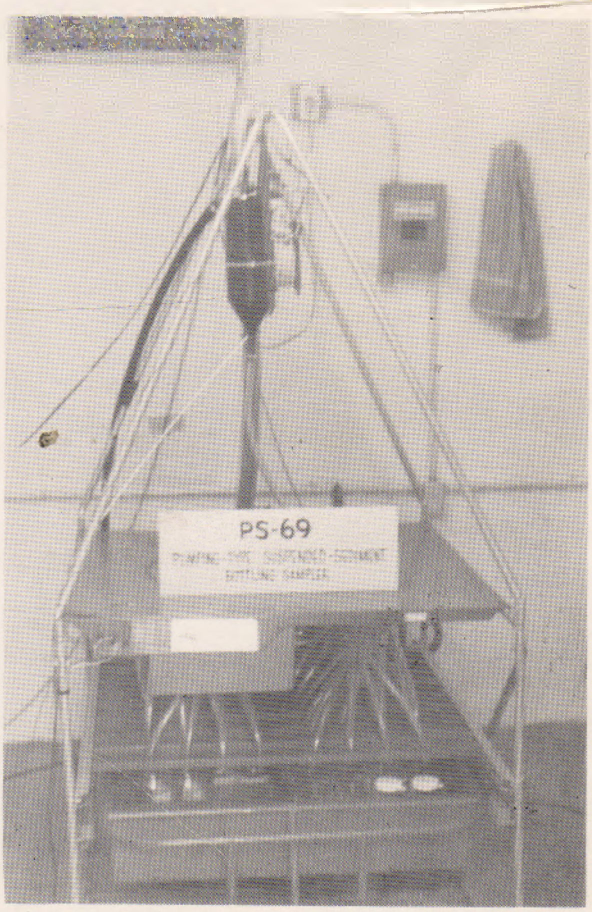
EFFECT OF SURFACE COAL MINING ON THE HYDROLOGY OF CROOKED AND TURKEY CREEK BASINS, JEFFERSON COUNTY, ALABAMA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 79-91



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August 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

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FACTORS FOR CONVERTING INTERNATIONAL SYSTEM (SI) UNITS TO INCH-POUND UNITS

Divide SI units	By	To obtain inch-pound units
millimeter (mm)	25.4	inch (in)
centimeter (cm)	2.540	inch (in)
meter (m)	.3048	foot (ft)
kilometer (km)	1.609	mile (mi)
square kilometer (km^2)	2.590	square mile (mi^2)
square kilometer (km^2)	.004047	acre
cubic meter (m^3)	.7645	cubic yard (yd^3)
metric ton (t)	.9072	ton
meter per kilometer (m/km)	.1894	foot per mile (ft/mi)
metric ton per square kilometer (t/km^2)	.3503	ton per square mile (ton/mi^2)
liter per second (L/s)	28.32	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	.02832	cubic foot per second (ft^3/s)
liter per second per square kilometer [$(L/s)/km^2$]	10.93	cubic foot per second per square mile [$(ft^3/s)/mi^2$]
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	.010934	cubic foot per second per square mile [$ft^3/s)/mi^2$]
liters per second (L/s)	.06309	gallons per minute (gal/min)

EFFECT OF SURFACE COAL MINING ON THE HYDROLOGY OF CROOKED AND TURKEY CREEK BASINS, JEFFERSON COUNTY, ALABAMA

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ABSTRACT

Streamflow, sediment yield, and water quality were monitored from October 1975 through May 1977 to determine the impact of surface coal mining on the hydrology of Crooked and Turkey Creek basins in Jefferson County, Alabama. The basins are in the northeast part of the Warrior coal field. Coal is and has been mined from the Blue Creek, Mary Lee, and Newcastle coal beds in the Mary Lee group. Results show water-quality degradation, increased sediment yields, and increased low flow in most tributaries draining mined areas. Highly mineralized mine drainage is commonly acidic, and contains large concentrations of sulfate, iron, aluminum, manganese, and dissolved solids. Some highly mineralized mine drainage in Crooked Creek basin is alkaline due to the presence of carbonate minerals in the shale overburden.

The impact of mine drainage and high sediment yields from mined subbasins on water in the main stem of Turkey Creek was small due to the alkalinity of the water in the creek and to dilution ratios that ranged from 1:30 to 1:300.

Mine drainage had a significant effect on the quality of water in Crooked Creek. The dissolved solids concentration in water downstream from the mined areas was as much as 7 times greater than that in water in unmined parts of the basin. The sediment yield to Crooked Creek was lower in the mined area than in the unmined segment of the stream. The lower yield is due, in part, to the trapping of sediment in sediment ponds in the mines and in a swamp downstream from the mines.

INTRODUCTION

Increasing demands for energy and limited oil and gas reserves have placed a renewed emphasis on the development of coal resources. Surface coal mining, like any disruption of the land surface, frequently affects the water resources of an area. Water problems or potential problems associated with surface coal mining include erosion and sedimentation, flooding, diversion of drainage, decline in ground-water levels, and the degradation of water quality (Knight and Newton, 1977). The degradation of water quality is the most serious and widespread problem.

The objective of this project is to measure the impact coal mining has on the hydrologic system and to develop the capability for predicting the effect of future mining on water resources. To achieve this necessitates isolating the problems and measuring the parameters involved before, during, and after mining.

During the first year of the project (1975), a report by Knight and Newton (1977) entitled "Water and Related Problems in Coal-Mine areas of Alabama," was prepared. From October 1975 through May 1977, streamflow, quality of water, and sediment parameters from mined and reclaimed areas in Crooked and Turkey Creek basins in Jefferson County were monitored. The basins are in the northeast part of the Warrior coal field (fig. 1), the most productive in Alabama. The purpose of this report is to present findings resulting from this phase of the project.

PREVIOUS STUDIES

Considering the magnitude and areal distribution of surface coal mining in Alabama (Knight and Newton, 1977), remarkably few data have been collected or evaluated to determine its impact on the hydrologic system. Studies of regional scope have been reconnaissance in nature, and more detailed studies have been confined to specific problems at specific sites.

Cherry (1963), based on a reconnaissance study, determined that the chemical quality of water in streams in most areas underlain by the coal-bearing strata was good. Hyde and others (1969) located acid-mine drainage in Walker, Tuscaloosa, and Jefferson Counties and observed that the number of streams affected was relatively small. Culbertson (1964) described coal groups and their distribution in Alabama. The distribution of geologic units and coal beds in the area of study has been mapped by Butts (1910). Floodflow (Hains, 1973) and the low flow and flow duration (Peirce, 1967; Hayes, 1978) have also been described. The availability and quality of surface water and ground water in Jefferson County have been described by Knight (1976). Water-quality data pertinent to the study have also been published in open-file and annual reports by the U.S. Geological Survey.

ACKNOWLEDGMENTS

Acknowledgment is made to several individuals, agencies, and companies for significant contributions to this investigation. Mr. Thomas W. Daniel, Jr., Geological Survey of Alabama, furnished identifications of coal seams and provided other information pertaining to strip mining methods. Mr. John Bensko, National Aeronautics and Space Admininstration, provided valuable photographic coverage of the project area. Mr. Dwight Hicks, Reclamation Division, Drummond Coal Company, arranged access to mining areas and monitoring sites and provided information pertaining to coal beds, production, and reclamation. The Hallmark Coal Company and Alabama Byproducts provided access to mining areas and monitoring sites.

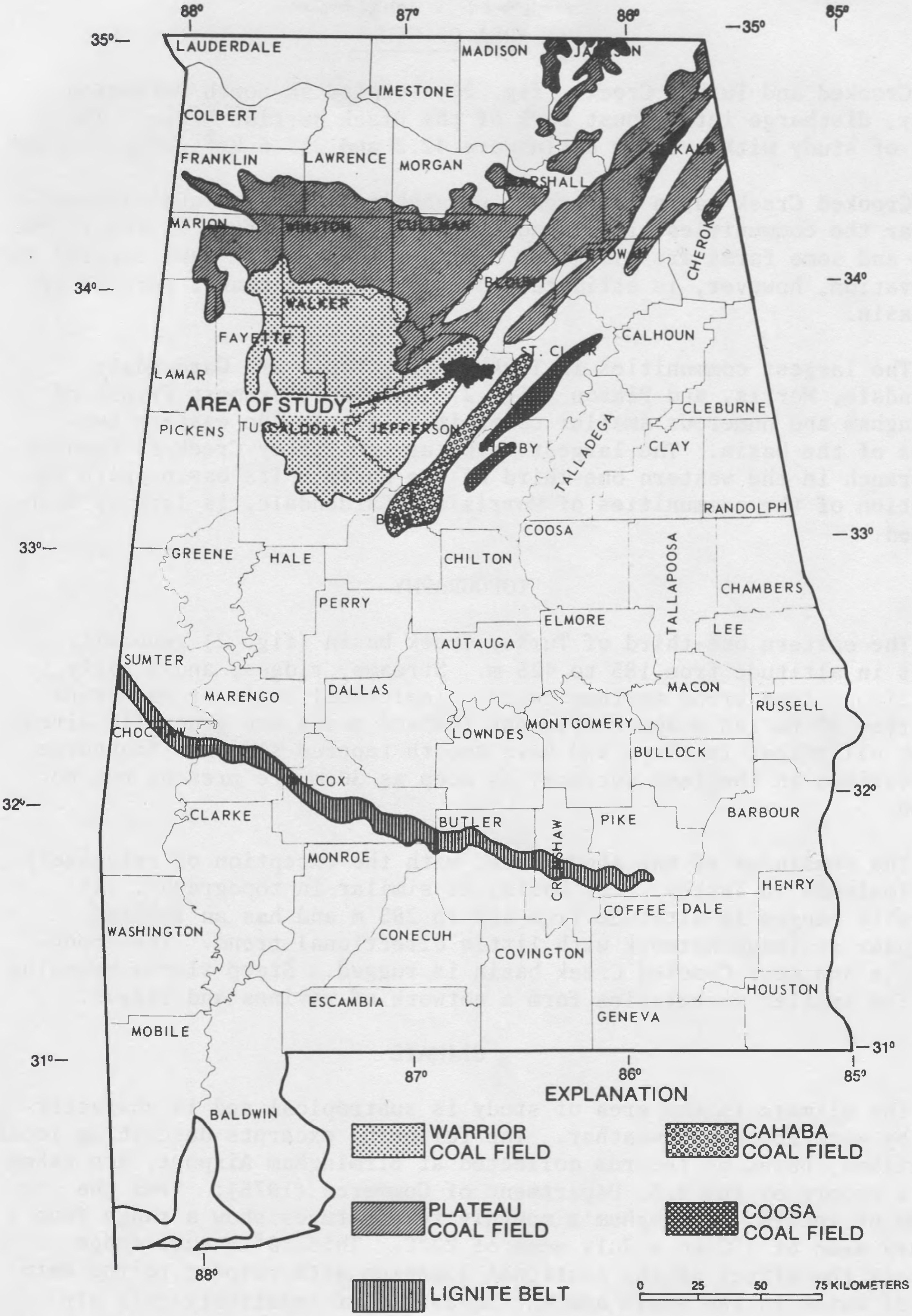


Figure 1.—Area of study and principal coal fields in Alabama (modified from Ward and Evans, 1975).

AREA OF STUDY

Crooked and Turkey Creeks (fig. 2), located in north Jefferson County, discharge into Locust Fork of the Black Warrior River. The areas of study within their basins are 42.2 and 217.6 km^2, respectively.

Crooked Creek basin is largely uninhabited. A few subdivisions at or near the communities of Gardendale and Mt. Olive (fig. 2) are in the basin and some farms are along its northwest boundary. Land cleared for cultivation, however, is estimated to comprise less than 2 percent of the basin.

The largest communities in Turkey Creek basin are Gardendale, Fultondale, Morris, and Pinson (fig. 2). The northernmost fringe of Birmingham and numerous smaller communities are in the eastern two-thirds of the basin. The largest tributary to Turkey Creek is Cunningham Branch in the western one-third of the basin. Its basin, with the exception of the communities of Morris and Gardendale, is largely uninhabited.

TOPOGRAPHY

The eastern one-third of Turkey Creek basin (fig. 2) generally ranges in altitude from 185 to 425 m. Streams, ridges, and a hilly to mountainous zone trend northeastward. Individual hills or mountains that rise 30 to 180 m above adjacent lowland areas are generally circular or elliptical in shape and have smooth tapered slopes. Sinkholes (depressions in the land surface) as deep as 30 m are present but not common.

The remainder of the study area, with the exception of relatively flat lowlands in Turkey Creek basin, is similar in topography. It generally ranges in altitude from 100 to 285 m and has an incised irregular drainage network with little directional trend. The topography in and near Crooked Creek basin is rugged. Steep slopes bounding even the smaller tributaries form a network of ravines and ridges.

CLIMATE

The climate in the area of study is subtropical and is characterized by warm and humid weather. The following excerpts describing local conditions, based on records collected at Birmingham Airport, are taken from a report by the U.S. Department of Commerce (1975): "For the period of record, Birmingham's monthly temperatures show a range from a January mean of 7°C to a July mean of 27°C. This 20° annual range reflects the effect of the stations' location with respect to the warm body of water to the south and the invasions of relatively cold air from the continental north and west. Precipitation, with a minimum occurring during October, has two maxima each year, one during the winter months, and another, slightly lower, in July. Snowfall is seldom

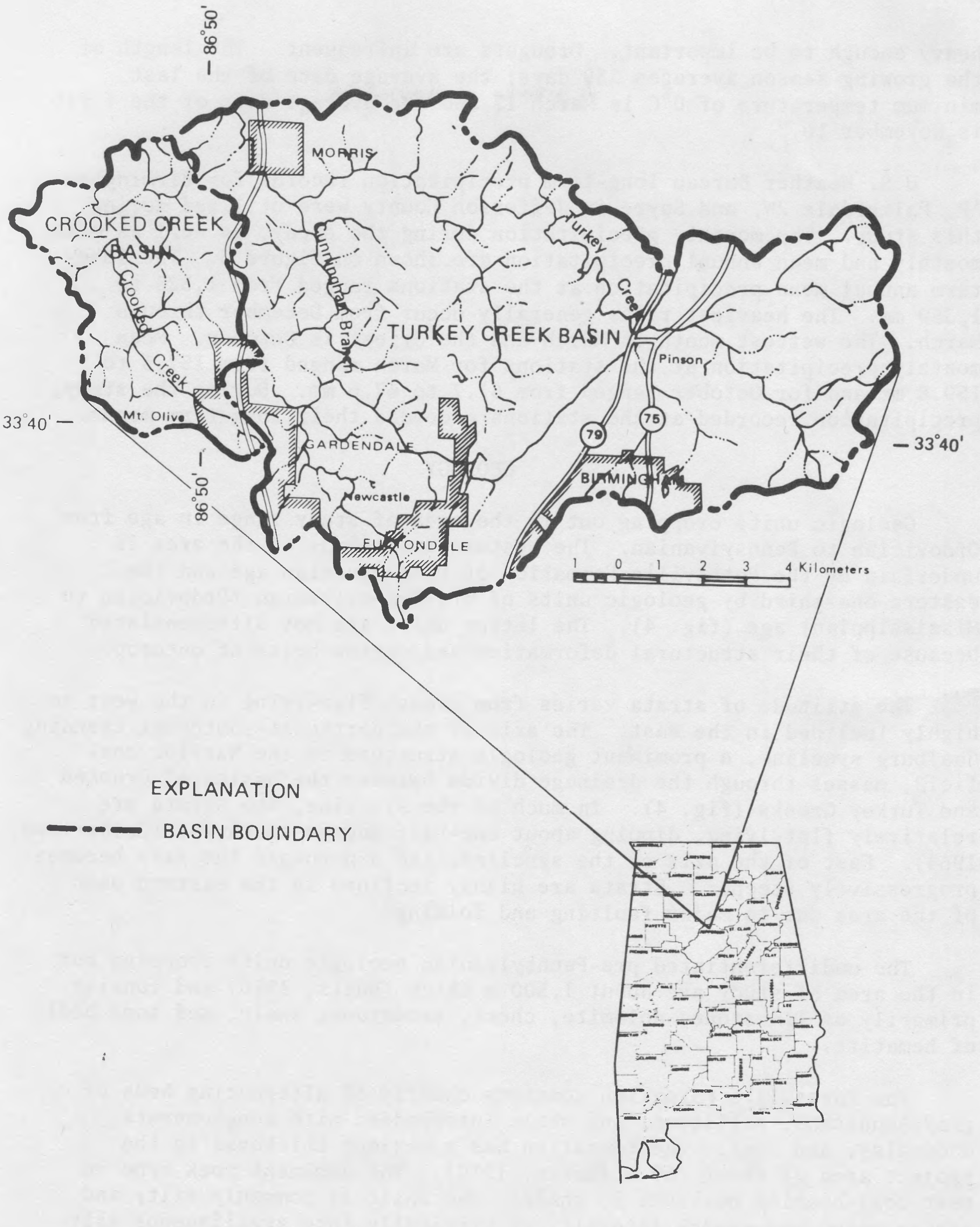


Figure 2.—Area of study.

heavy enough to be important. Droughts are infrequent. The length of the growing season averages 239 days; the average date of the last minimum temperature of 0°C is March 17 and the average date of the first is November 10."

U.S. Weather Bureau long-term precipitation records for Birmingham AP, Palmerdale 2W, and Sayre in Jefferson County were utilized during this study. The monthly precipitation during the study, as well as mean monthly and mean annual precipitation are shown on figure 3. The long-term annual mean precipitation at the stations ranged from 1,328 to 1,359 mm. The heaviest rains generally occur from December through March. The wettest month is March and the driest is October. Mean monthly precipitation at the stations for March ranged from 157.5 to 159.8 mm and for October ranged from 61.7 to 67.6 mm. During the study, precipitation recorded at the stations exceeded their long-term means.

GEOLOGY

Geologic units cropping out in the area of study range in age from Ordovician to Pennsylvanian. The western two-thirds of the area is underlain by the Pottsville Formation of Pennsylvanian age and the eastern one-third by geologic units of pre-Pennsylvanian (Ordovician to Mississippian) age (fig. 4). The latter units are not differentiated because of their structural deformation and narrow belts of outcrop.

The attitude of strata varies from almost flat-lying in the west to highly inclined in the east. The axis of the northeast-southwest trending Coalburg syncline, a prominent geologic structure in the Warrior coal field, passes through the drainage divide between the basins of Crooked and Turkey Creeks (fig. 4). In much of the syncline, the strata are relatively flat-lying, dipping about one-half degree southwest (Culbertson, 1964). East of the axis of the syncline, the dip toward the axis becomes progressively steeper. Strata are highly inclined in the eastern part of the area due to major faulting and folding.

The undifferentiated pre-Pennsylvanian geologic units cropping out in the area of study are about 1,500 m thick (Butts, 1910) and consist primarily of limestone, dolomite, chert, sandstone, shale, and some beds of hematite.

The Pottsville Formation consists chiefly of alternating beds of gray sandstone, siltstone, and shale interbedded with conglomerate, underclay, and coal. The formation has a maximum thickness in the project area of about 760 m (Butts, 1910). The dominant rock type in most coal-bearing horizons is shale. The shale is commonly silty and carbonaceous and grades laterally or vertically into argillaceous siltstone and very fine sandstone or is interbedded with them. Much of the shale contains nodules or layers of iron carbonate (siderite) or iron magnesium carbonate (ankerite); most nodules are lenses less than 75 mm long. The siderite also occurs as lenses as much as 0.3 m thick and

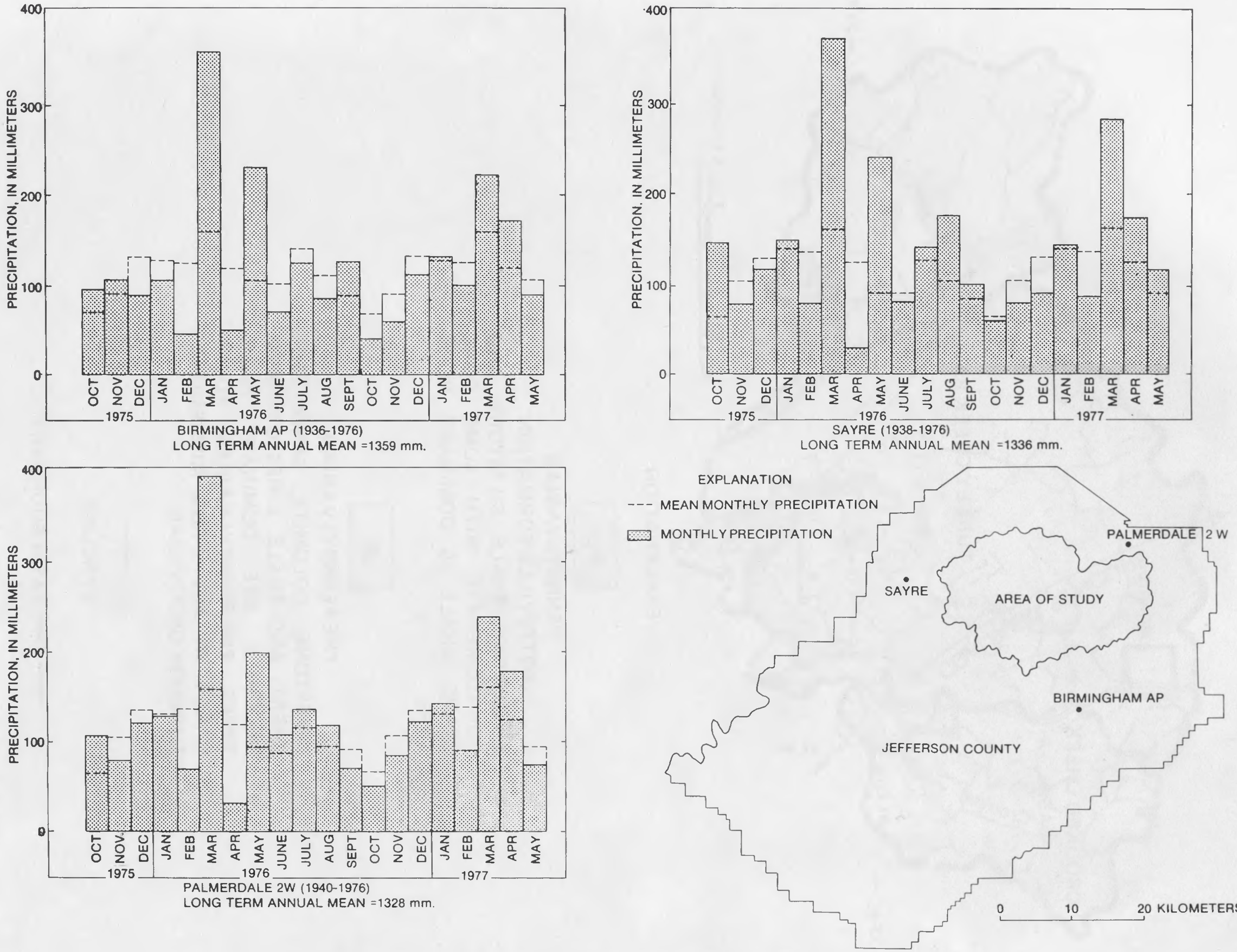
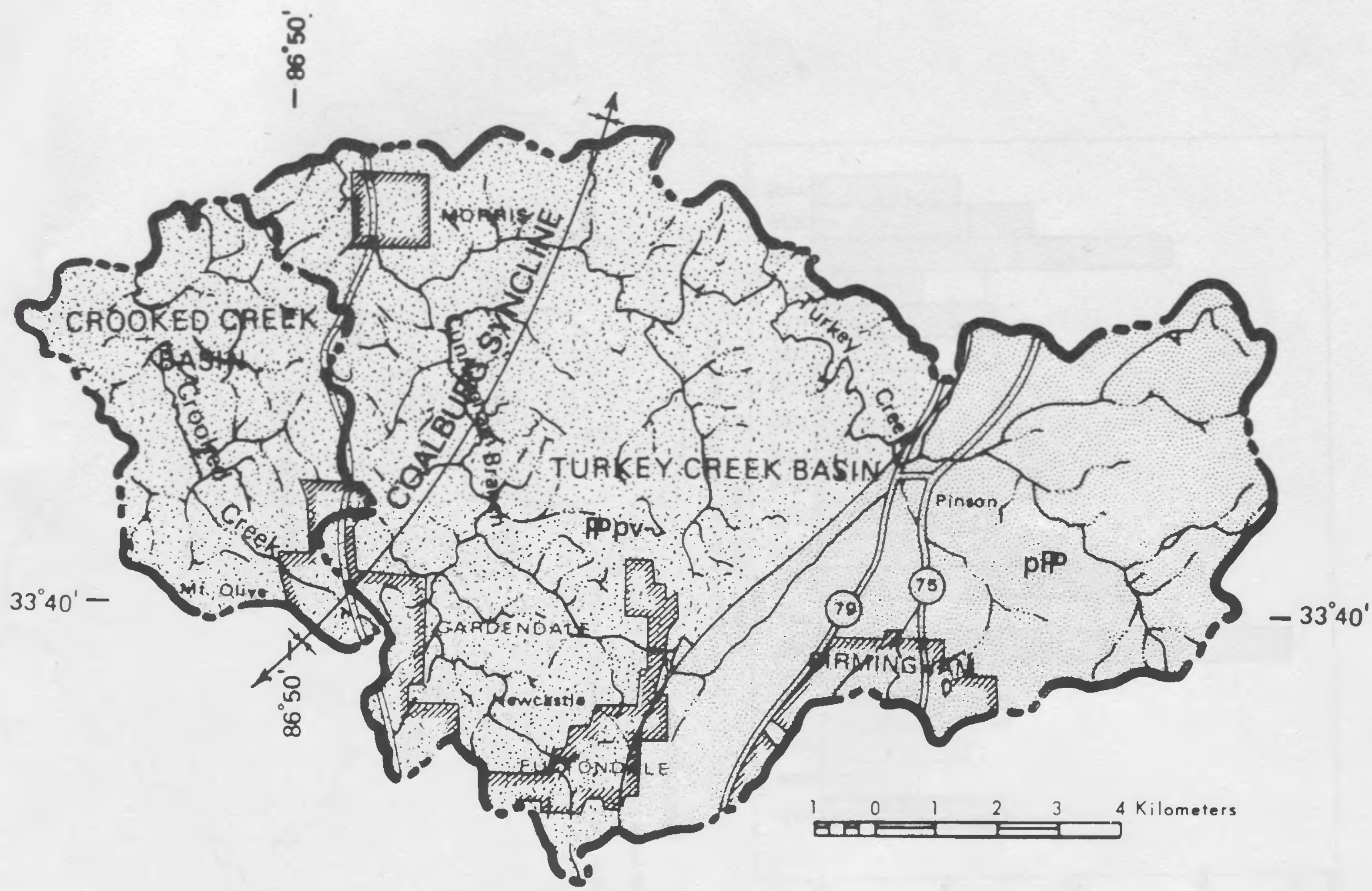


Figure 3.—Monthly and mean monthly precipitation at Birmingham AP, Palmerdale 2W, and Sayre, Alabama.



EXPLANATION

IPpv

PENNSYLVANIAN
POTTSVILLE FORMATION
SANDSTONE, SHALE, SILTSTONE, AND CONGLOMERATE WITH SOME COAL SEAMS. SHALE IS DOMINANT ROCK TYPE.

pIP

PRE-PENNSYLVANIAN
LIMESTONE, DOLOMITE, SANDSTONE, CHERT, AND SHALE. LIMESTONE AND DOLOMITE ARE DOMINANT ROCK TYPES. PRE-PENNSYLVANIAN ROCKS RANGE IN AGE FROM MISSISSIPPIAN. THROUGH ORDOVICIAN

SYNCLINE

BASIN BOUNDARY

Figure 4.—Geologic map of area of study (modified from Butts, 1910).

more than a meter long and, in places, layers of siderite less than 25 mm thick are interbedded with shale (Culbertson, 1964).

The Pottsville Formation, where thickest, contains about 60 beds of bituminous coal (Ward and Evans, 1975). Individual coal beds generally range in thickness from a few centimeters to 3 m. Although some beds are persistent laterally, others are lenticular and extend for only short distances. Most of the coal is high volatile A bituminous that contains 5 to 15 percent ash and less than 2 percent sulfur (Culbertson, 1964). In some coal beds, and overlying strata, pyrite is a conspicuous constituent.

In the Warrior coal field, almost all coal production has come from seven groups of coal beds: the Black Creek, Pratt, Mary Lee, Cobb, Guin, Utley, and Brookwood (Culbertson, 1964). In the area of study, production has been restricted to the Mary Lee group. This group, according to McCalley (1900), contains five coal beds that, in ascending order, are: Ream, Jagger, Blue Creek, Mary Lee, and Newcastle.

SURFACE COAL MINING

Surface mining in the area of study is in the Blue Creek, Mary Lee, and Newcastle coal beds. All of the beds are mined in Turkey Creek basin whereas only the Mary Lee has been mined in Crooked Creek basin. Production in Turkey Creek basin in 1977 was reported to be 32,000 t per month (Bill Craine, Drummond Coal Co., oral commun. 1977). Coal was not mined in Crooked Creek basin during the project period.

The progression of mining, based on aerial photography flown in 1970, 1973, and 1976, is shown in figure 5. All mining, with the exception of one very small area in Crooked Creek basin (fig. 5), was initiated after 1970. The small mined area, based on vegetative growth observed on the 1970 photography, was old at that time. All mining since January 30, 1976, has been restricted to Turkey Creek basin in the vicinity of Morris. Abandoned surface and subsurface mines are located in Turkey Creek basin upstream from the area of mining monitored; however, it is estimated that land disturbed by the abandoned mines comprises less than one-half of 1 percent of the upstream area.

The general lithology of strata disturbed by coal mining is shown in figure 6. The Blue Creek coal bed, at the base of the section mined, is about 0.7 m thick. It is overlain by 2 to 3 m of shale, siltstone, and sandstone that, in turn, is overlain by the Mary Lee coal bed. The Mary Lee is about 0.8 m thick. In Turkey Creek basin, the Mary Lee is overlain by 13 to 14 m of shale containing beds of siltstone and sandstone which, in turn, is overlain by the Newcastle coal bed. This bed, where present, is about 0.3 m thick. The Newcastle appears to be absent in the mined area in Crooked Creek basin. The Blue Creek bed reportedly has not been mined in the Crooked Creek basin because of its thinness (R. Williams, Drummond Coal Co., oral commun., 1977).

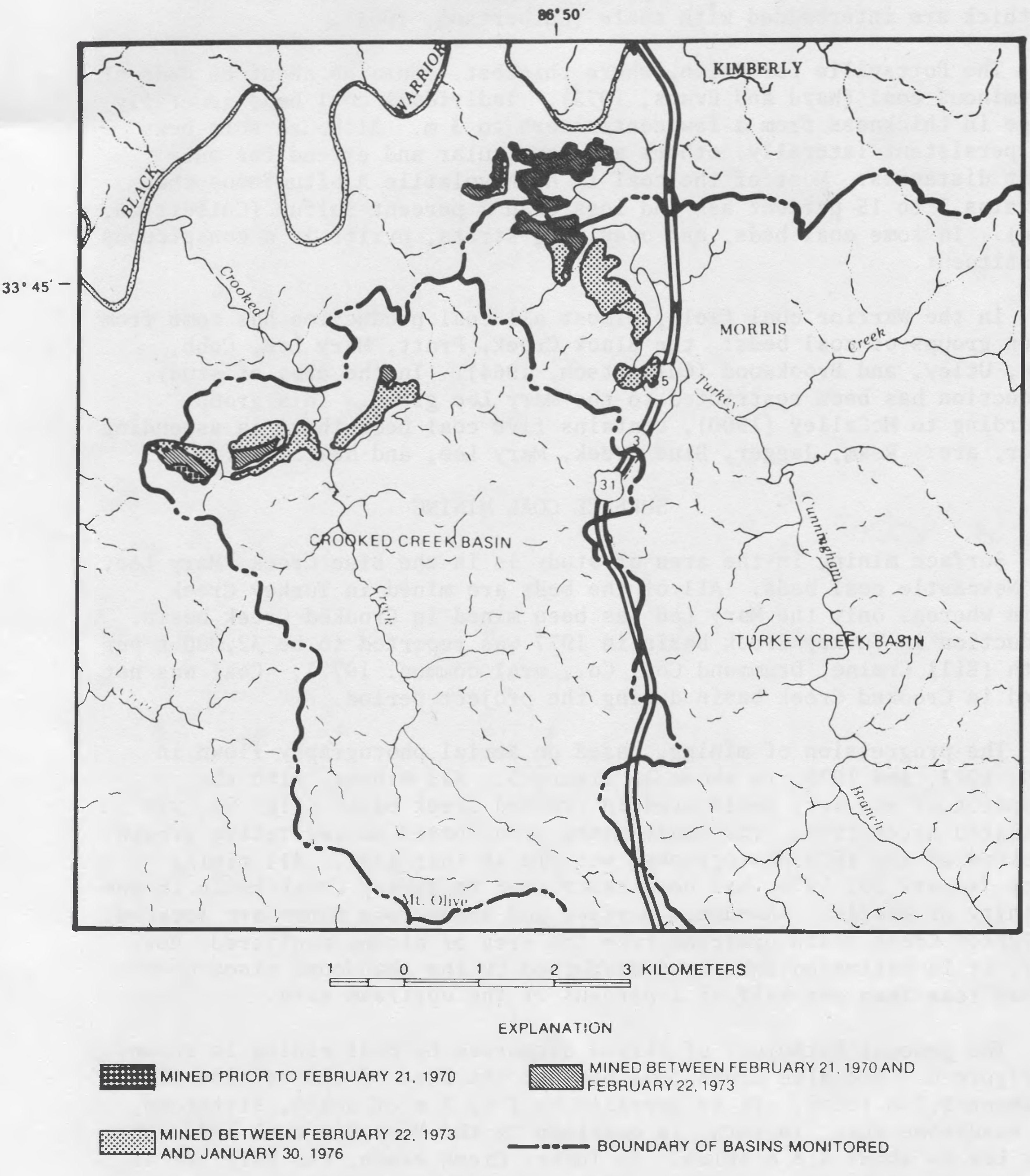


Figure 5.—Progression of surface mining in area monitored.

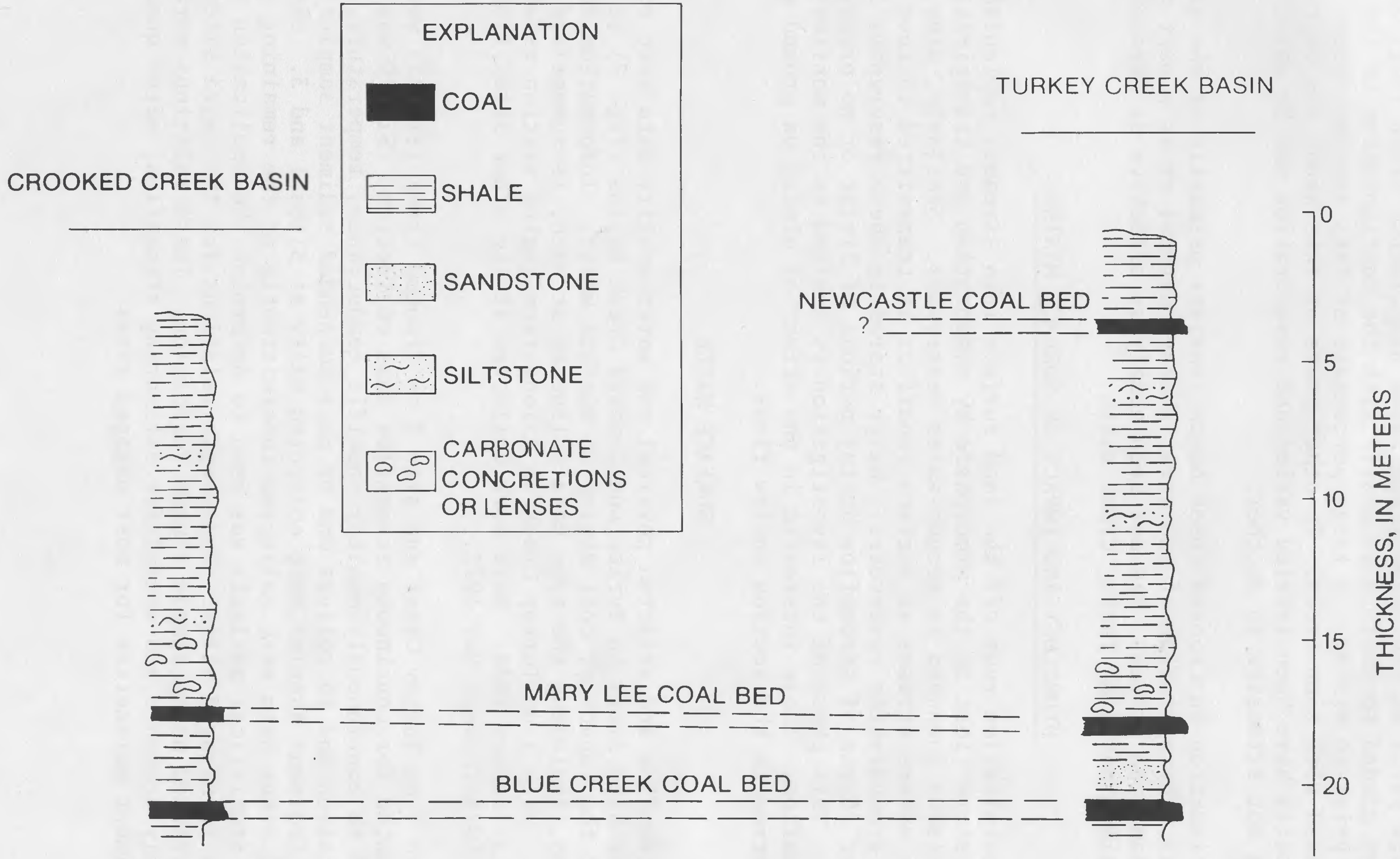


Figure 6.—Generalized lithologic sections showing coal beds mined.

Large parts of the older mined lands near Turkey Creek (fig. 5) have been graded to conform generally with the configuration of the land surface prior to mining. A large percentage of this area has been revegetated with pine trees. In other parts of this area, the degree to which spoils have been leveled varies and revegetation may be absent in one area but extensive in another.

Reclamation in Crooked Creek basin consists primarily of the grading of spoils. Revegetation of the area, whether natural or as a part of the reclamation process, has not been nearly as effective as revegetation in reclaimed parts of Turkey Creek basin.

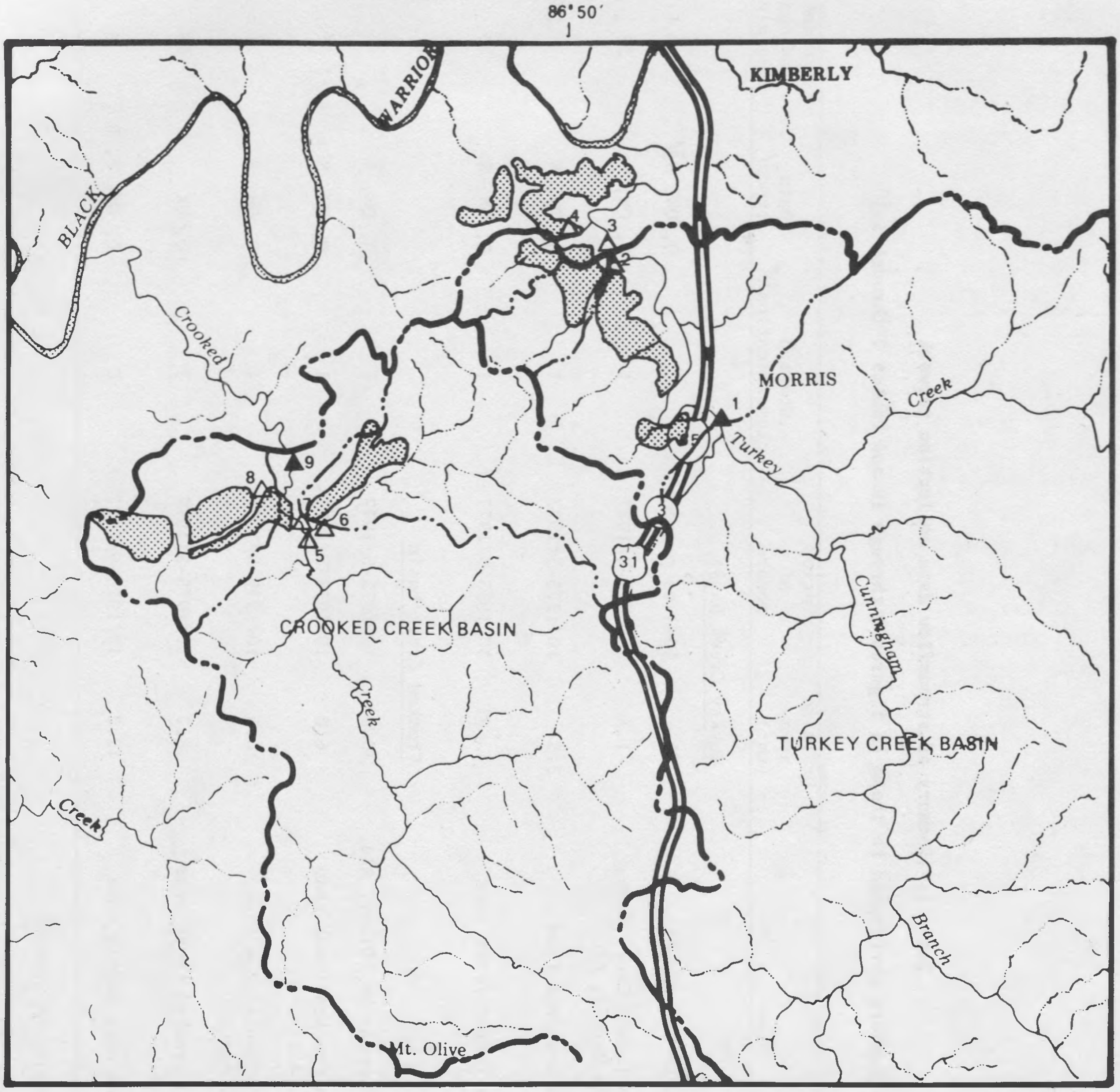
HYDROLOGY AND IMPACT OF SURFACE MINING

Precipitation runs off the land surface into streams, replenishes soil moisture (lost to the atmosphere by evaporation and transpiration), or percolates downward to ground-water reservoirs. Similarly, mine drainage enters streams as surface runoff or is transmitted to them through ground-water reservoirs. Water stored in these reservoirs is the major source of streamflow during periods of little or no precipitation. This phase of the investigation is limited to the monitoring of streamflow. Those interested in the effect of mining on ground water are referred to the section on low flows.

SURFACE WATER

Streamflow and selected physical and water-quality data were collected at nine sites in Turkey and Crooked Creek basins (fig. 7) to describe the impact of coal mining on surface water. Information for the sites, including the type data collected at each, is summarized in table 1. Site 1 on Turkey Creek is a long-term gaging station established in January 1944. Data were collected at the other sites from October 1975 through May 1977.

Site 1 on Turkey Creek and site 9 on Crooked Creek (fig. 7) were instrumented for continuous streamflow data collection. Site 9 was also equipped to continuously monitor specific conductance, temperature, and precipitation and to collect one or more suspended sediment samples daily. Sediment samples were collected daily at sites 1 and 3. Streamflow and other data were collected intermittently at the remaining sites. Statistical analysis was used to determine the application of the data to ungaged sites. Hydrologic relations for the gaged sites were developed using simple linear regression. These relations were reasonably accurate and useful for estimating streamflow, water quality, and sediment parameters for most ungaged sites.



1 0 1 2 3 KILOMETERS

EXPLANATION

▲[1] CONTINUOUS-RECORD GAGING STATION AND SITE NUMBER

△[2] INTERMITTENT-RECORD STATION AND SITE NUMBER

BASIN BOUNDARY

SUBBASIN BOUNDARY

SURFACE MINE

Figure 7 – Location of surface – water gaging stations

Table 1.--Summary of streamflow data collection network

(Site numbers correspond to those in figures 7 through 18 and tables 2 through 5.)

Site no.	USGS Station number	Name	Drainage area (km^2)	Period of record	Station classification 1/	Data type 2/	Percent drainage area mined
				Turkey Creek basin			
1	02456000	Turkey Creek at Morris, Ala.	211	1944 to present	C	Q, QW, S 3/	< 0.5
2	02456045	Tributary to Turkey Creek downstream from Morris, Ala.	1.3	10/1975-5/1977	I	Q, QW, S	23
3	02456050	Turkey Creek upstream from Kimberly, Ala.	218	10/1975-5/1977	I	Q, QW, S	.9
4	02456055	Tributary to Turkey Creek near Kimberly, Ala.	.91	10/1975-5/1977	I	Q, QW, S	23
				Crooked Creek basin			
5	02456310	Crooked Creek near Mt. Olive, Ala.	30.0	10/1975-5/1977	I	Q, QW, S	0
6	02456320	Tributary to Crooked Creek near Mt. Olive, Ala.	6.0	10/1975-5/1977	I	Q, QW, S	6
7	02456322	Crooked Creek downstream from Mt. Olive, Ala.	36.0	10/1975-5/1977	I	Q, QW, S	1
8	02456327	Tributary to Crooked Creek near Morris, Ala.	6.2	10/1975-5/1977	I	Q, QW	18
9	02456330	Crooked Creek near Morris, Ala.	42.2	10/1975-6/1977	C	Q, QW, S, R	4

1/ C - continuous record, I - intermittent record

2/ Q - stream discharge, QW - water quality, S - suspended sediment, R - precipitation

3/ Sediment data period of record: 10/1975-5/1977

Streamflow Characteristics

Streamflow characteristics are determined mainly by climatic, topographic, and geologic conditions, and by stream-regulating conditions imposed by man. Where these conditions are similar, basins may have similar median and floodflow characteristics. Low-flow characteristics may be dissimilar, however, because of small differences in land use, topography, and geology.

Discharge from the basins at sites 1 and 9 equaled about 35 percent of the precipitation during the period of study. Average daily discharges at outflow sites 1 and 9 on Turkey and Crooked Creeks (fig. 7) were 5.27 m^3/s and 1.02 m^3/s, respectively. The mean discharge at site 1 exceeded the long-term mean discharge (3.74 m^3/s) because of greater-than-average precipitation. The daily mean discharges for the period of study at site 1 ranged from 0.59 to 112 m^3/s and those at site 9 ranged from about 0.01 to 38.23 m^3/s. Daily mean discharges at the sites are shown in figure 8.

Low Flow

The suitability of streams for particular uses with respect to water availability is generally determined by the magnitude of low flows. Estimates of annual low-flow characteristics for site 1 on Turkey Creek (fig. 7) are summarized in table 2. Streamflow records for sites in Crooked Creek basin were insufficient to estimate low-flow characteristics.

The 7-day 2-year low flow ($7Q_2$) is the discharge at 2-year recurrence interval taken from a frequency curve of annual values of the lowest mean discharge for 7 consecutive days. $7Q_2$ at site 1 on Turkey Creek can be expected to average about 0.002 $(m^3/s)/km^2$ (table 2). The $7Q_2$ of Turkey Creek is greater than that estimated for Crooked Creek owing to the greater storage capacity and higher permeability of the carbonate rocks drained by Turkey Creek. During dry periods, little ground water is contributed to streamflow by relatively impermeable rocks in the Pottsville Formation that underlies the Crooked Creek basin. In similar basins throughout the Warrior coal field (fig. 1), the $7Q_2$ generally is very low and seldom exceeds 0.0005 $(m^3/s)/km^2$ (Peirce, 1967).

Flow Duration and Variability

The flow distribution and variability of streams may best be demonstrated with a flow-duration curve. This cumulative-frequency curve shows the percentage of time that a specific discharge may be equaled or exceeded in a given period. It combines into one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurrence. It is applicable only to the period of record used to develop the curve. Hydrologic and geologic

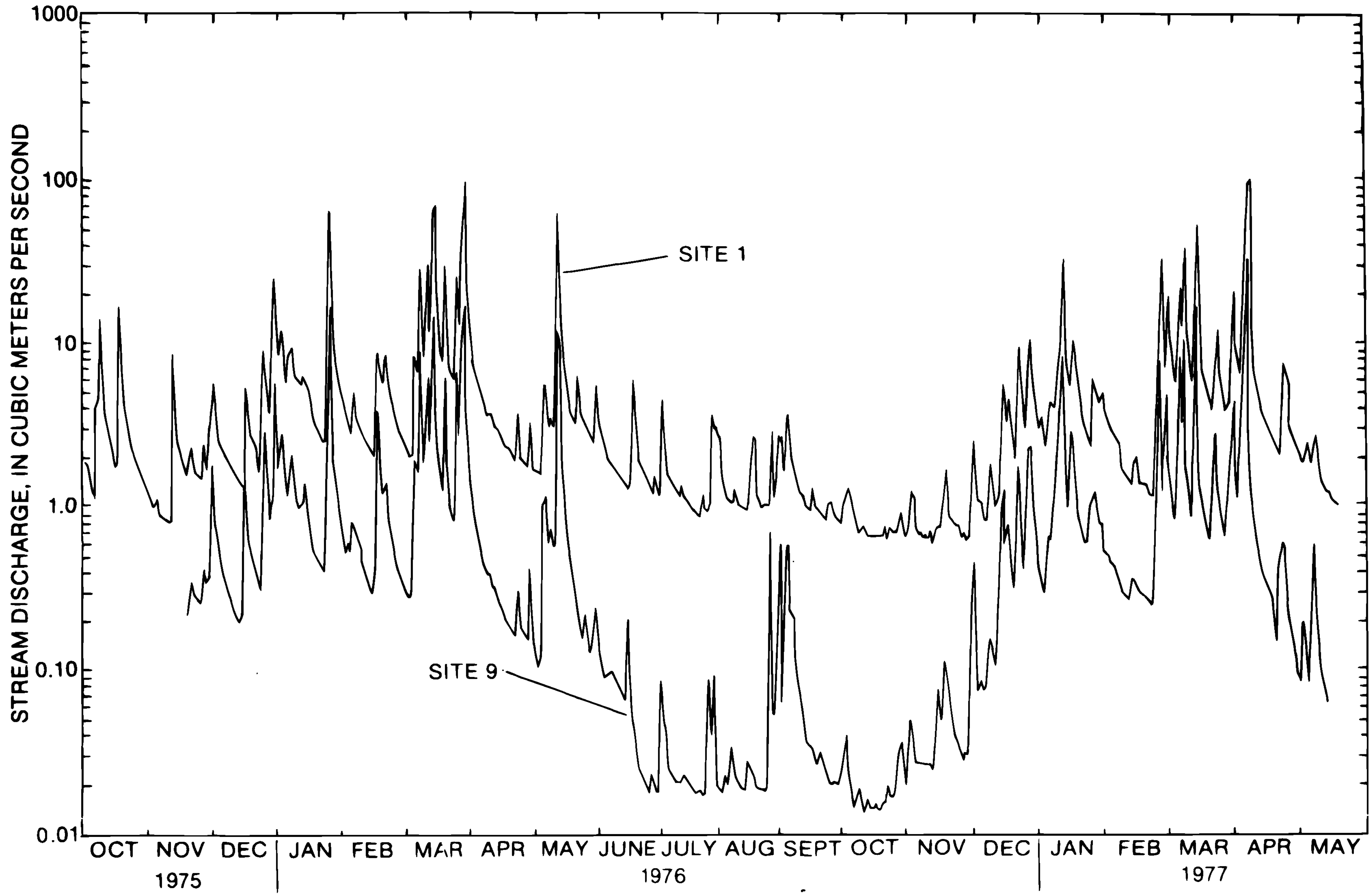


Figure 8.—Daily mean discharges for site 1 on Turkey Creek and site 9 on Crooked Creek, October 1975-May 1977. (Site numbers correspond to those in figure 7.)

Table 2.--Estimated annual low-flow characteristics for site 1 on Turkey Creek

Station and period of record	Period (consecutive days)	Estimated annual low flow in $(m^3/s)/km^2$ for indicated recurrence interval — Year 1.04	1.25	2.0	5.0	10.0	20.0
Turkey Creek at Morris, Ala. (site 1 in fig. 7) (1944-1976)	7	0.0032	0.0023	0.0018	0.0014	0.0013	0.0013
	30	.0043	.0028	.0022	.0018	.0015	.0014
	60	.0056	.0035	.0025	.0020	.0018	.0016
	120	.0074	.0048	.0034	.0024	.0021	.0019

characteristics of a drainage basin are generally the major factors that determine the shape of the flow-duration curve. A curve with a steep slope throughout denotes a highly variable streamflow that is mainly from direct surface runoff, whereas a curve with a flat slope indicates streamflow that is mainly from surface runoff and ground-water storage. A flat slope at the lower end of the curve indicates sustained base flow, whereas a steep slope indicates a negligible base flow (Searcy, 1959).

Flow-duration curves for site 1 on Turkey Creek and site 9 on Crooked Creek (fig. 7) are shown in figure 9. These curves are based on data collected from October 1975 through May 1977. The curves show that, 10 percent of the time, the flow was less than 0.0035 $(m^3/s)/km^2$ at site 1 on Turkey Creek and less than 0.0004 $(m^3/s)/km^2$ at site 9 on Crooked Creek.

Streamflow relations between the upstream unmined segment of Crooked Creek (site 5) and the downstream mined segment (site 9) (fig. 10) show the contribution of low flow from mines. During periods of little or no precipitation, discharge in the unmined reach (site 5) rapidly approaches zero, whereas discharge in the downstream mined reach (site 9) is higher because of the contribution of water from the mines between the sites.

Chemical Quality

Specific conductance, alkalinity, pH, and water temperature were measured in the field and samples were collected for detailed chemical analyses. Sampling was scheduled to provide water-quality information throughout the range of stream discharge.

Specific conductance is a measure of the ability of water to conduct an electric current and is directly related to the dissolved-solids concentration. The relation between specific conductance and dissolved solids concentrations for sites in mined basins is shown in figure 11.

Most water-quality data collected during the study have been published by the U.S. Geological Survey (1977) and are not presented in this report. Selected analyses are used in this report to illustrate variations in chemical quality that occur with variations in streamflow.

Origin of Constituents and Physical Characteristics

Streamflow is generally a mixture of base flow derived from ground water and overland flow. The chemical quality of streamflow derived from each source can be different. Base flow generally has higher dissolved chemical concentrations because of its prolonged contact with minerals in soils and rocks. Overland flow is generally less mineralized because of its shorter period of contact with soluble minerals at the surface. The chemical quality of water in streams varies with the degree of mixing of waters from both sources.

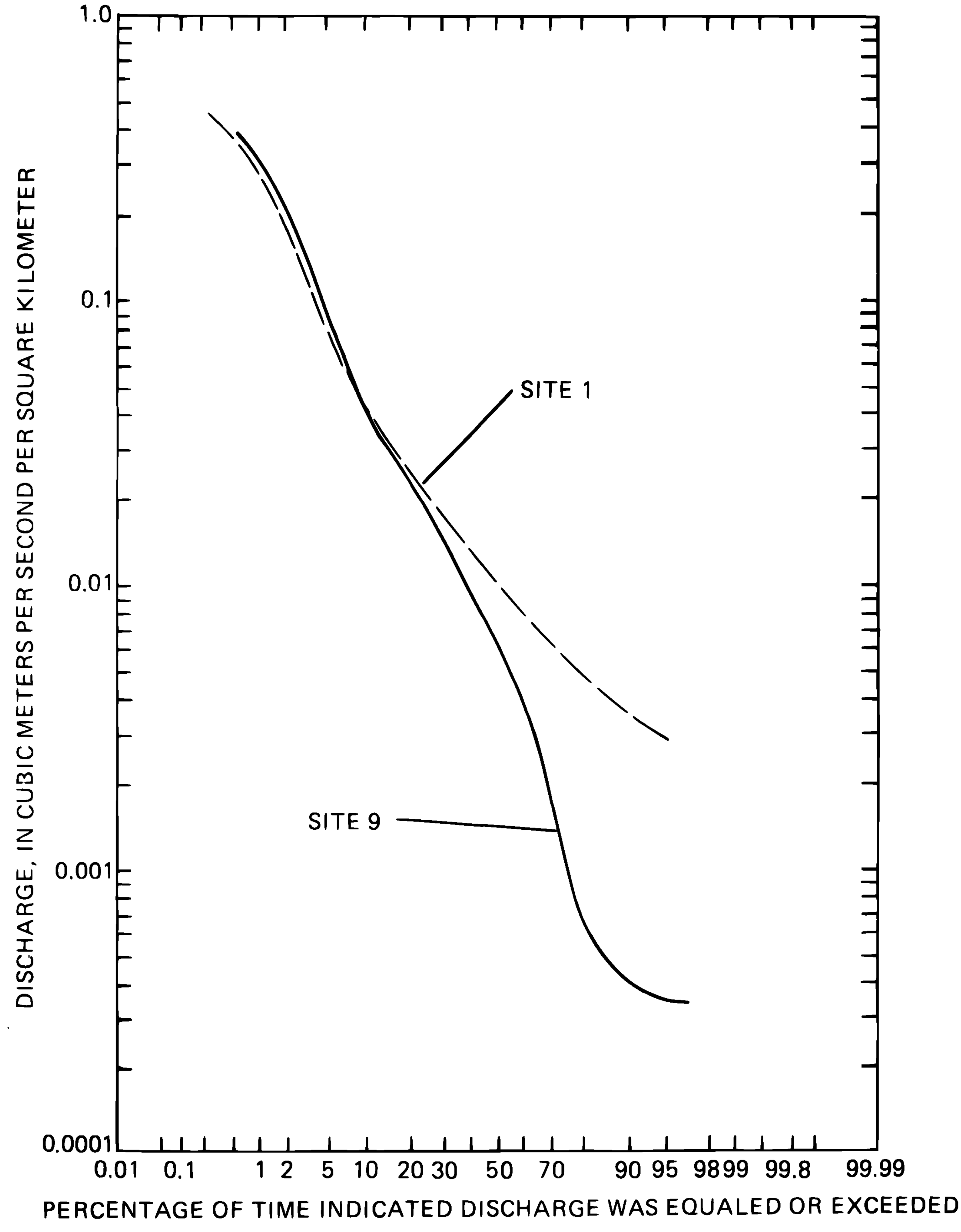


Figure 9.—Flow-duration curves for site 1 on Turkey Creek and site 9 on Crooked Creek, October 1975—May 1977. (Site numbers correspond to those in figure 7.)

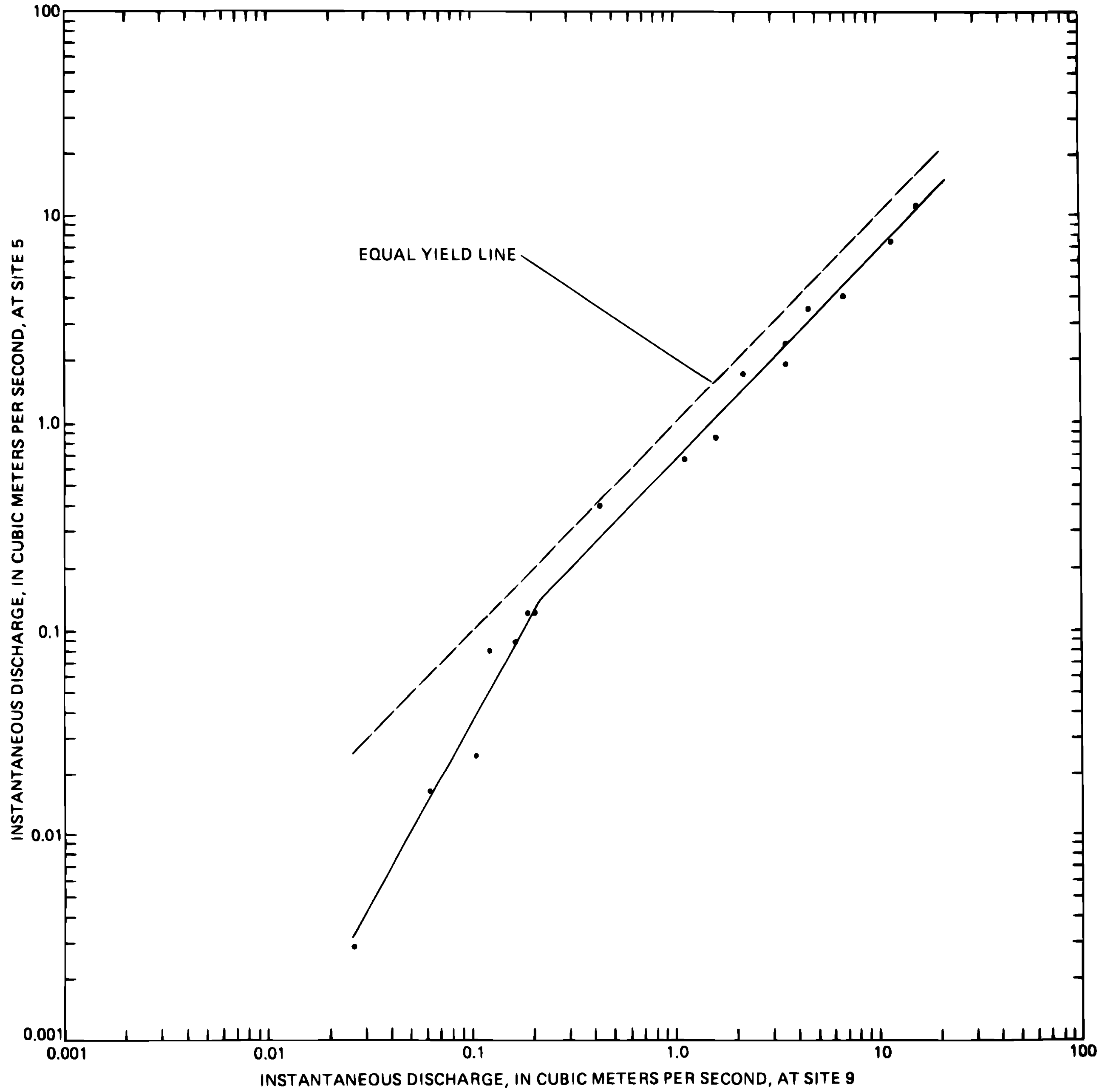


Figure 10.—Instantaneous stream discharge relation between mined and unmined sites (5 and 9) on Crooked Creek. (Site numbers correspond to those in figure 7.)

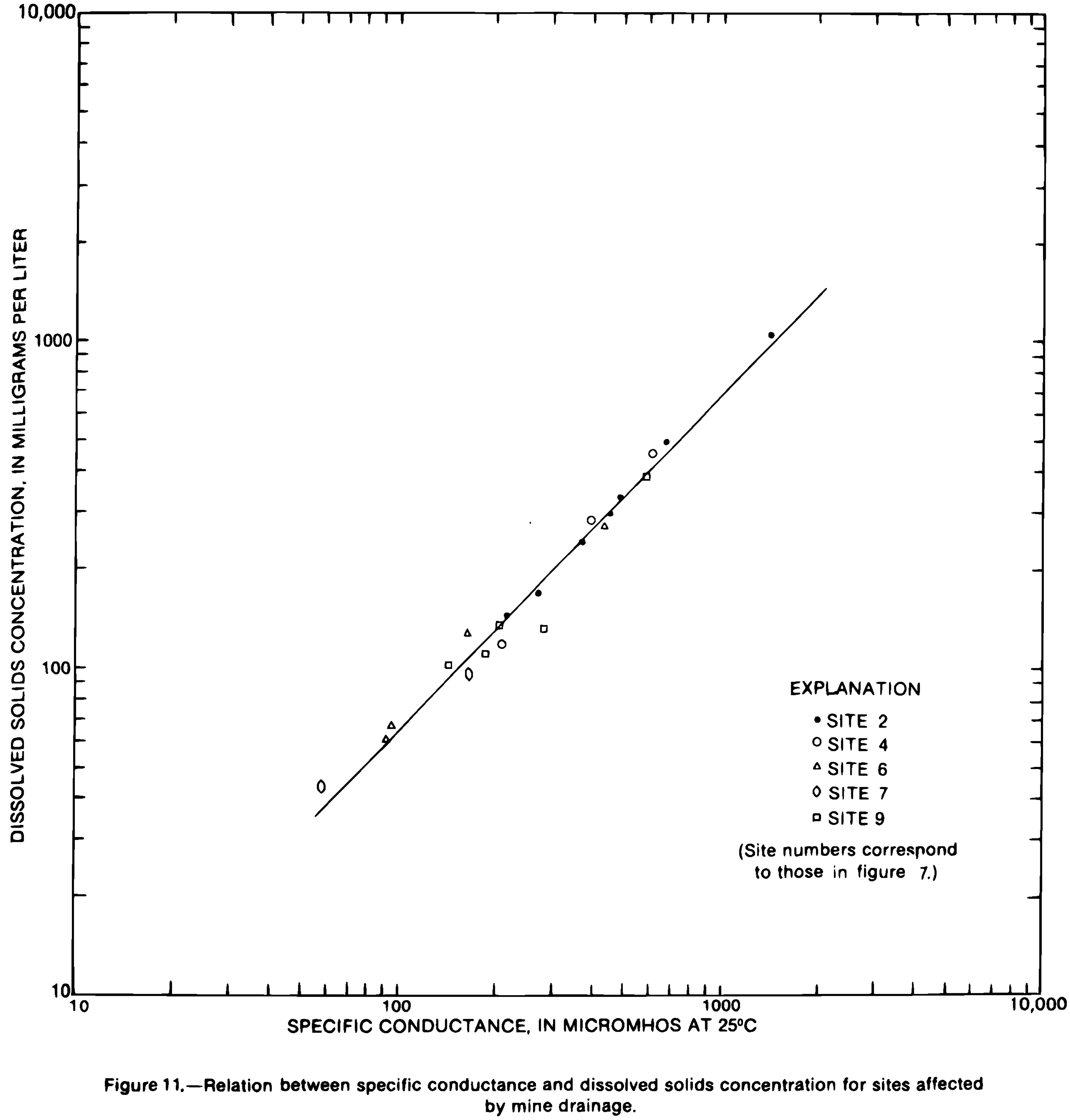


Figure 11.—Relation between specific conductance and dissolved solids concentration for sites affected by mine drainage.

During mining, large quantities of ferruginous minerals (pyrite and marcasite) in overburden and coal beds are exposed to air and water that accelerate weathering processes. Sulfuric acid and hydrous iron oxides are formed in the process. The pH of water draining the area will be low and the sulfate concentrations high. The following equations taken from Hendrickson and Krieger (1964) express some of the commonly postulated chemical reactions:

$$FeS + 2\ O_2 \rightarrow FeSO_4$$

$$2\ FeS_2 + 2\ H_2O + 7\ O_2 \rightarrow 2\ FeSO_4 + 2\ H_2SO_4$$

$$4\ FeSO_4 + 10\ H_2O + O_2 \rightarrow 4\ Fe(OH)_3 \downarrow + 4\ H_2SO_4$$

The acidic water reacts with other minerals and commonly increases aluminum, calcium, magnesium, manganese, and iron concentrations. The highly mineralized water collects in mine impoundments and spoil where it eventually evaporates, runs off into streams, or precolates downward into underlying aquifers.

Water Quality in Mined and Unmined Areas

Analyses of selected samples collected during low- and high-flow periods at sites on Turkey and Crooked Creeks are shown by bar graphs in figures 12 and 13.

Turkey Creek Basin.--Water at site 1 on Turkey Creek is of a calcium, magnesium, bicarbonate type (fig. 12 and table 3). The predominance of these ions is attributed to the carbonate rocks that crop out in the upper reaches of the basin. Highly mineralized base flow from tributaries draining mined areas in Turkey Creek basin (sites 2 and 4 on fig. 12) is a magnesium, sulfate type water.

Maximum dissolved solids concentrations observed at mined sites 2 and 4 were 1,060 and 456 mg/L respectively, while those observed at unmined sites 1 and 3 were 151 and 153 mg/L. At sites 2 and 4 (table 3), concentrations of other major indicators of mine drainage such as calcium, magnesium, sulfate, aluminum, iron, manganese, and noncarbonate hardness, and specific conductance were much greater than those observed at sites draining unmined areas. This greater degree of mineralization is shown by relations between specific conductance and discharge at unmined site 1 and mined site 2 (fig. 14) and by relations between specific conductance and sulfate concentrations for mined and unmined basins (fig. 15). Estimated mean annual loads of selected chemical constituents and suspended sediment for sites 1 through 4 in Turkey Creek basin, expressed in metric tons per square kilometer, are given in table 4.

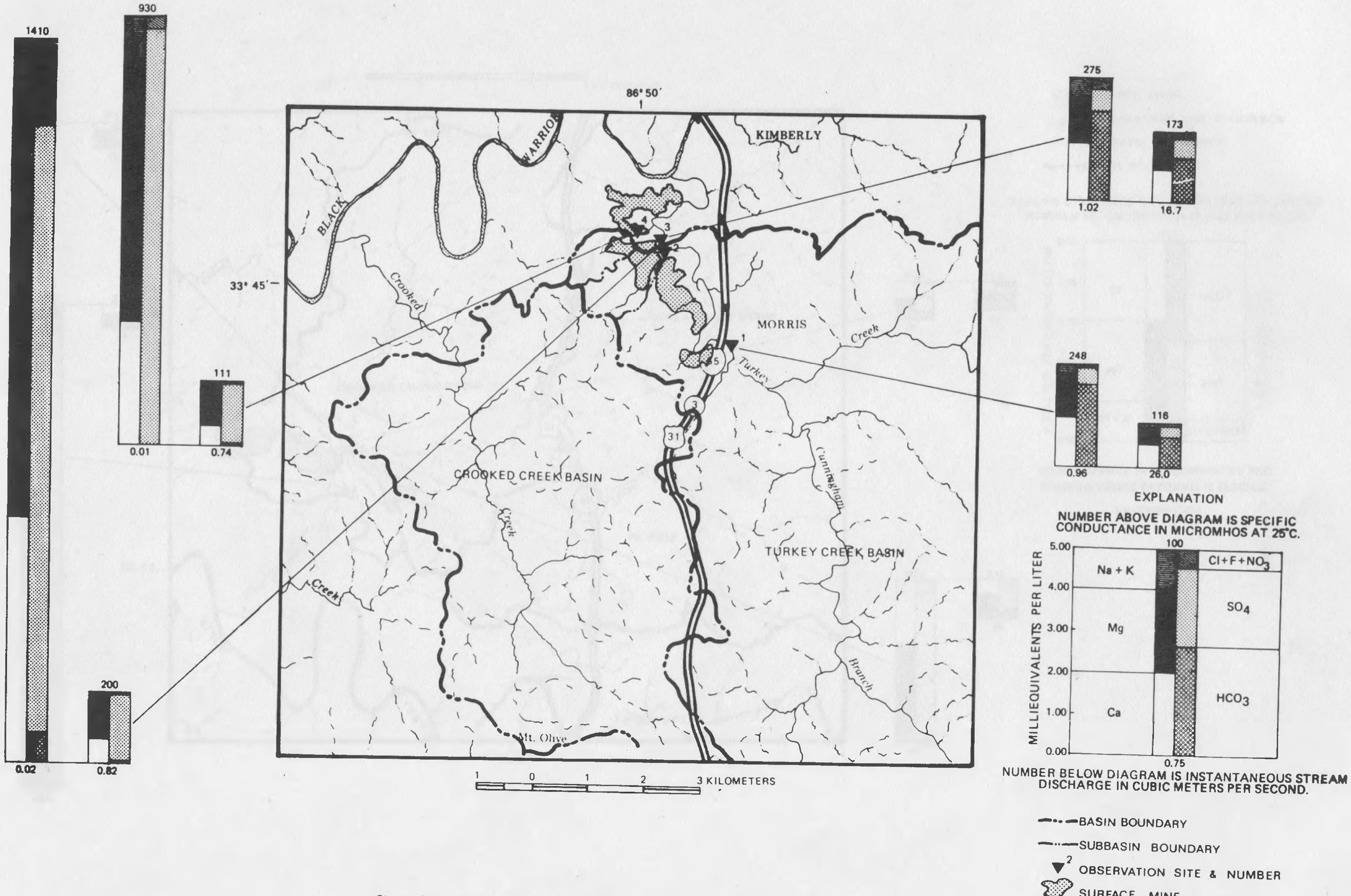


Figure 12.—Chemical characteristics of water during low flow and floodflow at sites in Turkey Creek Basin. (Site numbers correspond to those on figure 7.)

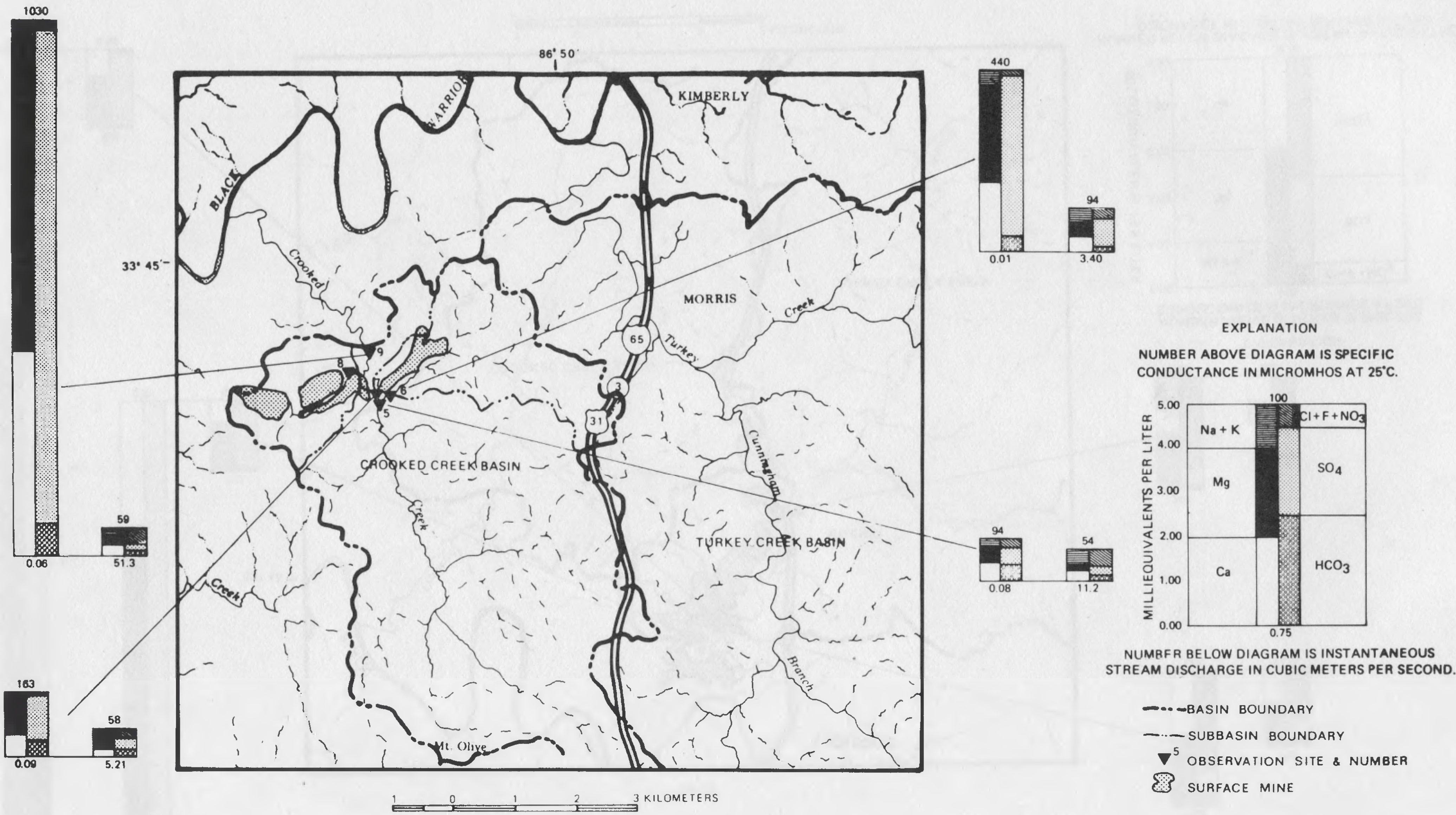


Figure 13 – Chemical characteristics of water during low flow and floodflow at sites in Crooked Creek Basin. (Site numbers correspond to those in figure 7.)

Table 3.--Summary of selected physical and chemical characteristics at sampling sites in Turkey Creek basin, October 1975-May 1977

(Chemical analyses in milligrams per liter except as indicated. Site numbers correspond to those in figure 7.)

	Site 1			Site 2		
Parameter	Minimum	Maximum	Number of observations	Minimum	Maximum	Number of observations
Specific conductance (micromhos at 25°C)	99	290	10	200	1500	12
pH	6.7	8.0	7	4.5	6.9	19
Dissolved oxygen (DO)	....	....	....	8.6	11	4
Hardness as $CaCO_3$:						
Calcium, magnesium	48	150	4	75	840	11
Noncarbonate	11	35	4	73	810	11
Acidity as H^+	....	....	....	.0	1.0	5
Calcium (Ca)	11	24	3	12	140	11
Magnesium (Mg)	5.0	12	3	11	120	11
Sodium (Na)	....	....	....	3.2	8.2	3
Potassium (K)	....	....	....	2.3	2.8	3
Bicarbonate (HCO_3)	40	140	5	0	45	18
Carbonate (CO_3)	0	0	5	0	0	18
Alkalinity ($CaCO_3$)	33	115	5	0	37	18
Carbon dioxide (CO_2)	2.4	10	5	2.0	152	17
Sulfate (SO_4)	15	23	4	79	1000	14
Dissolved solids (residue at 180°C)	68	151	3	106	1060	9
Total aluminum (Al) (ug/L)	....	....	....	200	180000	4
Dissolved aluminum (Al) (ug/L)	....	....	....	20	110	4
Total iron (Fe) (ug/L)	....	....	....	600	160000	4
Dissolved iron (Fe) (ug/L)	10	140	3	0	430	11
Total manganese (Mn) (ug/L)	....	....	....	1100	6100	4
Dissolved manganese (Mn) (ug/L)	....	....	....	670	1500	4

Table 3.--Summary of selected physical and chemical characteristics at sampling sites in Turkey Creek basin, October 1975-May 1977--Continued

Parameter	Site 3			Site 4		
	Minimum	Maximum	Number of observations	Minimum	Maximum	Number of observations
Specific conductance (micromhos at 25°C)	96	275	6	111	1250	12
pH	6.4	8.0	6	3.8	6.1	12
Dissolved oxygen (DO)	....	....	....	9.5	9.5	1
Hardness as $CaCO_3$:						
Calcium, magnesium	61	120	4	70	420	6
Noncarbonate	16	20	4	65	420	6
Acidity as H^+	....	....	....	.0	1.7	3
Calcium (Ca)	14	28	4	10	59	7
Magnesium (Mg)	6.3	13	4	11	66	7
Sodium (Na)	....	....	....	1.7	6.0	3
Potassium (K)	....	....	....	1.5	2.1	3
Bicarbonate (HCO_3)	55	130	4	0	6	9
Carbonate (CO_3)	0	0	4	0	0	9
Alkalinity ($CaCO_3$)	45	107	4	0	5	9
Carbon dioxide (CO_2)	1.9	6.5	4	.0	152	9
Sulfate (SO_4)	21	31	4	71	600	8
Dissolved solids (residue at 180°C)	92	153	3	118	456	4
Total aluminum (Al) (ug/L)	....	....	....	840	24000	2
Dissolved aluminum (Al) (ug/L)	....	....	....	250	780	3
Total iron (Fe) (ug/L)	....	....	....	1600	100000	2
Dissolved iron (Fe) (ug/L)	0	70	3	100	4000	6
Total manganese (Mn) (ug/L)	....	....	....	1800	4100	2
Dissolved manganese (Mn) (ug/L)	....	....	....	880	4100	3

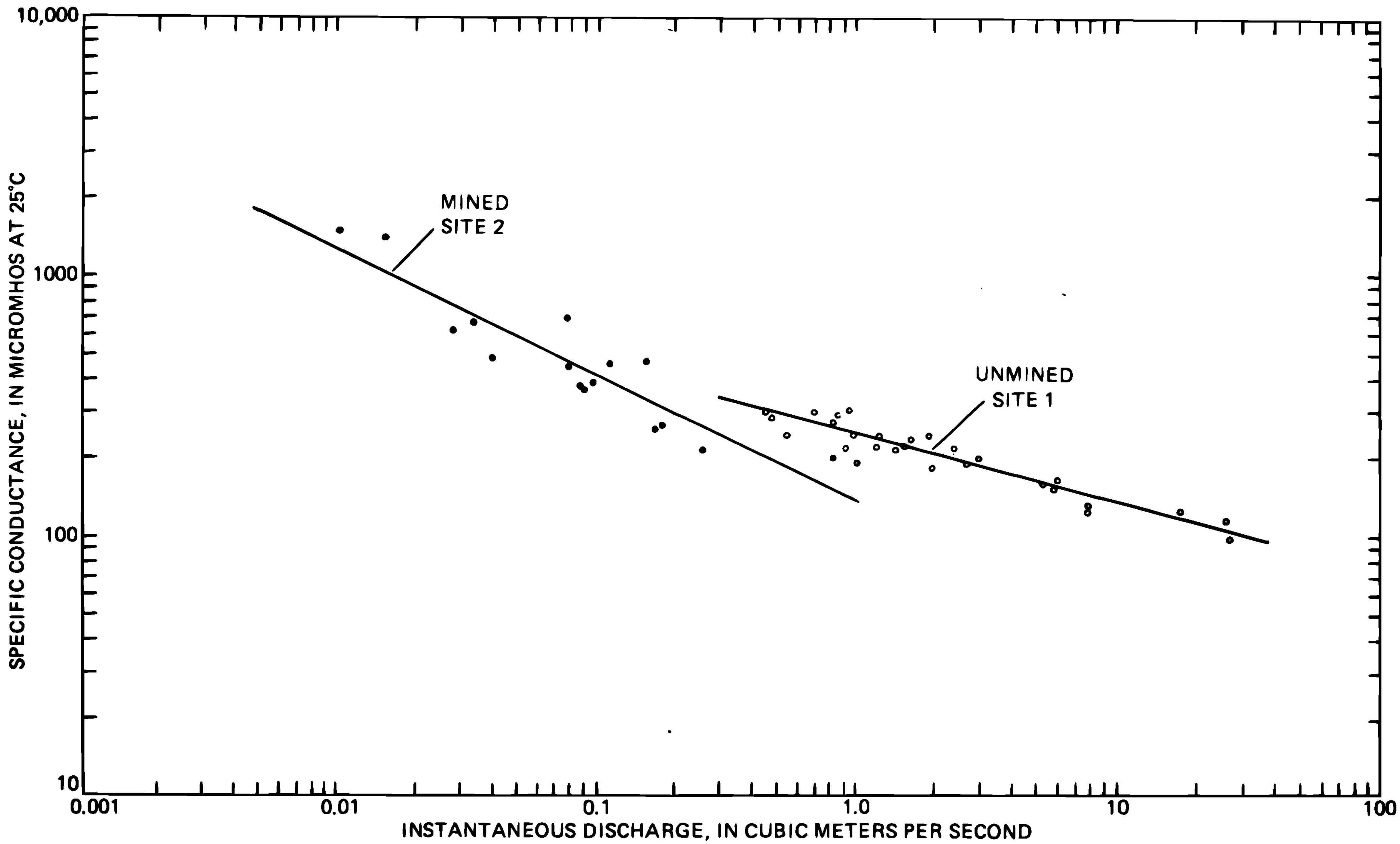


Figure 14.—Relation between specific conductance and instantaneous stream discharge at sites 1 and 2 in Turkey Creek Basin. (Site numbers correspond to those in figure 7.)

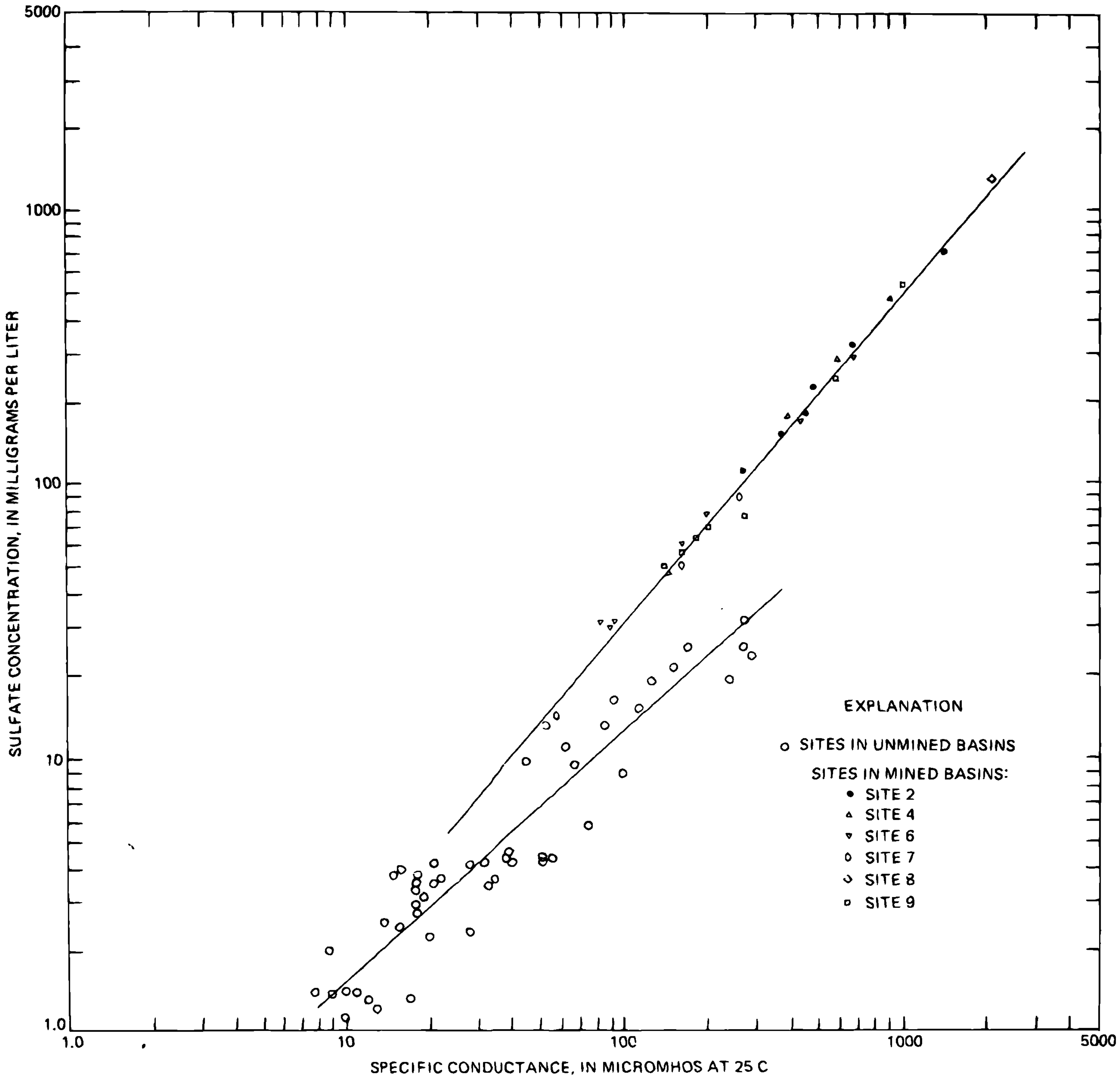


Figure 15. – Relation between specific conductance and sulfate concentration for sites in mined and unmined basins. (Site numbers correspond to those in figure 2.)

Table 4.--Estimated mean annual load of selected chemical constituents and suspended sediment for sites in Turkey and Crooked Creek basins, October 1975-May 1977

(Loads are in metric tons per square kilometer per year. Site numbers correspond to those in fig. 7.)

Basin	Site number	Sulfate	Dissolved solids	Calcium	Magnesium	Suspended sediment
Turkey Creek	1	14	74	10	5	180
	2	202	296	35	30	5110
	3	16	89	14	7	172
	4	156	243	27	22	1370
Crooked Creek	5	5	24	2	1	270
	6	35	67	7	5	134
	9	37	70	7	5	268

Large changes in water quality of streams in the mined areas (sites 2 and 4 in fig. 12) accompany changes in discharge. However, the highly mineralized water from site 2 has little impact on the water quality of the main stem of Turkey Creek. Water at sites 1 and 3 upstream and downstream from the inflow of mine drainage (site 2) is similar in quality (fig. 12 and table 3). This is due to the dilution of the mine drainage by the larger quantities of better quality water in Turkey Creek. Dilution ratios between the mined subbasin tributaries and Turkey Creek commonly range from 1:30 to 1:300.

Crooked Creek Basin.--The discharge, type, and degree of mineralization of water at sites monitoring mined and unmined areas in Crooked Creek basin is illustrated on figure 13. Water at site 5 (fig. 13 and table 5) in the unmined part of the basin is generally calcium, magnesium, bicarbonate, sulfate type water. The water has a dissolved solids concentration of 58 mg/L or less, a hardness of 38 mg/L or less, and a median pH value of 6.7. Only small concentrations of bicarbonate, calcium, magnesium, and sulfate were present.

Table 5.--Summary of selected physical and chemical characteristics at sampling sites in Crooked Creek basin, October 1975-May 1977

(Chemical analyses in milligrams per liter except as indicated. Site numbers correspond to those in figure 7.)

Parameter	Site 5			Site 6		
	Minimum	Maximum	Number of observations	Minimum	Maximum	Number of observations
Specific conductance (micromhos at 25°C)	41	102	25	83	780	28
pH	5.3	7.1	24	5.4	7.6	25
Dissolved oxygen (DO)	7.6	11	2	6.7	6.7	1
Hardness as $CaCO_3$:						
Calcium, magnesium	12	38	8	27	290	6
Noncarbonate	2	18	8	21	270	6
Acidity as H^+	.0	.20	5	....	....	....
Calcium (Ca)	2.3	8.2	8	4.6	45	6
Magnesium (Mg)	1.4	4.2	8	3.8	44	6
Sodium (Na)	3.1	3.5	3	....	....	....
Potassium (K)	1.0	1.1	3	....	....	....
Bicarbonate (HCO_3)	8	24	23	5	29	24
Carbonate (CO_3)	0	0	23	0	0	24
Alkalinity ($CaCO_3$)	7	20	23	4	24	24
Carbon dioxide (CO_2)	2.2	72	23	.3	39	24
Sulfate (SO_4)	9.2	16	11	30	290	7
Dissolved solids (residue at 180°C)	33	58	5	55	273	5
Total aluminum (Al) (ug/L)	170	1400	4	....	....	....
Dissolved aluminum (Al) (ug/L)	20	50	4	....	....	....
Total iron (Fe) (ug/L)	360	3900	4	....	....	....
Dissolved iron (Fe) (ug/L)	0	130	8	0	80	5
Total manganese (Mn) (ug/L)	40	100	4	....	....	....
Dissolved manganese (Mn) (ug/L)	30	50	4	....	....	....

Table 5.--Summary of selected physical and chemical characteristics at sampling sites in Crooked Creek basin, October 1975-May 1977--Continued

Parameter	Site 7 Minimum	Site 7 Maximum	Site 7 Number of observations	Site 9 Minimum	Site 9 Maximum	Site 9 Number of observations
Specific conductance (micromhos at 25°C	55	270	12	59	1030	1/35
pH	5.6	7.6	11	5.9	7.2	33
Dissolved oxygen (DO)	....	....	....	9.2	9.2	2
Hardness as $CaCO_3$:						
Calcium, magnesium	17	98	3	24	540	13
Noncarbonate	12	77	3	17	500	13
Acidity as H^+	....	....	....	.0	.20	8
Calcium (Ca)	3.2	16	3	4.5	92	13
Magnesium (Mg)	2.2	14	3	3.1	75	13
Sodium (Na)	....	....	....	2.1	4.5	6
Potassium (K)	....	....	....	1.2	3.7	6
Bicarbonate (HCO_3)	6	25	10	5	46	33
Carbonate (CO_3)	0	0	10	0	0	32
Alkalinity ($CaCO_3$)	5	21	10	4	38	33
Carbon dioxide (CO_2)	.8	32	10	1.0	20	32
Sulfate (SO_4)	14	88	3	19	530	16
Dissolved solids (residue at 180°C)	44	98	2	61	384	8
Total aluminum (Al) (ug/L)	....	....	....	280	14000	7
Dissolved aluminum (Al) (ug/L)	....	....	....	40	80	7
Total iron (Fe) (ug/L)	....	....	....	520	46000	7
Dissolved iron (Fe) (ug/L)	40	60	2	0	130	13
Total manganese (Mn) (ug/L)	....	....	....	210	890	7
Dissolved manganese (Mn) (ug/L)	....	....	....	130	390	7

1/ Does not include data from automatic water quality monitor

Sites 6, 7, and 8 (fig. 13) are on streams that drain reclaimed mines. Water in these streams during low-flow periods is generally of the magnesium, sulfate type. A large increase in mineralization occurs at site 9 downstream from the mined tributaries during low flow (fig. 13). This increase occurs when base flow from the upstream unmined reach (site 5) is not sufficient to dilute the mine drainage. The relation between specific conductance and discharge at sites 5 and 9 (fig. 16) show this occurrence. The maximum dissolved solids concentration observed at site 9 was 384 mg/L while the maximum dissolved solids concentration at site 5 in the unmined reach was 58 mg/L. Concentrations of other major indicators of mine drainage such as calcium, magnesium and sulfate, and non-carbonate hardness were also much greater at site 9.

Differences in the bicarbonate concentration and pH of water at mined and unmined sites in Crooked Creek basin were small. The neutralization of acid mine drainage is due to the common occurrence of nodules and layers of siderite ($FeCO_3$) and another unidentified carbonate mineral in shale overlying the Mary Lee coal bed.

Total iron, aluminum, and manganese concentrations were much greater in the reach of Crooked Creek draining mined areas (site 9) than those in the unmined reach (site 5). Dissolved iron in water in mined and unmined areas did not differ greatly. Dissolved manganese concentrations in some tributaries draining mined areas were much larger than those in water in the unmined reach. Estimated mean annual loads of selected chemical constituents for sites 5, 6, and 9 in Crooked Creek basin are given in table 4.

Suspended Sediment

Sediment samples were collected daily at site 9 on Crooked Creek (fig. 7) with an automatic sediment sampler (US PS-69). It collected two samples per day during base-flow periods and additional samples at changes in stage during high-flow periods. Daily samples were collected at sites 1 and 3 on Turkey Creek using a standard bridge mounted depth-integrating sampler (US-74). Data collected were adjusted by calibration procedures described by Porterfield (1972). Intermittent samples were collected at other sites using standard methods described by Guy and Norman (1970).

Bedload, defined here as sediment transported between the sampler intake nozzle and the streambed, was unsampled. Its contribution to the total-sediment yield was probably small because of the grain size of dominant rock types (shale, siltstone, and very fine and fine-grained sandstone) that underlie most of the area. Suspended sediment transported during high flows were predominantly in the clay and silt size range (finer than 0.062 mm).

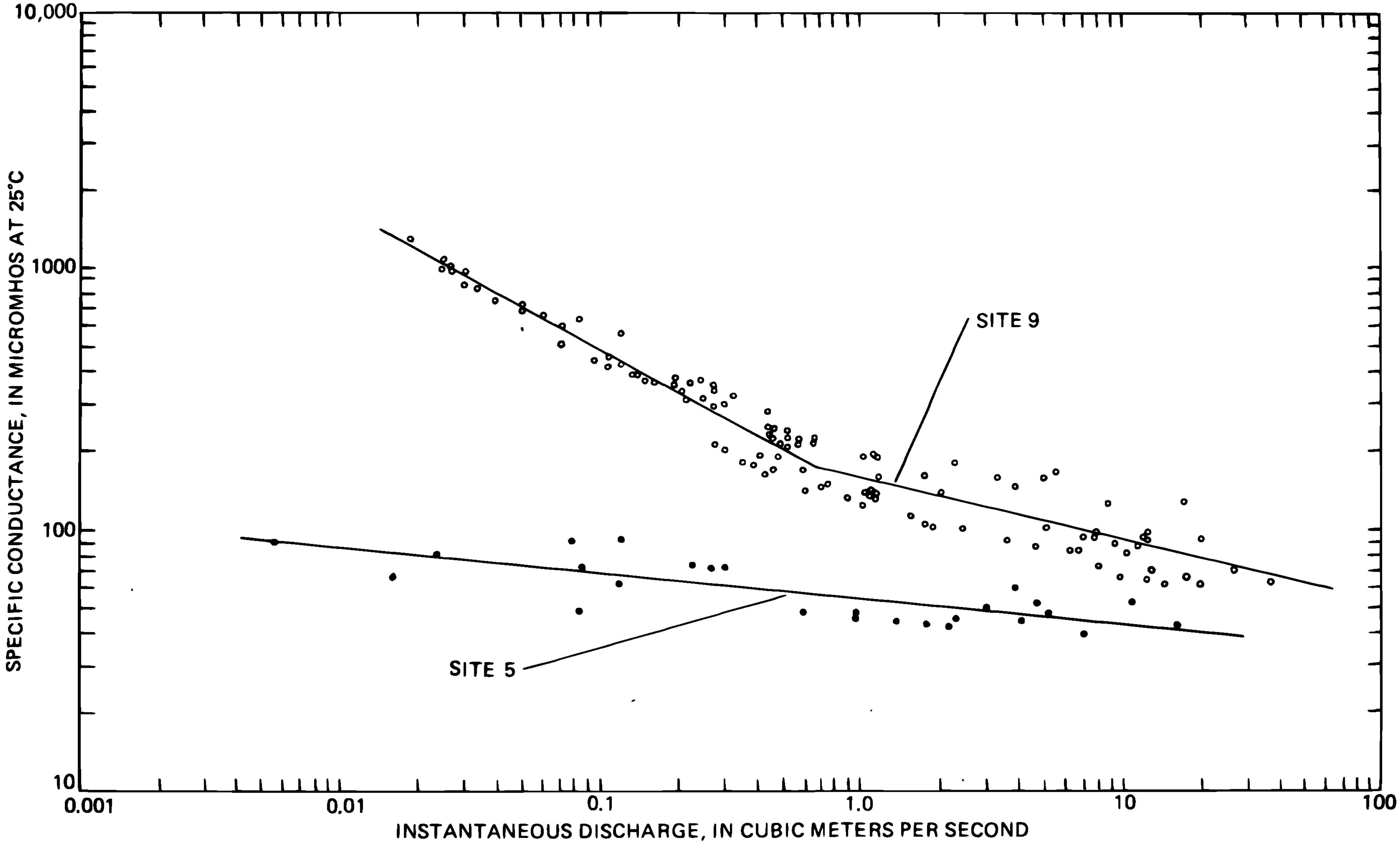


Figure 16.—Relation between specific conductance and instantaneous stream discharge at sites 5 and 9 on Crooked Creek. (Site numbers correspond to those in figure 7.)

Factors Affecting Sediment Yield

Basins in the study area are underlain by relatively impervious rocks and are characterized by a hilly terrain with moderate to steep slopes. These characteristics tend to produce rapid runoff with high erosion potential; however, most of the study area has a dense forest cover which tends to lower runoff velocities and decrease the influence of topography on erosion.

Strip mining in undisturbed areas drastically alters natural erosion and sediment yields. Mining activities including removal of forest cover, construction of haul roads, excavation, and creation of spoil areas greatly increase the weathering processes of exposed materials. These activities provide large volumes of unconsolidated materials for erosion.

Previous studies by other investigators (Wark, 1965; Rainwater, 1962; Collier and Musser, 1964; and Hubbard, 1976) indicate that average annual sediment yields may vary from 7 $(t/km^2)/yr$ for completely forested, undisturbed basins to 105,000 $(t/km^2)/yr$ for severely exposed strip-mined areas in southern Appalachia.

Concentration and Transport

The maximum suspended-sediment concentration recorded during the study was 46,000 mg/L at site 2 in Turkey Creek basin (fig. 7). Approximately 23 percent of the basin upstream from this site has been disturbed by mining and it was the only area mined during the study. The maximum suspended-sediment concentration recorded at the unmined site on Turkey Creek (site 1) was 1210 mg/L, while sites 3 and 4 had maximum concentrations of 1890 mg/L and 3970 mg/L, respectively. In Crooked Creek basin, the maximum suspended-sediment concentrations recorded at sites 5, 6, and 9 were 1320 mg/L, 780 mg/L, and 4570 mg/L, respectively. The relation between discharge and suspended-sediment concentration at site 9 on Crooked Creek is illustrated in figure 17.

Estimates of average annual suspended-sediment loads for sites in Crooked Creek and Turkey Creek basins for the period of study are given in table 4.

Relations between sediment yield and unit stream discharge for several sites are shown on figure 18. The highest yields occurred in mined tributaries to Turkey Creek and the lowest at sites 1 and 3 on its main stem. The similarity between the sediment yield curves for sites 1 and 3 (fig. 18) also indicates that sediment from mined areas between the sites has a negligible impact on the main stem. This results from dilution of the flow from tributaries by the larger volume of water in the main stem. The lowest suspended-sediment yield was at site 6 in Crooked Creek basin located downstream from a large reclaimed mine. This yield, smaller than that of the unmined reach (site 5), is partially due to the trapping of sediment in ponds in the mines and in a swamp between the mines and the downstream site.

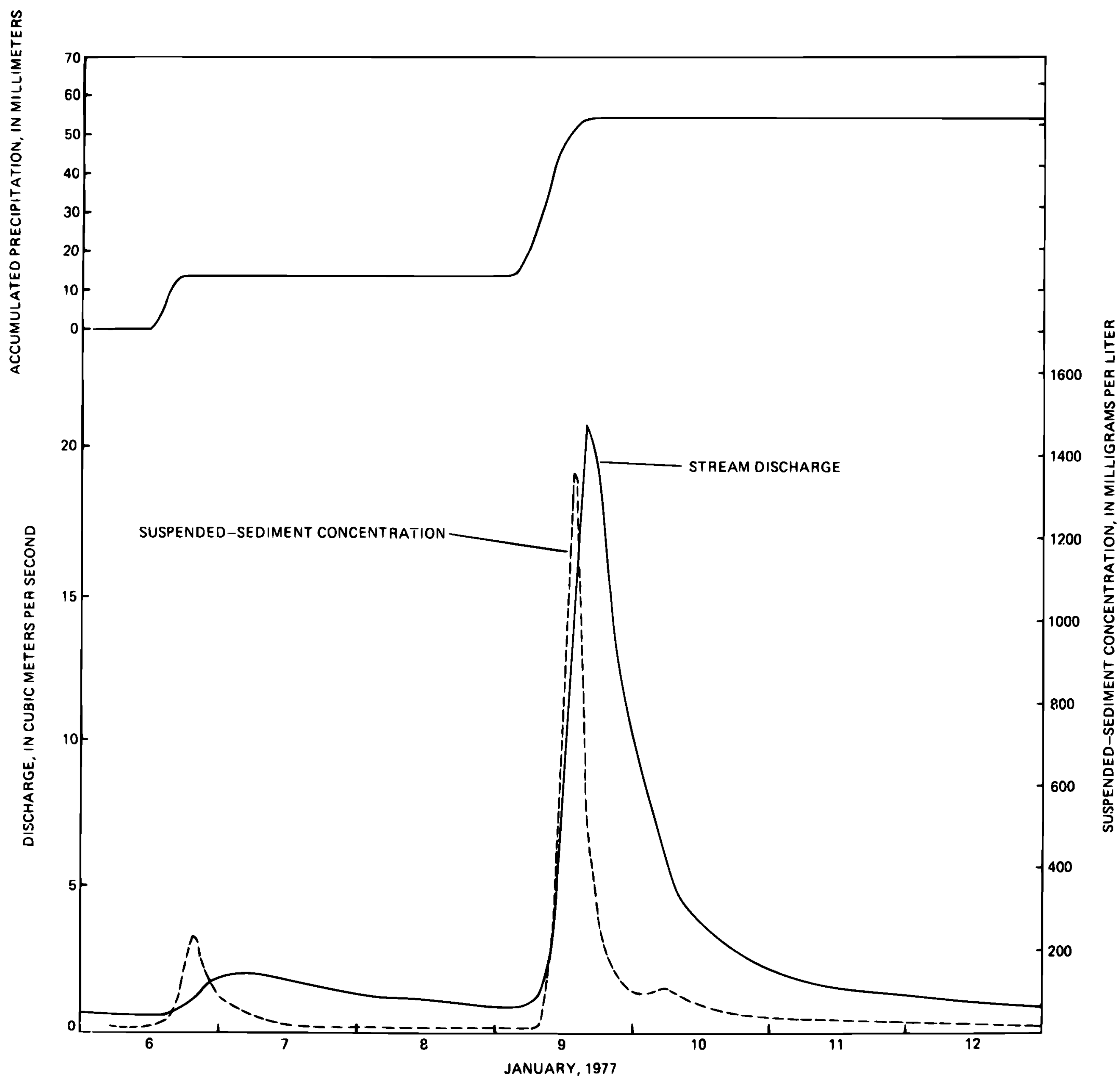


Figure 17.—Accumulated precipitation, stream discharge, and suspended-sediment concentration at site 9 on Crooked Creek, January 6-12,1977.

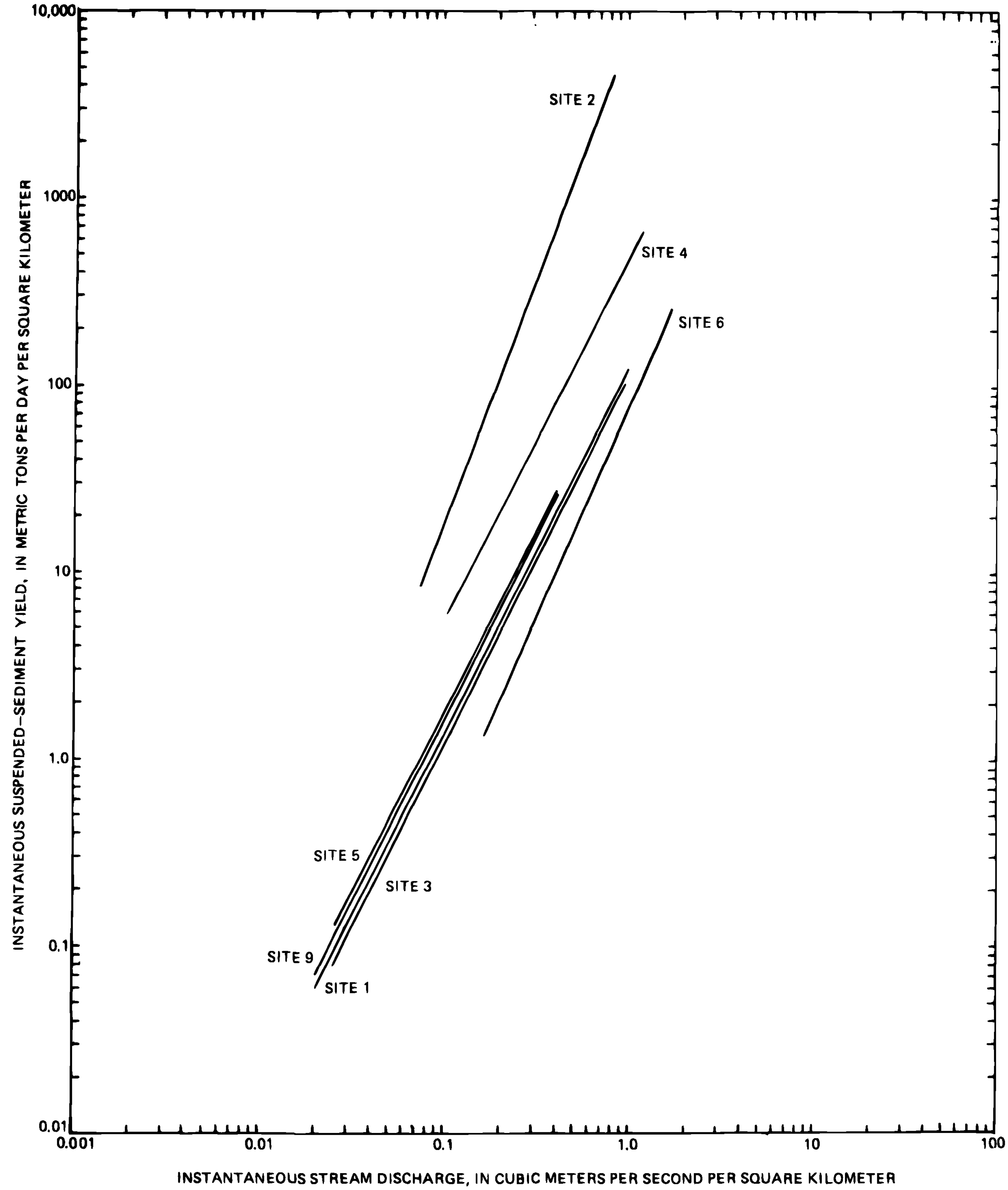


Figure 16 — Relation between sediment yield and unit stream discharge for selected sites. (Locations of sites and mines monitored are shown in figure 7; dates of mining are shown in figure 5; and percentages of mining in subbasins monitored are given in table 1.)

CONCLUSIONS

1. Storm runoff in Turkey and Crooked Creeks is characterized by peak flows of short duration that rapidly recede to low-flow. Low flows in the basins contrast greatly. Relatively impermeable strata in the Pottsville Formation yield limited base flow to Crooked Creek. Low flow in Turkey Creek is generally much larger due to the base flow contributed by permeable carbonate rocks in its upstream reaches.

2. Low flows in mined areas in Turkey and Crooked Creek basins were higher than those in unmined areas because of the discharge contributed from mine storage.

3. Water in Turkey Creek in areas unaffected by mining is of good chemical quality. The maximum dissolved solids concentration was 151 mg/L. Turkey Creek contains calcium, magnesium, bicarbonate type water reflecting the presence of carbonate rocks in the headwaters of the stream. The pH ranged from 6.7 to 8.0.

4. Water in the unmined segment of Crooked Creek is a calcium, magnesium, bicarbonate, sulfate type water. Dissolved solids concentrations ranged from 33 to 58 mg/L, and the pH ranged from 5.3 to 7.1.

5. Water in streams draining mined areas is often highly mineralized. The maximum dissolved solids concentration in water in the mined reach on Crooked Creek was about 7 times greater than that in water in the unmined reach. Water affected by mining generally is magnesium sulfate in type but also contains high concentrations of dissolved and total iron, aluminum, and manganese.

6. The pH of water in tributaries in the mined areas in the Turkey Creek basin ranged from 3.8 to 6.9. The pH of water in tributaries in the mined areas in Crooked Creek basin ranged between 5.4 and 7.6. The pH of some mine drainage in Crooked Creek basin frequently exceeded 7.0. This is attributed to the common occurrence of siderite and another unidentified carbonate mineral in shale overlying the Mary Lee coal bed.

7. Highly mineralized water from mined tributaries to Turkey Creek had little impact on the water quality in Turkey Creek due to dilution ratios that ranged from 1:30 to 1:300. In contrast, highly mineralized water from mined tributaries in Crooked Creek basin did have an effect on the quality of water in Crooked Creek.

8. Relations between specific conductance and various chemical constituents, developed by simple regression techniques, were very useful in estimating concentrations of chemical constituents associated with mine drainage.

9. Estimated mean annual loads of selected chemical constituents for tributaries to Turkey and Crooked Creeks draining mined areas were greater than those for tributaries not affected by mining.

10. Estimated mean annual sediment loads for tributaries in mined areas in Turkey Creek basin were 28 and 8 times greater than that estimated for the main stem of Turkey Creek upstream from the mining area. Due to dilution, however, the high sediment loads had an insignificant impact on the main stem of Turkey Creek. Sediment loads from a mined area draining into Crooked Creek also had a negligible impact on the main stem.

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U. S. GOVERNMENT PRINTING OFFICE: 1979-645-475