EFFECTS OF SURFACE MINING ON STREAMFLOW, SUSPENDED-SEDIMENT, AND WATER QUALITY IN THE STONY FORK DRAINAGE BASIN, FAYETTE COUNTY, PENNSYLVANIA

By Donald E. Stump, Jr. and Thomas M. Mastrilli

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

Multiply Inch-Pound unit	By	To obtain (SI) unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

A study of the 7.44-square-mile Stony Fork basin was made from 1977 through 1980 to determine the impacts of surface coal mining on the quality of water in Stony Fork. Stony Fork was sampled at six sites, during which time surface mining increased in the basin from 0.5 to 5.5 percent.

Streamflow, suspended-sediment, and water-quality data were collected at gaging stations upstream and downstream from mining. The total runoff between the upstream and downstream stations differed by 1 percent during the investigation, which suggests that streamflow was not noticeably affected by mining. Surface mining increased the suspended-sediment yield during storms due to erosion from mine sites. The suspended-sediment yield doubled at the downstream site following mining.

Specific conductance was highly variable during storm runoff but generally varied inversely with flow and increased slightly during the investigation. Treatment of mine drainage before it leaves the mines increased the specific conductance of baseflow; pH ranged from 7.9 to 4.8, with values below 6.0 generally occurring during storms.

Values of acidity and alkalinity did not show changes normally associated with mining activity. Concentrations of dissolved zinc and sulfates increased between the upstream and downstream sampling sites. The remaining chemical properties analyzed showed no consistent increases due to mining. An area that had been underground mined and subsequently surface mined, resulted in the discharge of increased levels of acidity and iron.

INTRODUCTION

Purpose and Scope

With increased demand for coal, the Pennsylvania Department of Environmental Resources (PaDER) has received numerous permit applications for surface coal mining in the Stony Fork drainage basin. The U.S. Geological Survey, in cooperation with PaDER, studied the effects of mining on water quality in the basin.

This report assesses the effects of surface coal mining on the quality of water in the Stony Fork basin in southwestern Pennsylvania. The assessment is based on analysis of monthly surface-water samples that were collected at six sites in the basin to establish water-quality characteristics and trends (fig. 1). Comparisons of streamflow, suspended-sediment and water quality at two gaging stations--one upstream from mining, the other downstream from mining--were used to determine surface-water-quality changes caused by mining.

Acknowledgements

Louis DiLissio and Eugene Hess of the Pennsylvania Department of Environmental Resources, Bureau of Mining and Reclamation, provided many man-hours and sound technical advice throughout the investigation. His assistance is greatly appreciated.

DESCRIPTION OF THE STUDY AREA

The Stony Fork basin drains 7.44 mi^2 in Wharton Township, Fayette County, Pennsylvania (fig. 1). Stony Fork is southwest of U.S. Route 40 along State Route 381 between Farmington and Elliottsville. It lies between the Chestnut Ridge and Laurel Hill in the Ohiopyle valley of the Allegheny Mountain section of the Appalachian Plateau Province in Pennsylvania (Hickok and Moyer, 1971, p. 20-21). The basin is a rural area containing about 40 percent cropland and pasture and 60 percent forest. PaDER classifies Stony Fork as a high-quality, cold-water fishery.

Climate

The climate of the study area is classified as humid continental with warm summers and cold winters. Temperatures ranges from 95°F in July to 0°F in January. Precipitation is well distributed throughout the year; annual precipitation for the 1978-80 water years[1] was 47.0, 47.5, and 45.6, inches, respectively.

Geologic Setting

Bedrock units in the Stony Fork drainage basin belong to the Allegheny group and the overlying Conemaugh group. Structurally, the basin is on the Preston anticline about midway between the Chestnut Ridge anticline and the Laurel Hill anticline. Originally, it was thought that the Brush Creek and Mahoning coals of the Conemaugh group were being mined. However, more recent core hole drillings (1980) show that the bituminous coal seam being excavated is the Upper Kittanning of the Allegheny group (fig. 2). The Upper Kittanning coal is from 1 to 5 feet thick. The roof generally consists of sandy shale or thin-bedded sandstone, and the floor of black shale or clay (Hickok and Moyer, 1971). Limestone is present in the overburden, within the Pine Creek and Brush Creek marine zones and below the Upper Freeport coal seam. Pyrite layers occur near the base of the Brush Creek seam and pyrite lenses within the Mahoning and Lower Freeport seams.

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[1] The 12-month period ending September 30 each year is termed the "water year."

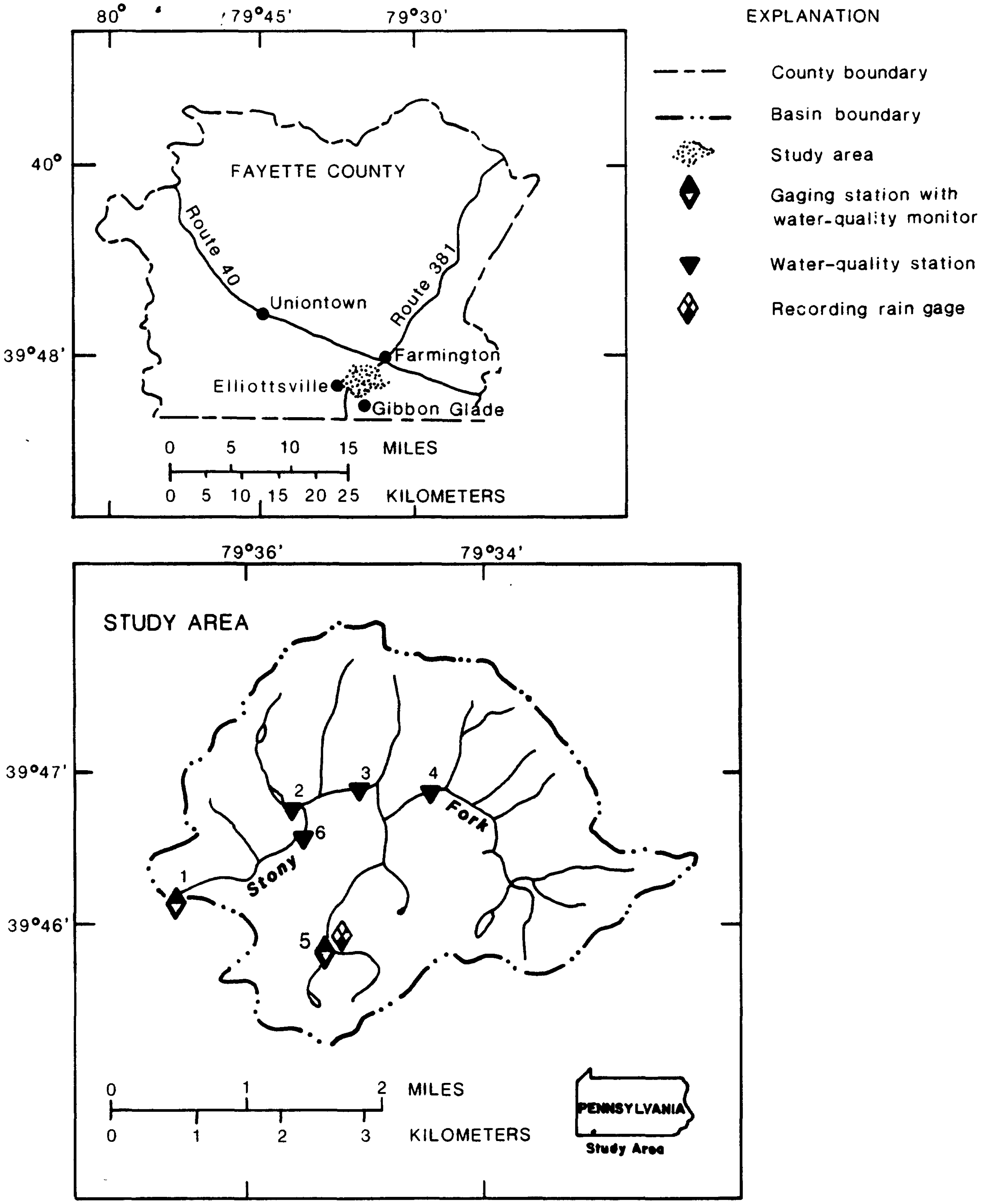


Figure 1.--Data-collection sites in the Stony Fork watershed.

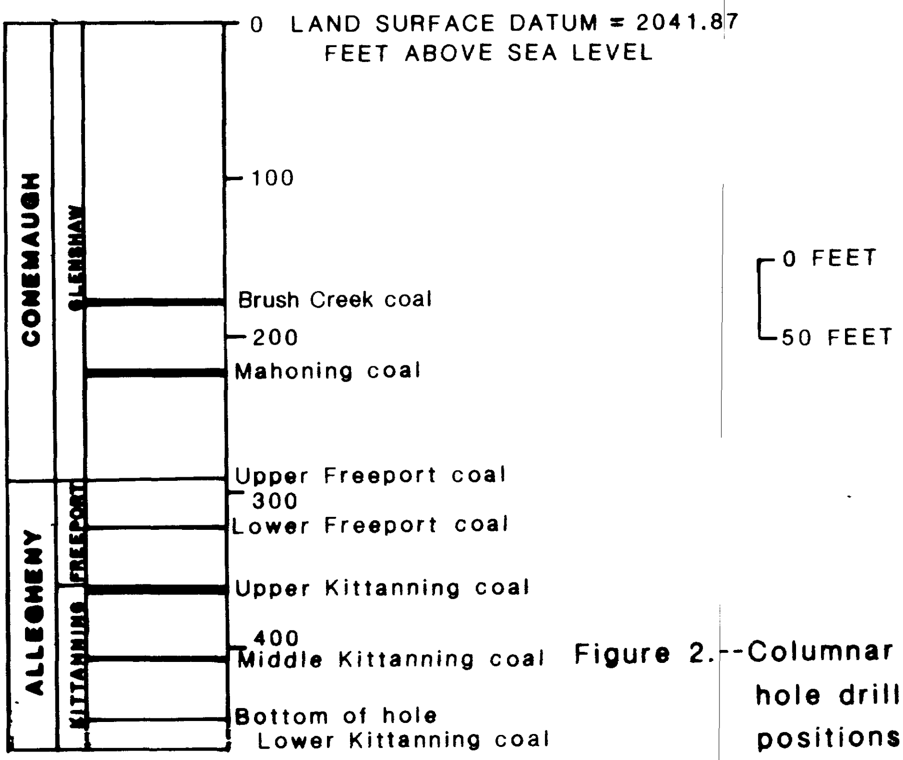


Figure 2.--Columnar section from core hole drilling showing relative positions of coal seams.

Previous Investigations

The Pennsylvania Department of Environmental Resources, Bureau of Topographic and Geologic Survey published a county wide investigation by W. O. Hickok, IV and F. T. Moyer (1971) that describes the geologic framework of the county.

F. A. Ward, (1977) describes the geographic and environmental characteristics of a portion of the Big Sandy Creek watershed.

The U.S. Department of Agriculture, Soil Conservation Service, published a county wide soil survey (1973). This survey identifies the surface and subsurface soil characteristics and composition of the county.

SURFACE MINING

Contour and haul-back mining techniques have been used; both are economical because the mined coal beds have gentle slopes and little overburden. Surface mining disrupts the vegetation, soils, and rock formations above the coal seam and alters the hydrologic characteristics of the mined areas. Possible hydrologic effects of surface mining include increased soil erosion, lower infiltration rates, higher runoff rates, changes in patterns of groundwater movement, higher runoff temperatures, and exposure of rock materials to weathering.

In surface contour mining, overburden excavation proceeds around the hillside and the working area appears as a contour line. Successive excavations or cuts are made into the hillside and overburden is deposited down slope.

Normally, mining continues until removal of the overburden becomes uneconomical. The high ridge of overburden along the down slope perimeter of the mined area is subject to erosion, landslides, and mineral weathering. A diversion is constructed at the base of the ridge to transport surface water runoff to a sedimentation pond. The sedimentation pond should allow sufficient retention time for soil particles in the water to settle.

In haul-back surface mining, the excavation is made perpendicular to contour lines. Overburden removed from a new cut is placed in the pit of the previous cut. The spoil ridge is along the edge of the mine area, and reclamation can be integrated into the mining schedule, and generally less overburden is exposed than with contour mining. Erosion, landslide and mineral decomposition problems are reduced and reclamation costs less because the overburden material is handled only once. A diversion and sedimentation pond similar to those described for contour mining are also used for this method.

Location and Description of Surface-Mine Areas

Four surface mines, shown as A, B, C, and D on figure 3, were intermittently active during the data collection phase of this study. Coal production and characteristics of the surface-mine areas are given in tables 1 and 2 respectively. The area disturbed by surface mining increased from 0.04 to 0.44 square miles (0.5 to 5.5 percent of the study area) from October 1977 through September 1980 (fig. 3 and 4).

Operations in mine a began in 1975 and continued on an intermittent basis until June 1978 when backfilling began. Backfilling proceeded until September 1978 when the site was seeded with rye grass. Mine B was operated from September 1977 through December 1977, when a strike halted operations. The strike ended in March 1978 and operations were resumed. Mining continued until September 1980, when the mined areas were backfilled and seeded. Operations at mine C began in March 1978 and continued until backfilling began in March 1979. Backfilling was completed September 1979 and seeding began. Mine D was operated from May 1979 and continued until September 1980.

Acid-Mine Drainage

The removal of overburden during surface mining may expose pyritic material which, when oxidized, may produce acid-mine drainage. Pyrite (FeS_2), a mineral commonly found in coal and the overlying strata, oxidizes when in contact with air and water to produce iron oxides, hydrogen ions and sulfate. The amount and rate of pyrite oxidation depends on the composition of pyrite exposed, the amount and quality of water flowing over it, the circulation of air through the material, the presence of iron bacteria, and the amount of calcereous material present. As a result of pyrite oxidation, the pH of the final discharging water may be lowered to levels at which metals, such as iron, aluminum, manganese, and zinc become more soluble. Ferric hydroxide, $Fe(OH)_3$, another product of pyrite oxidation, precipitates out of solution as the mine drainage comes in contact with oxygenated stream water or air, and covers the stream bottom as yellow-orange precipitate (yellowboy). Other metals in solution will also precipitate as the water becomes more basic.

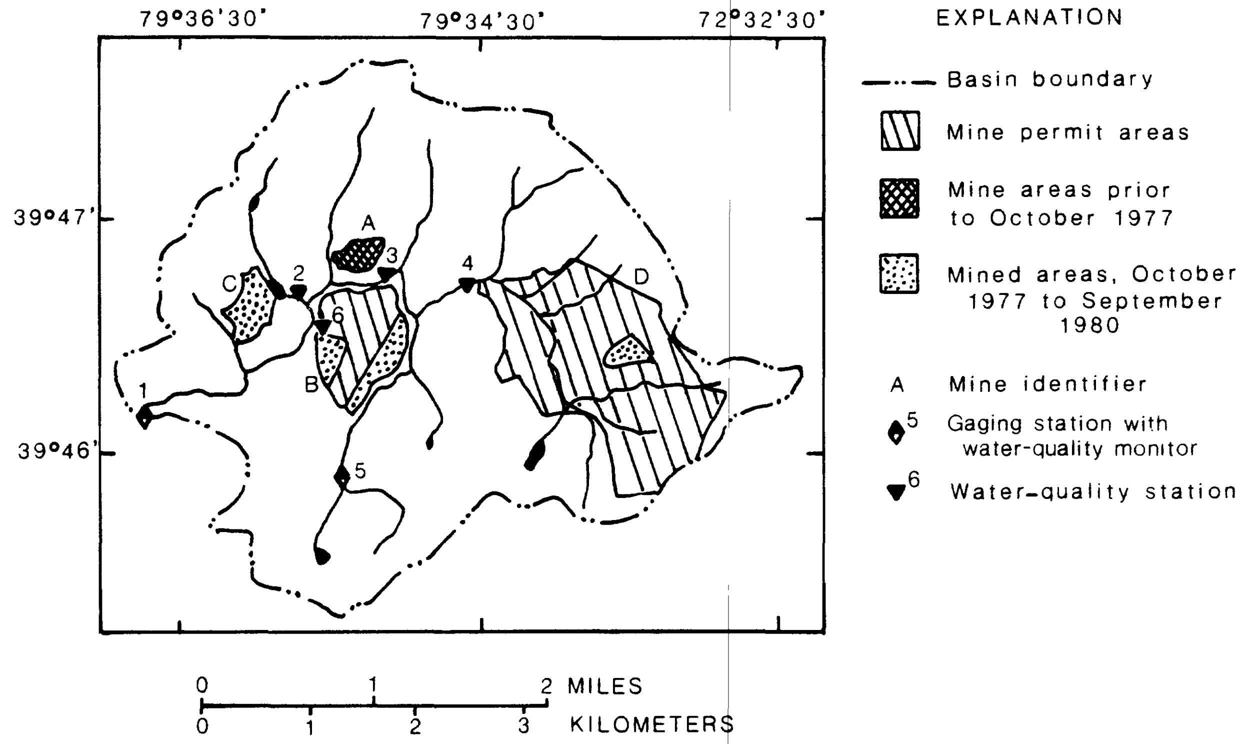


Figure 3.--Mined areas in the Stony Fork watershed.

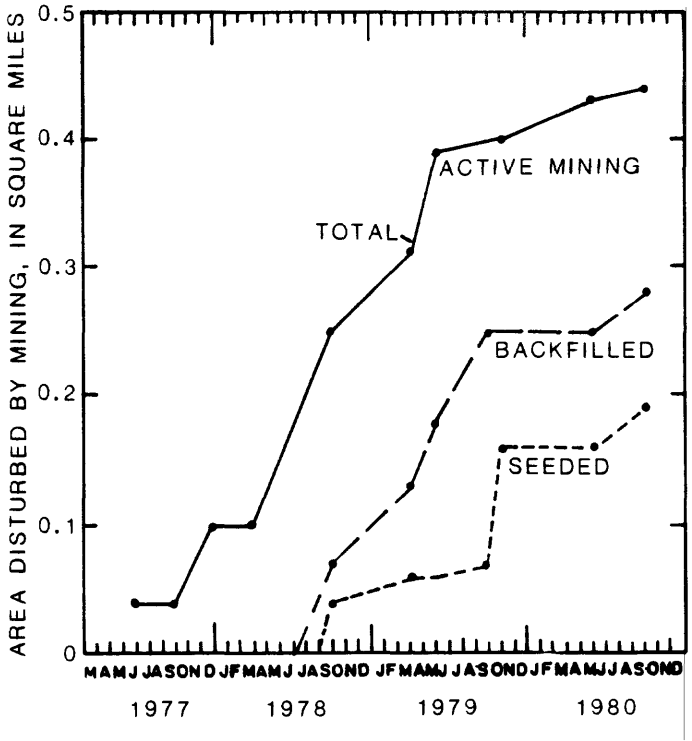


Figure 4.--Condition of surface-mined areas between June 1977 and September 1980.

Table 1.--Annual coal production of surface mines, in tons [Data from Pennsylvania Department of Environmental Resources]

Surface mine	1975	1976	1977	1978	1979	1980
A	5,452	10,116	11,817	1,668	0	0
B			33,360	124,214	111,801	48,235
C				55,463	0	0
D					16,819	38,915

Table 2.--Surface-mine area characteristics

Surface mine	Area (mi^2)	Prior land use	Slope (percent)	Mining method
A	0.04	Pasture	8-15	Contour
B	.20	Pasture & Forest	3-60	Haul-back
C	.10	Pasture	3-20	Contour
D	.10	Forest	0-60	Haul-back

Soil Erosion and Deposition

Soil erosion and deposition involves the detachment, transport and subsequent deposition of soil particles. The soil particles are detached from the ground by raindrop impact and water movement and transported down slope by flowing water (Haan and Barfield, 1978, p. 178). Soil erosion is influenced by soil properties, land slope, length of slope, climate, amount and intensity of rainfall, and the type and percent of vegetative ground cover (Grim and Hill, 1974, p. 101). Surface mining changes several of the factors influencing soil-erosion rates and can increase the volume of sediment available for transport.

HYDROLOGIC DATA COLLECTION

Hydrologic data collected for this study include streamflow, suspended sediment, water quality, and precipitation. These data are published in the U.S. Geological Survey water resources data for Pennsylvania (1978-80).

Gaging stations were established at site 1 and 5 in May 1977. At each gaging station, a water-stage recorder continuously recorded the elevation of the stream's surface (stage). Periodic measurements of water discharge were also made. Stage was converted to water discharge by means of a stage-discharge relationship. From October 1977 to September 1980, measurements of specific conductance, pH, and temperature were recorded continuously at sites 1 and 5 with U.S. Geological Survey water-quality monitors. From June 1977 to September 1980, precipitation was recorded at site 5 using a recording graphic rain gage; a precipitation quality sample was collected at site 5 on December 8, 1978.

From October 1977 to September 1980 suspended-sediment samples were collected at sites 1 and 5 with PS-69 automatic pumping samplers. Depth-integrated samples were collected during medium and high flows and compared to the point samples taken by the automatic sampler for the purpose of rating the automatic sampler. During low-flow periods, suspended-sediment samples were collected by hand with DH-48 and DH-59 samplers (Guy, 1970, p. 4-6). Sediment concentrations were determined using a filtered dry-weight method (Guy, 1969, p. 11-13). Daily mean water discharge, sediment concentrations, and sediment discharge were calculated for each of the two stations according to the techniques described by Porterfield (1972).

Location of Sampling Sites

Begining in October 1977, water-quality samples were collected monthly at six sites (fig. 1). A complete list of the sampling sites and drainage areas is given in table 3.

Table 3.--Sampling sites in the Stony Fork basin

Site	USGS identification numbers	Drainage area (mi^2)	Station name
1	03070455	7.44	Stony Fork near Elliotsville
2	03070435	.54	Stony Fork Tributary No. 4
3	03070430	4.85	Stony Fork at Bethel Chapel
4	03070415	2.50	Stony Fork near Farmington
5	03070420	.93	Stony Fork Tributary near Gibbon Glade
6	03070440	----	Hager mine discharge

Stony Fork tributary near Gibbon Glade (site 5), is upstream from all surface mining activity, and drains an area that is pastureland. This station was selected as the reference against which downstream sites could be compared to determine changes in water quality due to activities in the mined areas.

Stony Fork near Farmington (site 4) is on the main stem of Stony Fork and was downstream from mine D. Stony Fork at Bethel Chapel (site 3) is on the main stem of Stony Fork and is downstream from mine D and a part of mine B. Stony Fork tributary number 4 (site 2) is downstream from mine C. Stony Fork near Elliottsville (site 1) is downstream from all mining activity. A mine discharge (site 6), is located at an underground mine entrance on the northwest perimeter of surface mine B.

From October 1977 through September 1980, samples were collected monthly at all six sampling sites. Field measurements included discharge, pH, specific conductance, temperature, alkalinity, and acidity. Laboratory determinations included sulfate, suspended sediment, iron, aluminum, manganese and zinc. Semi-annual laboratory determinations included arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, nickel, silver, selenium, and mercury.

EFFECTS OF SURFACE MINING

Streamflow

Surface mining in the Stony Fork watershed during 1978-80 did not alter the runoff characteristics at site 1 significantly. The annual runoff at sites 1 and 5, for water years 1978-80 differed by less than 5 percent for any one year and only 1 percent for the period of record (table 4). The magnitudes of these differences are within the error of measurement of runoff. The average runoff was 27.2 inches or 58 percent of the total precipitation at site 1, and 27.4 inches or 59 percent at site 5. The closeness of the plotted points to the line of equality in figure 5 also indicates that the monthly runoff totals of sites 1 and 5 were not altered by surface mining during the study period.

Table 4.—Annual precipitation and runoff at sites 1 and 5 for water years 1978-80

		Runoff				
		site 1		site 5		
Water year	Precipitation (inches)	(inches)	(percentage of precipitation)	(inches)	(percentage of precipitation)	Percentage difference 100-[(site 1/site 5) x 100]
1978	47.0	27.7	59	28.8	61	+4
1979	47.5	28.4	60	27.5	58	-3
1980	45.6	25.4	56	25.9	57	+2
TOTAL	140.1	81.5		82.2		+1

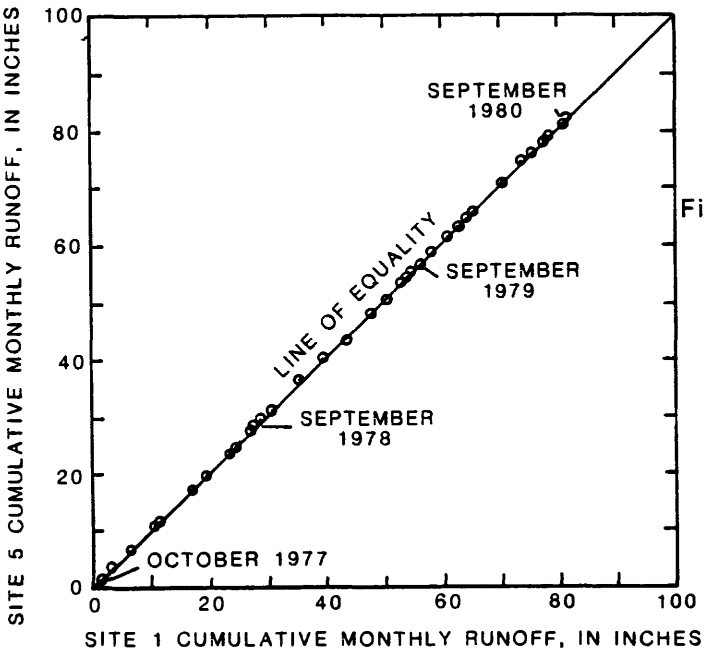


Figure 5.--Cumulative monthly runoff at sites 1 and 5 for water years 1978-80.

Suspended-Sediment Yield

Variables that influence sediment and runoff include, soil type, rock type, land use, rainfall amount and intensity, antecedent soil moisture, slope, vegetation, drainage area size, and climate. The effect of land use change on suspended-sediment in streams can be evaluated by comparing unit-area sediment yields upstream and downstream of the altered area. This suspended-sediment yield ratio (SSYR) was used to evaluate impacts. An SSYR has the unit-area suspended-sediment yield of the upstream site (site 5) in the denominator and the unit-area suspended-sediment yield for downstream site (site 1) in the numerator.

The ratios for water years 1978-80 were 0.53, 1.04 and 1.08, respectively. For 1978, the SSYR of 0.53 indicates that about half as much suspended-sediment per unit area was carried by the stream at site 1 as at site 5. This relationship was altered following mining when the suspended-sediment yield at site 1 increased over the yield at site 5.

A plot of the cumulative monthly suspended-sediment yields at site 1 as a function of yields for site 5 (fig. 6) shows a change in the slope of the line at the end of 1978. The location of a specific point or month where the slope changes is not clearly definable, but there is an area of transition from one slope to the other in December 1978. The change in slope indicates that there has been an increase the suspended-sediment discharge at site 1 relative to site 5. The relation between peak flow minus the pre-storm base-flow at site 5 and 1 for 1978-80 is shown in figures 7 and 8, respectively. A least squares technique was used to determine coefficients for the equation $y=ax^b$, where y = suspended-sediment yield, x = discharge, and a and b are regression coefficients (Riggs, 1968, p.7). Regression coefficients and standard errors of estimate for each year for both sites are given in table 5.

Table 5.--Regression coefficients and standard errors of estimate from water years 1978 through 1980 at sites 1 and 5

Water Year	*a*		*b*		Standard error Se (tons/mi^2)		Average Standard error in percentage Se (percent)	
	site 1	site 5	site 1	site 5	site 1	site 5	site 1	site 5
1978	0.03	0.17	1.28	1.55	0.15	0.12	36	28
1979	.13	.09	1.41	1.52	.40	.11	116	26
1980	.19	.23	1.54	1.25	.21	.16	51	38

The regression lines and data points for site 5 (fig. 7) overlap, indicating that all the data are from the same population; in other words, the storm sediment yield characteristics of the site have not changed measurably over this period.

At site 1, the relation of suspended-sediment yield to the increase in discharge during storms (fig. 8) indicates that the suspended-sediment yield for a given increase in discharge was much higher in 1979 and 1980 than in 1978. The change of the relation and the increased scatter of the 1979 and 1980 data are indications of increased sediment yields due to mining.

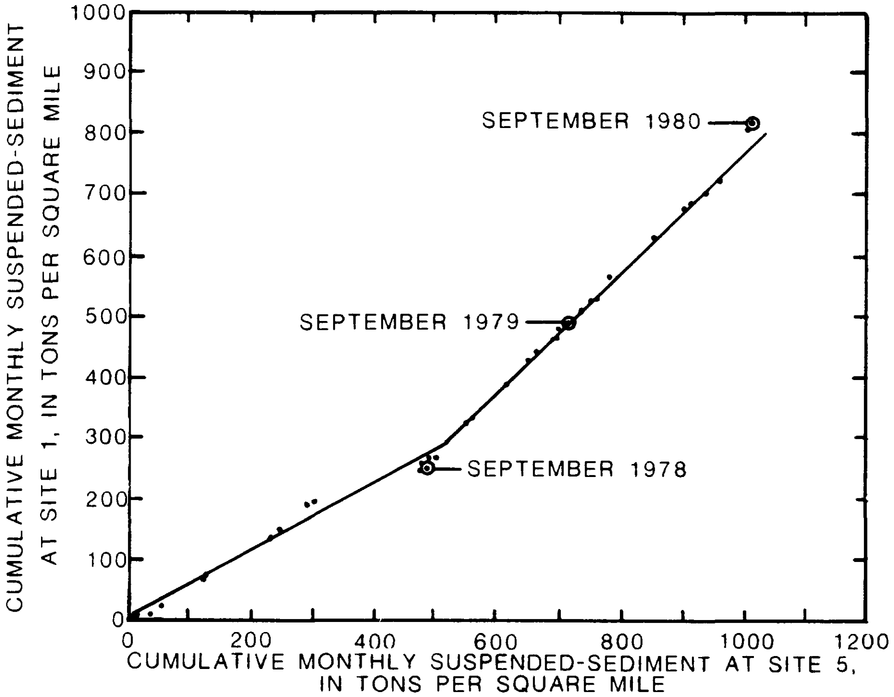
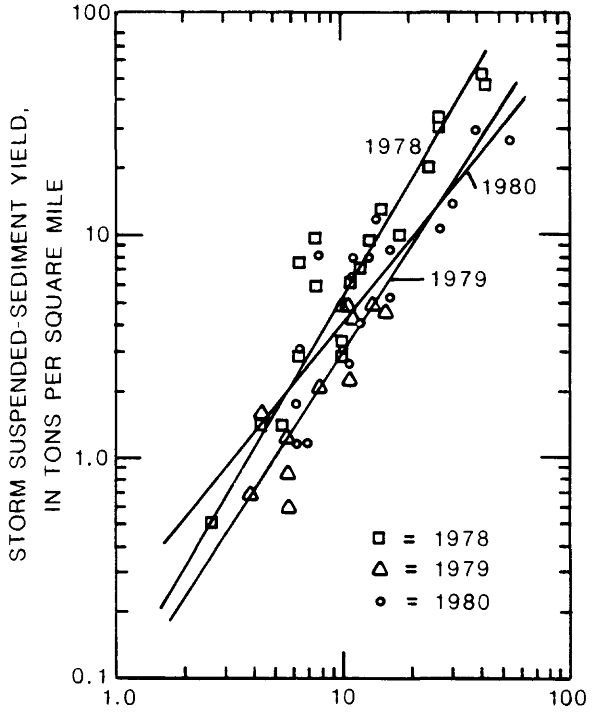


Figure 6.--Cumulative monthly suspended-sediment yield for sites 1 and 5, October 1977 to September 1980.



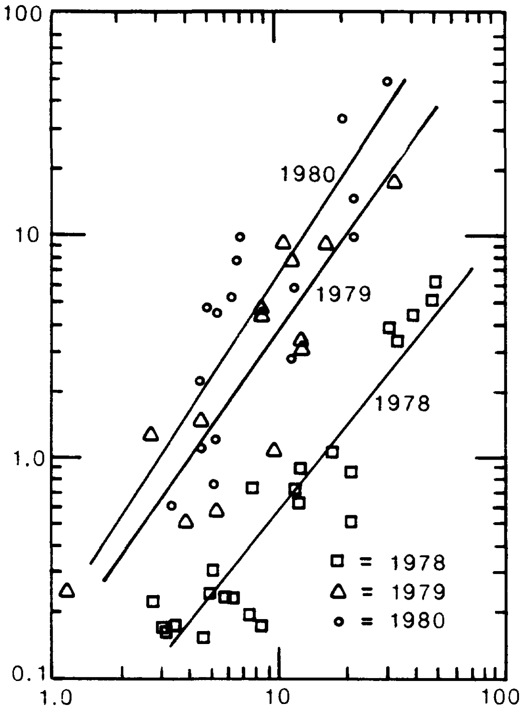


Figure 7.--Relation of suspended-sediment yield to the increase in discharge during storms at site 5, water years 1978-80.

Figure 8.--Relation of suspended-sediment yield to the increase in discharge during storms at site 1, water years 1978-80.

Water Quality

With the exceptions of December 1977 and February 1978, samples for water-quality analysis were collected monthly during base-flow periods from October 1977 to September 1980 at sites 1 through 5. Tables 6-10 show a summary of the constituents sampled. Additionally, tables 6 and 10 show daily mean values of temperature, pH and specific conductance. Monthly mean water temperatures of site 1 and 5 (fig. 9) show that both sites have similar temperature ranges, with mean values of about 20°C during July and August, and mean values of about 0°C during January and February. The maximum and minimum values at site 1 were 25°C and 0°C. The maximum and minimum temperatures at site 5 were 27.5°C and 0°C. Figure 9 does not indicate increases in monthly mean water temperatures downstream of mining at site 1.

Maximum and minimum monthly pH (fig. 10) measured at site 5 were 7.9 and 5.8, respectively. Maximum and minimum pH at site 1 were 7.7 and 4.8, respectively. Minimum pH values of 4.9 and 4.8 at site 1 occurred during storms in July and August 1980, respectively. On July 28 and 29, 1980, the pH of storm runoff at site 1 decreased from 7.0 before the storm to 5.4 during the storm and returned to 6.8 after the storm (fig. 11).

Values of specific conductance were slightly higher at site 1 than at site 5. The highest monthly specific-conductance values were during months of low discharge (summer) when ground water contributed the largest percentage of streamflow, and the dilution effects of surface runoff were minimum. The lowest monthly values were during high discharge snow-melt periods in the winter and spring months (fig. 12).

Monthly maximum and minimum specific conductance at sites 1 and 5 are shown in figure 13. A maximum value of 498 µS/cm occurred at site 1 during a period of low flow in September 1980. Several other high values occurred during winter periods due to road-salt washoff.

Figure 14 shows hourly values of specific conductance, pH, and discharge at sites 1 and 5 during a low-flow period in September 1980. The specific conductance at site 5 stayed near 100 µS/cm, but, at site 1, increased from almost 120 to almost 400 µS/cm and then decreased to 145 µS/cm during a 24-hour period. The increase in conductance at site 1 was due to the pumping of treated water from a mine upstream. The base-flow specific conductance at site 5 ranged from an average of 60 µS/cm at 2 ft^3/s to an average of 110 µS/cm at 0.06 ft^3/s (fig. 15).

The base-flow specific conductance at site 1 ranged from an average of 60 µS/cm at 20 ft^3/s to an average of 130 µS/cm at 0.6 ft^3/s during 1978. During water years 1979 and 1980 the scatter of the values increased relative to 1978 (fig. 16). The notably increased scatter in specific conductance, for 1980, was due to the discharge of treated mine water and the mine discharge at site 6.

Table 6.--Daily mean and instantaneous maximum, minimum and mean water-quality values at site 1, water years 1978-80

[A dash indicates that an analysis was not performed.]

Constituent	1978 max.	1978 min.	1978 mean	1979 max.	1979 min.	1979 mean	1980 max.	1980 min.	1980 mean
					Daily Mean Values				
temperature (°C)	22.5	0.0	9.5	23.5	0.0	10.0	25	0.0	10.0
pH (units)	7.4	5.5	6.8	7.7	6.3	6.8	7.4	4.9	6.8
Specific conductance (µS/cm)	168	48	84	268	34	82	498	45	97
					Instantaneous Values				
acidity (mg/L)	5	2	3	4	2	3	12	1	4
alkalinity (mg/L)	18	1	8	26	4	12	42	5	14
dissolved sulfate (mg/L)	37	6	16	20	8	15	100	8	31
dissolved aluminum (µg/L)	--	--	--	310	40	101	360	10	100
dissolved iron (µg/L)	580	50	194	330	80	159	500	50	175
dissolved manganese (µg/L)	--	--	--	260	50	124	1,370	120	413
dissolved zinc (µg/L)	--	--	--	60	10	19	40	10	22

Table 7.--Instantaneous maximum, minimum and mean water-quality values at site 2, water years 1978-80

[A dash indicates that an analysis was not performed.]

Constituent	1978 max.	1978 min.	1978 mean	1979 max.	1979 min.	1979 mean	1980 max.	1980 min.	1980 mean
acidity (mg/L)	6	2	4	13	1	4	8	2	4
alkalinity (mg/L)	66	11	26	118	4	39	34	10	22
dissolved sulfate (mg/L)	33	7	15	54	8	25	22	4	13
dissolved aluminum (µg/L)	--	--	--	200	80	128	180	30	98
dissolved iron (µg/L)	1,130	150	466	640	110	302	840	140	426
dissolved manganese (µg/L)	--	--	--	1,370	70	350	1,310	130	384
dissolved zinc (µg/L)	--	--	--	30	10	13	20	10	14

Table 8.--Instantaneous maximum, minimum, and mean water-quality values at site 3, water years 1978-80

[A dash indicates that an analysis was not performed.]

Constituent	1978 max.	1978 min.	1978 mean	1979 max.	1979 min.	1979 mean	1980 max.	1980 min.	1980 mean
acidity (mg/L)	8	2	4	5	2	4	14	2	6
alkalinity (mg/L)	18	3	10	22	4	10	16	4	10
dissolved sulfate (mg/L)	19	3	10	15	5	10	30	7	15
dissolved aluminum (µg/L)	--	--	--	150	40	98	460	10	132
dissolved iron (µg/L)	570	130	282	760	100	267	450	60	232
dissolved manganese (µg/L)	--	--	--	290	60	118	320	110	182
dissolved zinc (µg/L)	--	--	--	50	10	18	30	10	20

Table 9.--Instantaneous maximum, minimum, and mean water-quality values at site 4, water years 1978-80

[A dash indicates that an analysis was not performed.]

Constituent	1978			1979			1980		
	max.	min.	mean	max.	min.	mean	max.	min.	mean
acidity (mg/L)	7	1	4	11	2	5	6	4	5
alkalinity (mg/L)	7	1	3	12	1	4	5	2	4
dissolved sulfate (mg/L)	16	3	7	15	4	9	19	4	13
dissolved aluminum (µg/L)	--	--	--	200	50	104	180	10	87
dissolved iron (µg/L)	310	70	152	530	70	221	350	60	175
dissolved manganese (µg/L)	--	--	--	150	50	77	590	110	256
dissolved zinc (µg/L)	--	--	--	70	10	22	40	20	28

Table 10.--Daily mean and instantaneous maximum, minimum and mean water-quality values at site 5, water years 1978-80

[A dash indicates that an analysis was not performed.]

Constituent	1978			1979			1980		
	max.	min.	mean	max.	min.	mean	max.	min.	mean
				Daily Mean Values					
temperature (°C)	24.5	0.5	10.0	25.0	0.0	10.0	27.5	0.0	10.0
pH (units)	7.8	6.0	6.7	7.3	6.0	6.6	7.9	5.8	6.6
Specific conductance (µS/cm)	446	29	70	263	34	79	309	46	72
				Instantaneous Values					
acidity (mg/L)	10	2	5	7	3	4	12	4	5.5
alkalinity (mg/L)	26	2	12	37	4	17	20	8	14
dissolved sulfate (mg/L)	25	3	9	15	5	11	28	4	14
dissolved aluminum (µg/L)	—	—	—	310	20	97	500	10	163
dissolved iron (µg/L)	510	100	231	290	110	188	600	100	282
dissolved manganese (µg/L)	—	—	—	190	50	89	200	50	128
dissolved zinc (µg/L)	—	—	—	50	10	23	30	10	19

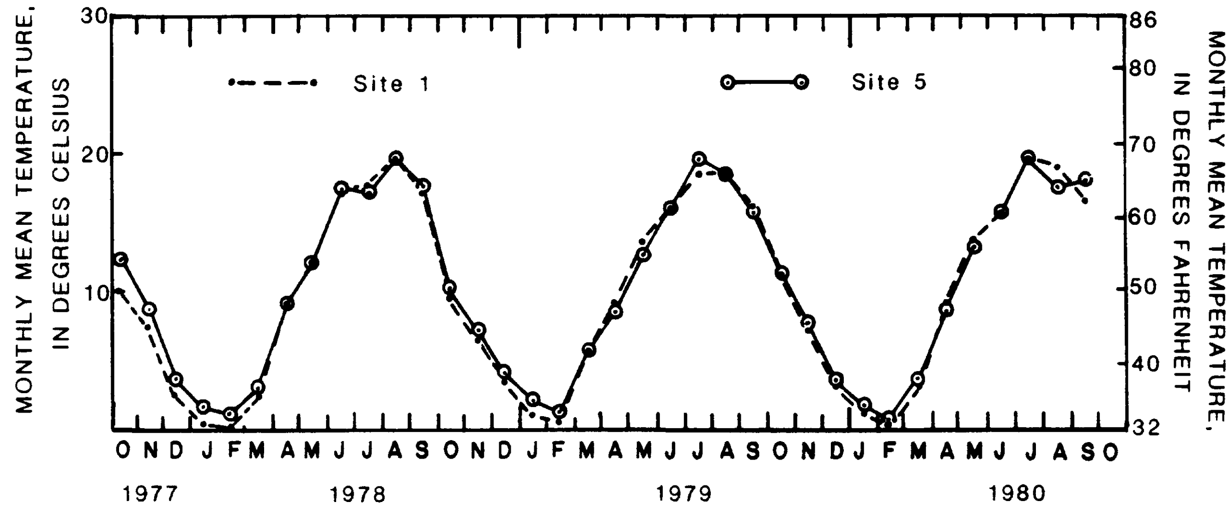


Figure 9.--Mean water temperature for sites 1 and 5, water years 1978-80.

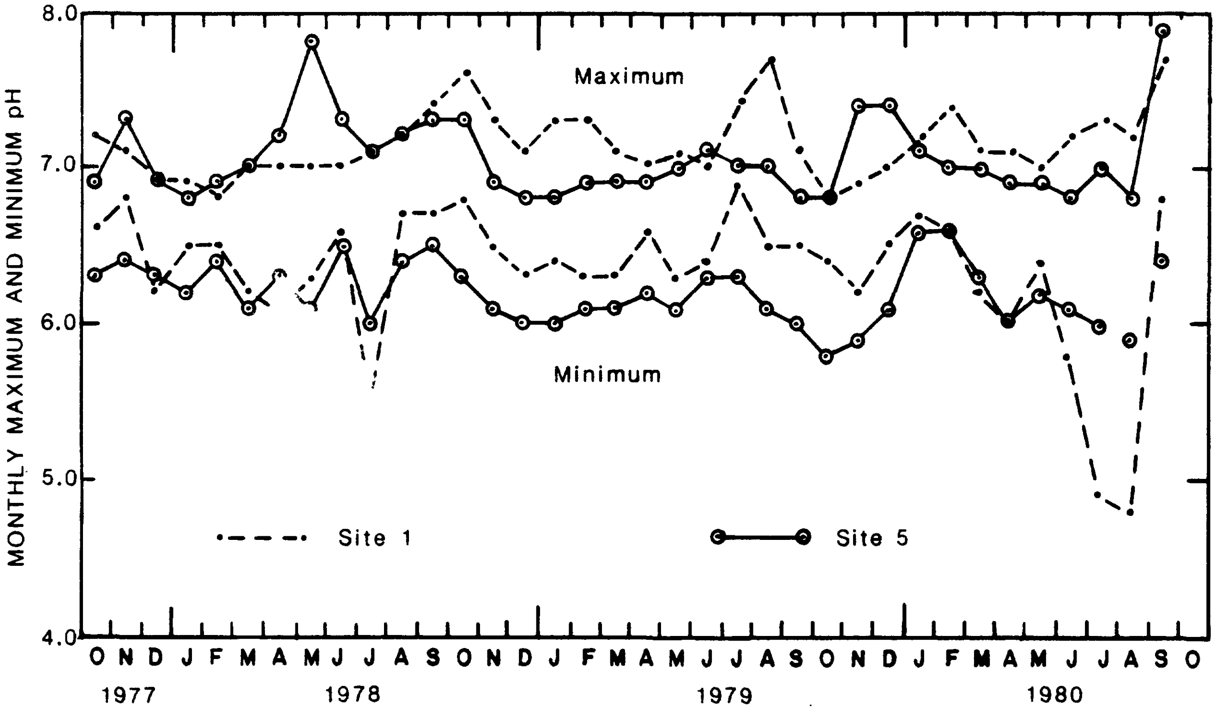


Figure 10.--Maximum and minimum pH at sites 1 and 5, water years 1978-80.

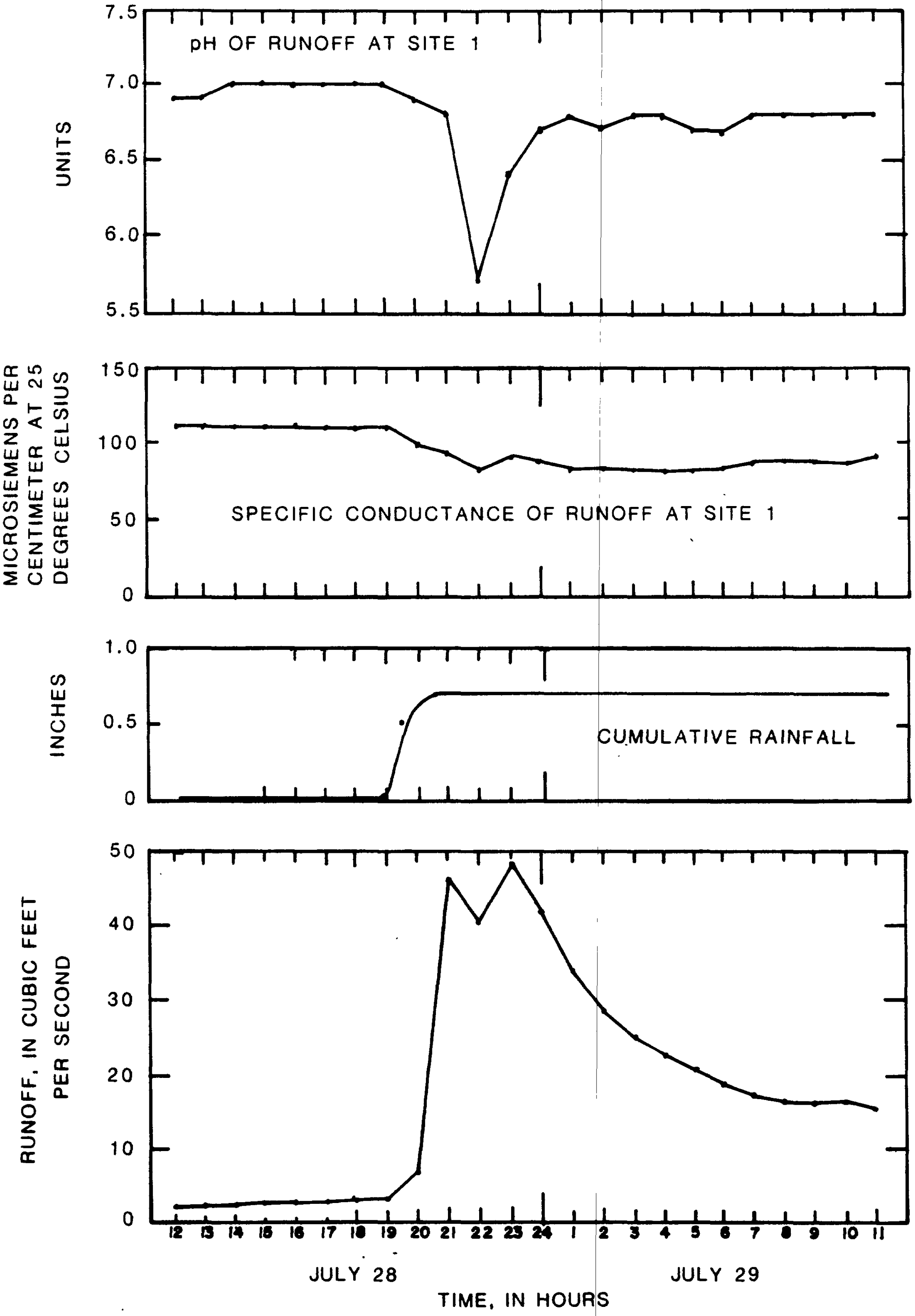


Figure 11.--Streamflow, cumulative rainfall, specific conductance and pH at site 1, during a storm on July 28-29, 1980.

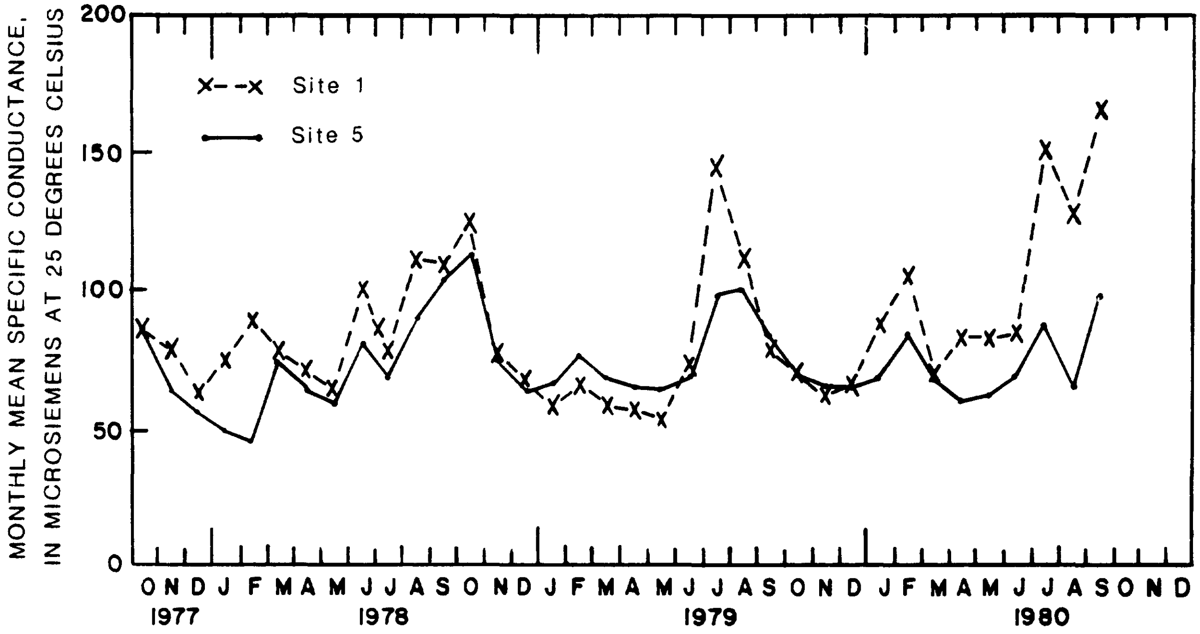


Figure 12.--Mean specific conductance at sites 1 and 5, water years 1978-80.

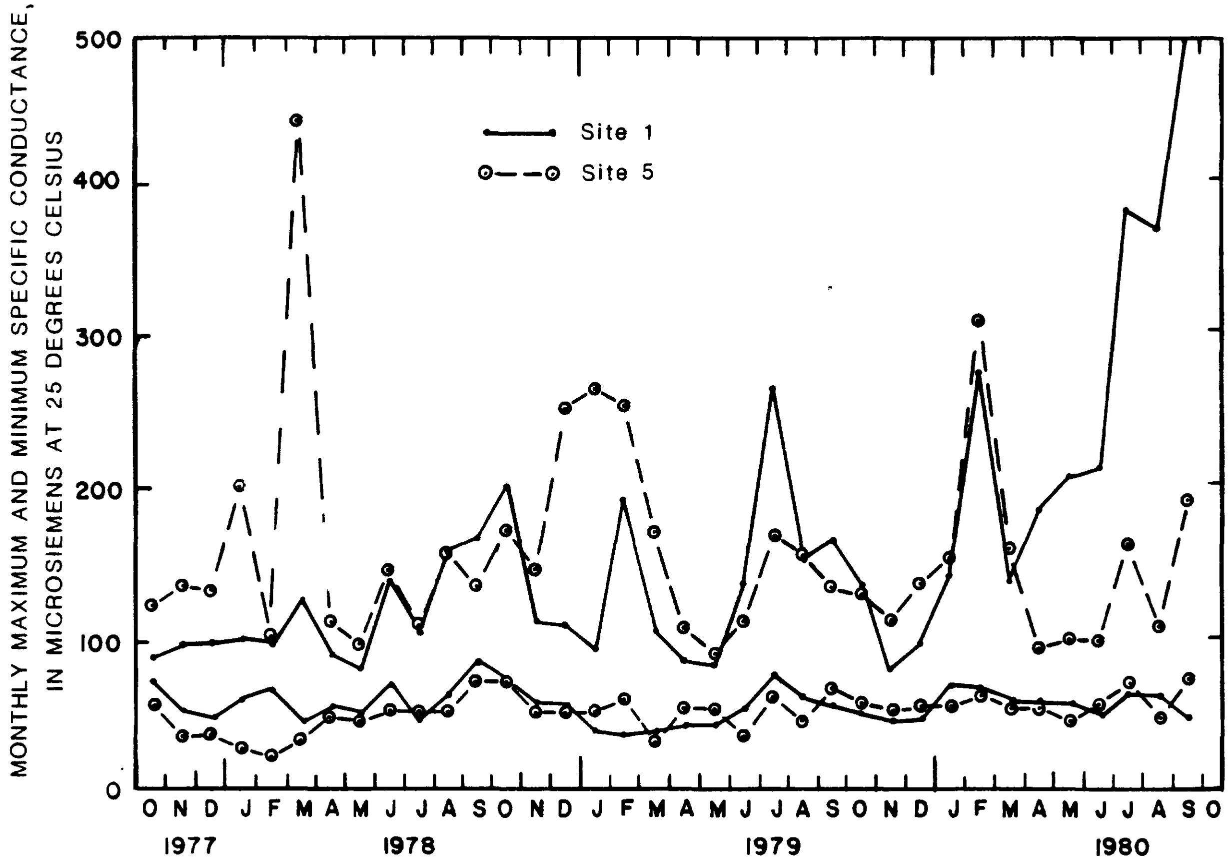


Figure 13.--Maximum and minimum specific conductance at sites 1 and 5, water years 1978-80.

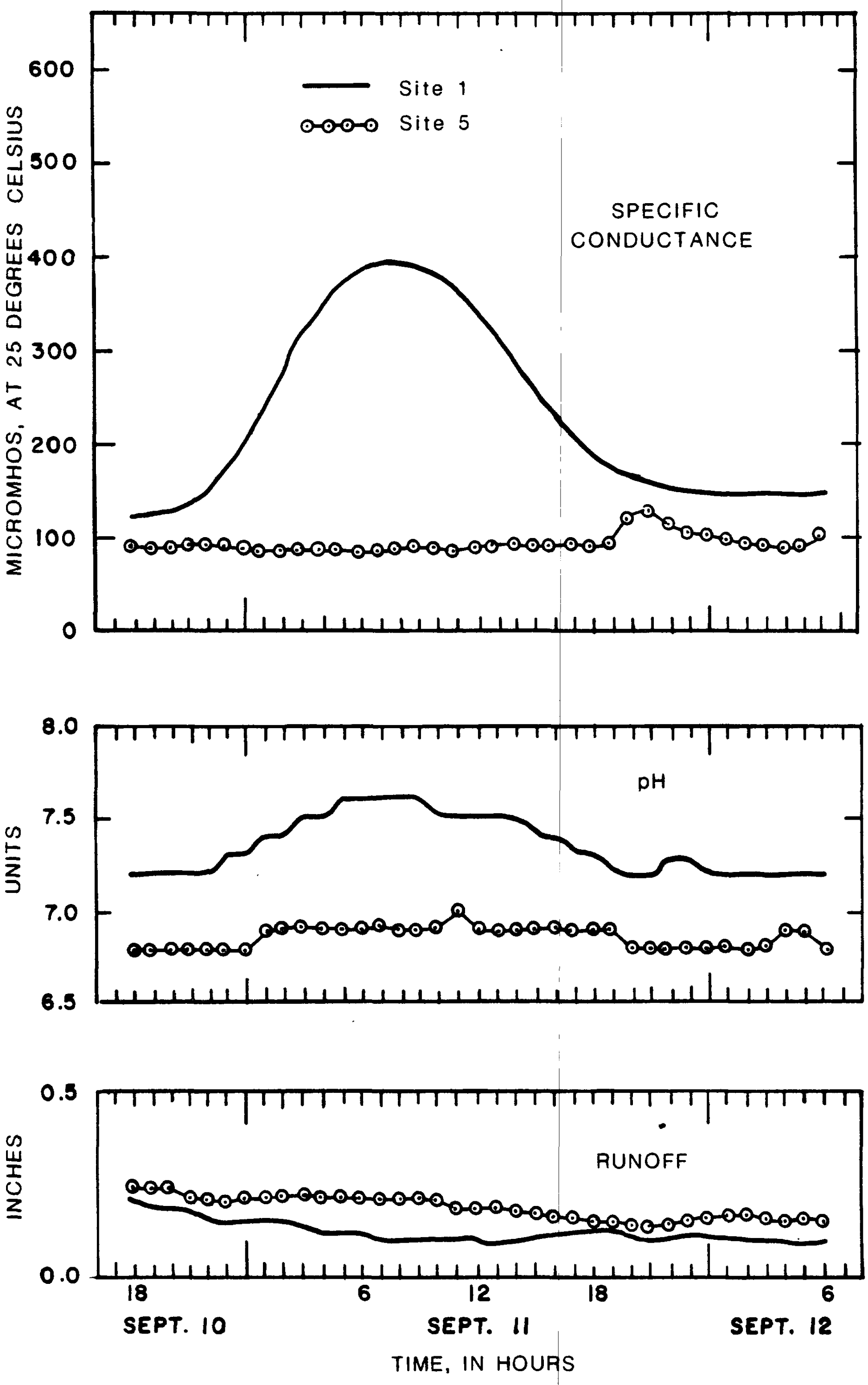


Figure 14.--Specific conductance, pH, and runoff at sites 1 and 5 during September 10-12, 1980.

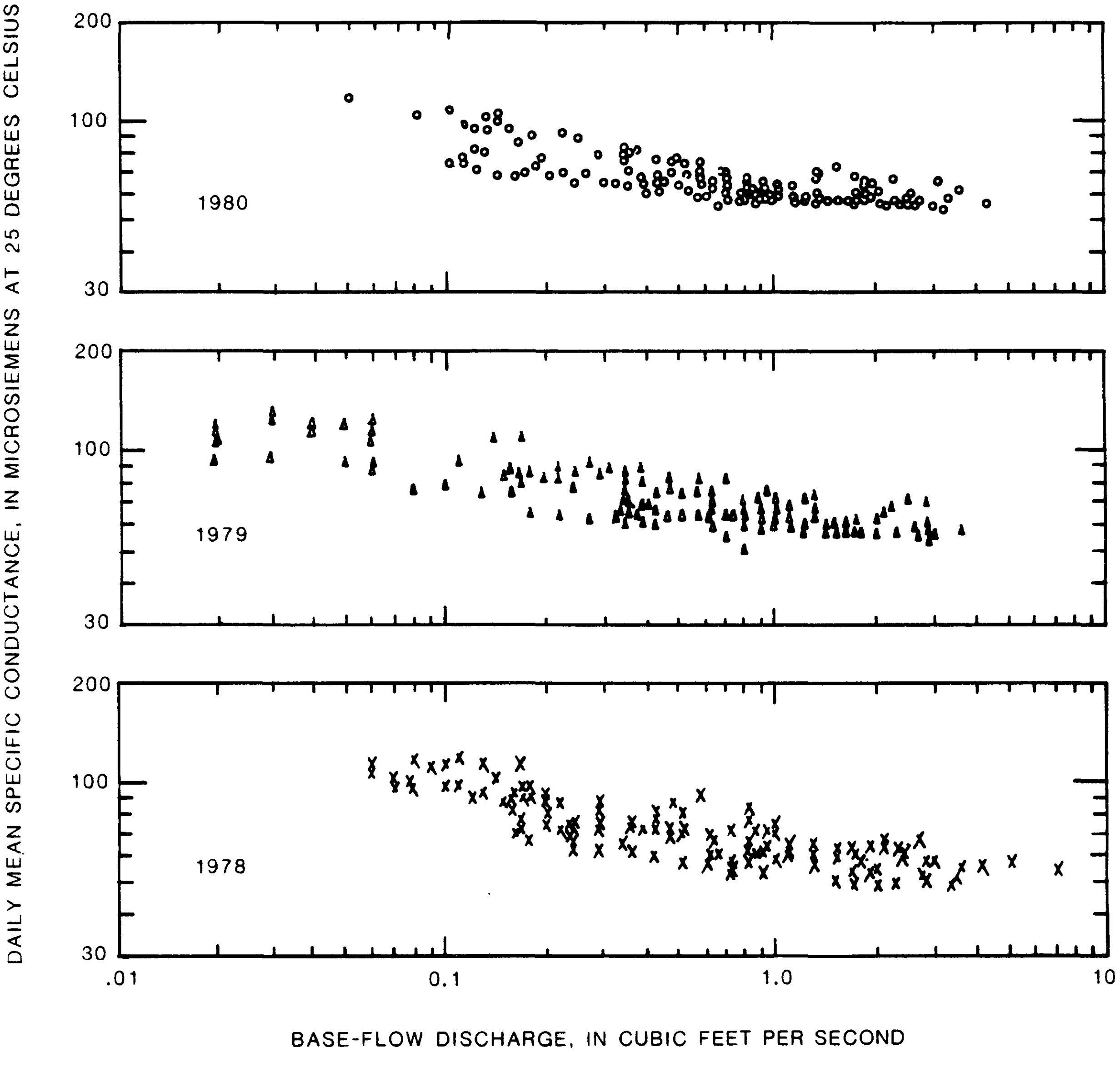


Figure 15.--Relation of specific conductance to base-flow discharge at site 5, water years 1978-80.

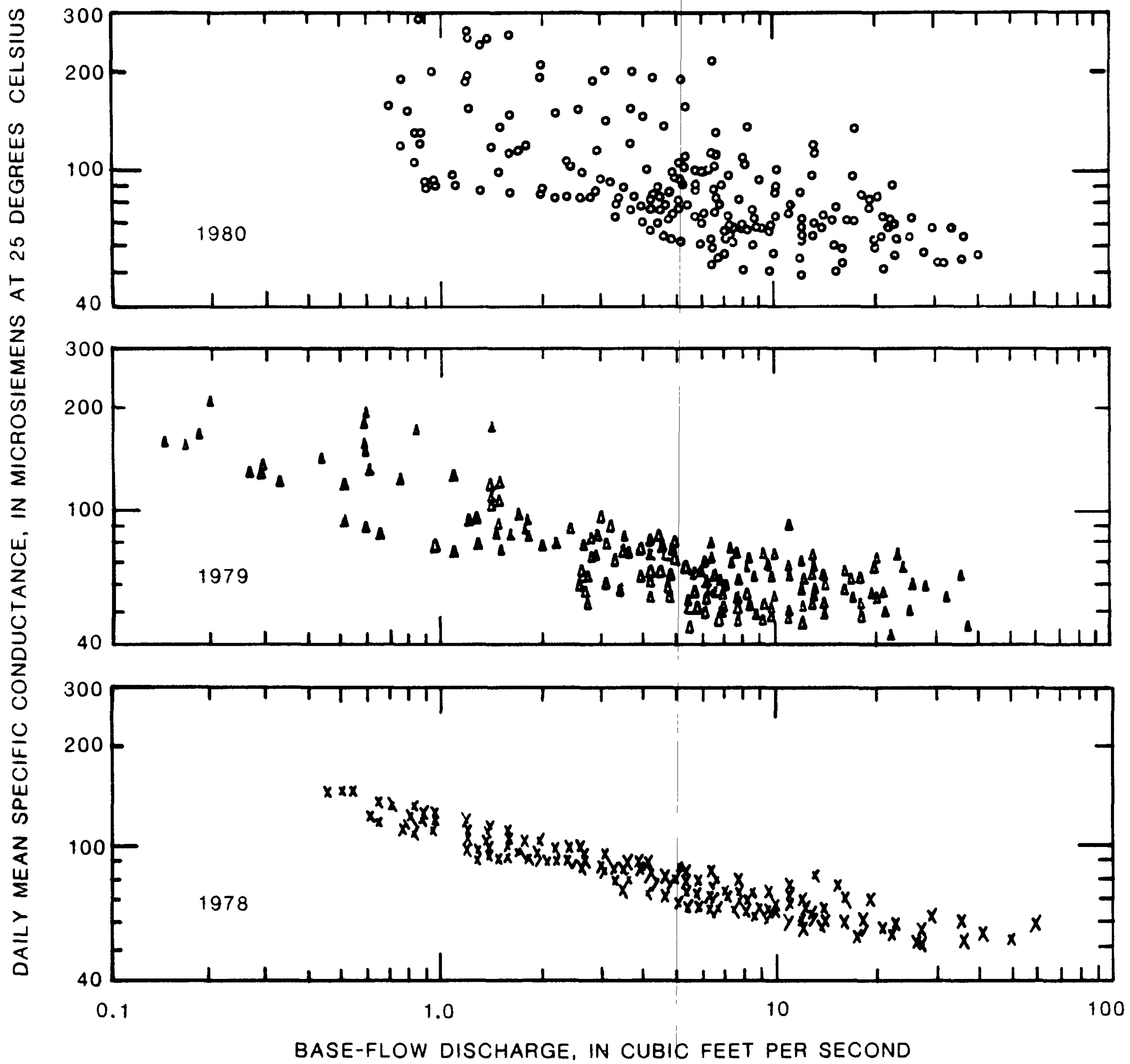


Figure 16.--Relation of specific conductance to base-flow discharge at site 1, water years 1978-80.

Acidity values ranged from a maximum of 14 mg/L at site 3 (table 8) to a minimum of 1 mg/L at sites 1, 2 and 4 (tables 6, 7 and 9). Alkalinity values ranged from a maximum of 118 mg/L at site 2 (table 7) to a minimum of 1 mg/L at sites 1 and 4 (tables 6 and 9). Values of acidity and alkalinity in the study area do not show changes normally associated with mining activity. This may be the result of dilution occurring between a given sampling site and the downstream location. Overall, the water within the study area maintained a low buffering capacity and showed no consistent change during the period of investigation. This may be the result of a relatively small amount of land affected by mining in the basin and the possibility that water quality effects appear as slugs during storm events and therefore may not be observed during monthly sampling.

Dissolved sulfate concentrations ranged from a maximum of 100 mg/L at site 1 (table 6) to a minimum of 3 mg/L at sites 3, 4 and 5 (tables 8, 9 and 10). Higher dissolved sulfate values were found at Stony Fork near Elliottsville (site 1) downstream of the mining activity than at site 5. The higher sulfate values may be the result of high amounts of pyrite commonly present in the coal deposits.

Iron and aluminum are widespread and fairly abundant components of rocks and soils, especially clay soils where it is usually a major constituent. Dissolved aluminum concentrations ranged from a maximum of 500 µg/L at site 5 (table 10) to a minimum of 10 µg/L at sites 1,3, 4 and 5 (tables 6 and 8-10). Dissolved-iron concentrations ranged from a maximum of 840 µg/L at site 2 (table 7) to a minimum value of 50 µg/L at site 1 (table 6). Several values exceeded recommended US EPA and PaDER levels for iron. Site 2, a small tributary to Stony Fork, has the highest dissolved iron values. This site is a pond outflow that drains a reclaimed portion of mine C (fig. 3). This accounts for the high value of dissolved iron. It should be noted that site 1 does not have high iron levels relative to site 5. This condition suggests that the iron is in particulate form and therefore is not observed as dissolved iron during sampling.

Dissolved manganese concentrations ranged from a maximum of 1,370 µg/L at sites 1 and 2 (tables 6 and 7) to a minimum of 50 µg/L at sites 1, 4 and 5 (tables 6, 9 and 10). Dissolved-zinc concentrations ranged from a maximum of 70 µg/L at site 4 (table 9) to a minimum of 10 µg/L at sites 1 through 5 (tables 6-10).

Trace elements are those elements that are found naturally in extremely small quantities. Collection of stream samples for the analysis of dissolved trace elements began in October 1977 and continued semiannually until September 1980. Eleven elements were analyzed: Arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium and silver. Concentrations of arsenic, beryllium, cadmium, chromium, copper, lead and selenium typically were less than 10 µg/L. Cobalt and silver concentrations were less than 1 µg/L. Concentrations of mercury and nickel were less than 0.5 µg/L and less than 20 µg/L, respectively. Concentrations of most trace metals were below the recommended levels established by the Environmental Protection Agency (1977). Table 11 shows the EPA recommended and mandatory water-quality criteria for selected constituents.

Table 11.--Summary of U.S. Environmental Protection Agency recommended and mandatory water-quality criteria

[Values expressed are in micrograms per liter except as indicated.]

Constituent	Recommended limit[1]	Mandatory Limit[2]
alkalinity as $CaCO_3$	>20 mg/L	--
arsenic	--	50
cadmium	--	10
chromium	--	50
copper	100	--
iron	300	--
lead	--	50
manganese	--	50
mercury	--	2
selenium	--	10
silver	--	50
sulfate	250 mg/L	--
zinc	5 mg/L	--

[1] U.S. Environmental Protection Agency (1977, p. 17146).
[2] U.S. Environmental Protection Agency (1975, p. 5957).

A precipitation sample was collected at site 5 for chemical analysis on December 8, 1978, between noon and 5 p.m. Field analyses (pH, alkalinity, acidity, and specific conductance) were done at 5 p.m. as the sample was being prepared for the laboratory (table 12). The precipitation sample, which had a pH of 4.5 and a specific conductance of 12 µS/cm, was poorly buffered (low alkalinity). The acidity of the precipitation sample was only 4 mg/L, which is similar to that of Stony Fork. This data suggests that acid precipitation may be partly responsible for pH depressions during storm runoff.

Although acid precipitation may be responsible in part for pH depressions, this is not the case for increased metal concentrations. Analysis of the rainfall sample shows that generally, the precipitation contained low levels of metals that are associated with acid mine drainage. This suggests that increases in these metals (Aluminum, Iron, Manganese and Zinc) would not be the result of acid precipitation.

Acid-mine drainage remains a major water-quality concern especially in the poorly buffered waters within the study area. As a result of acid-mine drainage, the pH may be lowered sufficiently to keep metals such as aluminum, iron, manganese and zinc in solution. If present in high enough concentrations, these metals, particularly aluminum, can be harmful to aquatic communities. Ferric hydroxide $Fe(OH_3)$, is a common precipitate that occurs as a yellow-orange material (yellow boy) that can coat stream bottoms. This coating can harm the habitats and spawning grounds of fish. Acid-mine drainage can also contribute to increased concentrations of acidity, dissolved solids and dissolved sulfate.

Table 12.--Results of precipitation sample collected at site 5, December 8, 1978

Constituent (in μg/L except as noted)	December 8, 1978 (12 noon to 5 p.m.)
total rainfall (inches)	0.5 inches
field pH (units)	4.5
laboratory pH (units)	4.7
specific conductance (μS/cm at 25°C)	12
acidity, as $CaCO_3$ (mg/L)	4
alkalinity, as $CaCO_3$ (mg/L)	0
sulfate (SO_4) (mg/L)	20
total iron (Fe)	.11
dissolved iron (Fe)	.01
total manganese (Mn)	<.01
dissolved manganese (Mn)	<.01
total aluminum (Al)	.15
dissolved aluminum (Al)	.04
total zinc (Zn)	.09
dissolved zinc (Zn)	.08

As part of the monthly water-quality sampling program, the discharge from an underground mine (site 6, fig. 1), on the northwestern perimeter of surface-mine B (fig. 3), was sampled. The underground mine, 3.5 acres in area, collapsed and was subsequently backfilled as the result of surface-mining operations at mine B. The disturbance of the coal pillars and overburden in the underground mine exposed new rock and coal surfaces to weathering, which caused increases in acidity and sulfate and iron concentrations. Differences in the quality of the underground mine discharge in samples collected in June and July 1978 were noted. Between July 1978 and August 1979, the quality differed because mine B operations in the area channeled surface runoff though the underground mine and pumpage of sub-surface drainage occurred. A comparison of the quality of samples collected before and after mine collapse is given in table 13. Prior to surface mining of the area, the mean pH was 3.4, and after backfilling the mean pH was 3.6. If only pH were examined, the mine-discharge quality of site 6 would look as if it had returned to premining conditions. However, the pH does not reflect changes in the other chemical properties summarized in table 13. The mean values of specific conductance, acidity, and dissolved sulfate and dissolved iron after backfilling increased 293, 200, 1,300, and 290 percent, respectively, when compared to premining values.

Table 13.--Summary of mine-discharge quality at site 6

Parameter	Mean value*		Difference	Percent change
	Before mine collapse June 1977-May 1978	After mine collapse Oct. 1979-Sept. 1980	(2)-(1)	[(2)-(1)/(1)] x 100
pH	3.4	3.6	+0.2	37 percent
specific conductance (µS/cm at 25°C)	280	1,100	+820	+293
acidity (mg/L) as $CaCo_3$	45	135	+90	+200
dissolved sulfate (mg/L)	44	620	+576	+1,300
dissolved iron (µg/L)	4.4	17	+12.6	+290

*for pH the value represents the negative, base 10 logarithm of the mean hydrogen ion concentrations.

SUMMARY

With increased demand for coal, several surface mines began operations in the Stony Fork watershed. The area disturbed by surface mining increased from 0.5 to 5.5 percent of the study area from October 1977 through September 1980. The U.S. Geological Survey, in cooperation with the Pennsylvania Department of Environmental Resources, investigated the effects of mining on the Stony Fork watershed.

Streamflow, suspended-sediment, and water-quality data collected at gaging stations upstream and downstream of mined areas indicate hydrologic changes have occurred in the watershed as a result of mining. Total runoff measured at the gaging stations changed slightly; however, this change may not reflect mining during the study period, but rather the error of measurement for runoff. Surface mining increased the suspended sediment yield during storms as a result of reclamation activities, which placed highly erodible soils on overburden before vegetation could be established. The suspended-sediment-yield ratio at site 1 nearly doubled following surface mining. Specific conductance was highly variable during storm runoff but generally varied inversely with flow and increased slightly during the study period. Treatment of mine drainage before it leaves the mines increased the specific conductance of baseflow periods. No significant variations of pH occurred between sites 1 and 5. The pH ranged between 7.9 and 4.8; values below 6.0 usually occurred during storm runoff periods. An analysis performed on a precipitation sample suggests that acid precipitation may be partly responsible for reduced pH during storms.

Higher mean values of dissolved sulfates and zinc at site 1, relative to site 5, suggest that mining activity increased the concentrations of these constituents. However, dissolved iron and aluminum concentrations generally remained below recommended limits. The remaining chemical properties do not show significant trends between sites 1 and 5.

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GLOSSARY

Base-flow.--Sustained or fair weather runoff. In most streams, base-flow is composed largely of groundwater effluent.

Bedrock.--Unbroken solid rock, overlaid in most places by soil or rock fragments.

Calcareous.--Containing calcium carbonate.

Cubic feet per second per square mile.--The average number of cubic feet of water per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area.

Drainage basin.--A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Evapotranspiration.--Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Gaging station.--A particular site on a stream, canal, lake or reservoir where systematic observations of gage height or discharge are obtained.

Hydrograph.--A graph showing stage, flow, velocity or other property of water with respect to time.

Infiltration.--The flow of a fluid into a substance through pores or small openings.

Overburden.--Rock and strata above the zone of interest.

Precipitation.--The discharge of water in liquid or solid state, out of the atmosphere, generally on a land or water surface.

Rainfall.--The quantity of water that falls as rain only.

Recession.--The part of a hydrograph showing the decreasing rate of runoff following a period of rain or snowmelt.

Regression line.--The plot of a line which best represents the trend of the data.

Runoff.--That part of the precipitation that appears in surface streams.

Sediment.--Fragmental material that originates from the weathering of rocks that is transported, suspended, or deposited, by water or air in beds by other natural agents.

Sediment discharge.--The rate at which dry weight of sediment passes a section of a stream or the quantity of sediment, as measured by dry weight, or by volume, that is discharged in a given time.

Soil.--All unconsolidated materials above bedrock.

Soil moisture.--Water diffused in the soil; the upper part of the zone of aeration from which water is discharged by the transpiration of plants or by soil evaporation.

Streamflow.--The part of surface runoff traveling in a stream whether or not it is affected by diversion or regulation.