normally be delineated and applied over a significant area.

Three of the response units in Turkey Creek basin are common with Bear Creek and two of them, Forested and Steep Pottsville, account for greater than 95 percent of the Bear Creek basin. The calibration for Bear Creek is essentially a calibration for undisturbed Pottsville settings that includes two response units which are common to virtually all undisturbed Pottsville basins in the general area. Parameter values from Bear Creek for these two response units were transferred directly to those areas of the Turkey Creek basin which were similar and held constant during the Turkey Creek calibration process. Adjustments to parameter values during the Turkey Creek calibration were in the Coker and Mined response units. The parameter transfer was considered successful since a good calibration was obtained. Application of PRMS in a basin which has a significant portion of Coker and little or no mining should indicate any differences between the Coker and Mined response units. At present the characteristics of these two response units have been considered to be very similar (table 11).

The major problem encountered when transfer of the Bear Creek calibration to the Pottsville parts of the Turkey Creek basin was attempted involved initial storage values. A relatively small error for the initial values in either the soil moisture storage, or storage in the ground or subsurface reservoirs (SMAV, RES, and GW respectively) can have a substantial affect on simulated results.

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey's Precipitation-Runoff Modeling System (PRMS) was calibrated and verified for unmined and mined conditions in two watersheds in different geologic-hydrologic areas in the Warrior coal field of Alabama. The daily mode calibration of PRMS consisted of a four phase approach of (1) hydrograph matching of observed and simulated daily flows, (2) matching simulated and observed annual runoff volumes and adjusting flow reservoir volumes, (3) adjusting the simulated water budget, and (4) final adjustments. The inability of PRMS to remove water from the ground water reservoir by evapotranspiration resulted in the simulated recessions continuing beyond the observed flow in late spring and the simulated base flow being slightly higher than the observed during the late summer and fall. The simulated water budget showed the majority of streamflow consists of subsurface and ground water contributions. Well hydrographs support the rapid movement of large volumes of ground water through the Pottsville aquifers.

The Storm mode of PRMS was calibrated for Bear Creek basin using unit discharge and precipitation data for seven storms; four during wet months and three during dry periods. The Turkey Creek basin calibration is based on discharge and precipitation data from four storms during wet months. Final storm calibrations for both basins simulate storm hydrographs, peaks, and volumes that approximate observed runoff. The calibration in the Turkey Creek basin improved significantly when the routing configuration was modified so that it consisted of small flow planes.

Verification of the Daily mode of PRMS consisted of applying the calibration of each basin to periods outside the calibration period. Verification period for Bear Creek basin included from January 1978 to October 1978 and from October 1980 through September 1982 and for Turkey Creek basin, October 1981 through September 1983. No changes in model parameters were made for the verification period. The results obtained for the verification period are comparable to those of the calibration period for both basins.

Transfer of parameter values for two similar response units from Bear Creek to Turkey Creek worked well. This suggests that determining a general classification of response unit types which occur in the Warrior coal field and developing calibrations for them would facillitate modeling of ungaged basins throughout the Warrior coal field.

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