

# EFFECTS OF SURFACE MINING ON THE HYDROLOGY AND BIOLOGY IN THE STONY FORK BASIN, FAYETTE COUNTY, PENNSYLVANIA, 1978-85

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## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	by	To obtain
<u>Length</u>		
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
<u>Area</u>		
acre	0.4047	hectare
square mile (mi <sup>2</sup> )	2.590	square kilometer
<u>Flow</u>		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
<u>Mass</u>		
ton, short	0.9072	megagram
ton per square mile (ton/mi <sup>2</sup> )	0.3503	megagram per square kilometer
<u>Temperature</u>		
°C=5/9 (°F-32)		

**Sea level:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

**Abbreviated water-quality units used in report:**

- milligrams per liter (mg/L)
- micrograms per liter (µg/L)
- microsiemens per centimeter at 25 degrees Celsius (µS/cm)
- tons per square mile per year (ton/mi<sup>2</sup>)/yr

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## ABSTRACT

The effects of surface coal mining on the water quality, sediment discharge, and aquatic biology of streams in the Stony Fork Basin in southwestern Pennsylvania were studied from 1978 through 1985. Data were collected at five stream sites and one mine discharge site. Field data included streamflow, temperature, specific conductance, pH, acidity, and alkalinity. Laboratory analyses included sulfate, aluminum, iron, manganese, zinc, and selected trace elements.

Annual streamflow at gaged sites was not substantially different, suggesting that mining did not affect the total volume of streamflow significantly. Comparisons of sediment yields of the upstream control site (site 5) to the downstream site (site 1) indicated that the sediment yield at site 5 was greatest in 1978, 1981-83, and 1985. The sediment yields at both sites in 1979-80 were about the same. Differences in the drainage area sizes and effective control of sediment in the mined areas may explain the lack of increased sediment yield at the downstream site.

As mining became more extensive throughout the basin in 1979-80 and later, several water-quality effects were observed downstream. Generally, specific conductance, sulfate, manganese, aluminum, and zinc increased; pH and alkalinity decreased. Acidity and iron typically increased immediately downstream of mined areas. No trace-element concentrations exceeded maximum contaminant levels established by the U.S. Environmental Protection Agency.

Surface mining in the Stony Fork Basin severely affected the stream invertebrate and fish populations. During 1977-84, the number of taxonomic groups of invertebrates at sites affected by mine drainage decreased by 45 to 71 percent; the number of fish species decreased by 81 to 88 percent.

## INTRODUCTION

The Stony Fork Basin in Fayette County in southwestern Pennsylvania (fig. 1) is considered especially sensitive to the effects of coal mining because of its high-quality, cold-water fishery (Pennsylvania Department of Environmental Resources, 1978, p. 679). Although the basin has been extensively mined, the Pennsylvania Department of Environmental Resources (PaDER) has continued to receive many permit applications for additional surface coal mining. The U.S. Geological Survey (USGS), in cooperation with the PaDER, conducted a study of the effects of mining on the hydrology and biology in the basin from water year<sup>2</sup> 1978 through water year 1985. The results of this study will aid the PaDER in the management of surface mining in the Stony Fork Basin and other similar basins.

### Purpose and Scope

This report presents an evaluation of the effects of surface coal mining on streamflow, suspended sediment, chemistry, and aquatic biology in the Stony Fork Basin. The evaluation is based on data collected at five stream sites and one mine discharge site during 1978-85. The chemistry, sediment, and biological characteristics of the six sites are described and the trends of these characteristics are defined.

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<sup>1</sup> Pennsylvania Department of Environmental Resources, 400 Waterfront Drive, Pittsburgh, Pa., 15222.

<sup>2</sup> A water year is a 12-month period, October 1 through September 30, designated by the calendar year in which it ends. In this report, years are water years unless otherwise noted.

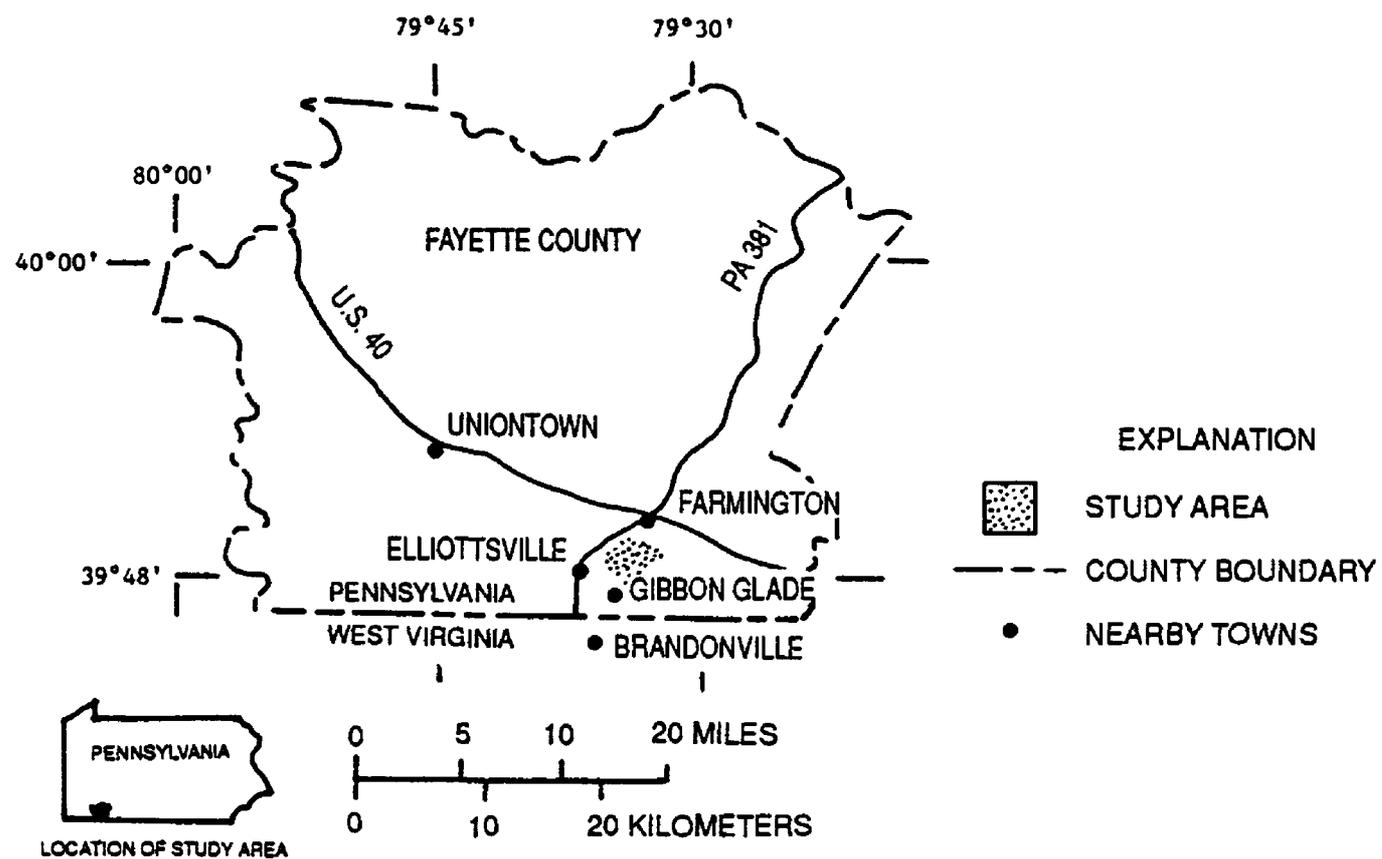


Figure 1. Location of Stony Fork Basin.

### Description of Stony Fork Basin

#### Physiography, Land Use, and Climate

Stony Fork drains 7.44 mi<sup>2</sup> in Wharton Township, Fayette County, and is south of U.S. Route 40 between the towns of Farmington and Elliottsville (fig. 1). State Route 381 traverses the basin. The basin is between Chestnut Ridge and Laurel Hill in the Ohiopyle Valley of the Allegheny Mountain section of the Appalachian Plateau physiographic province (Hickok and Moyer, 1971, p. 20-21). Slopes are gentle to steep, and the maximum relief is about 520 ft. Elevations range from more than 2,100 ft above sea level in the northern part to less than 1,640 ft along the floodplain of Stony Fork in the western part of the basin. Land use is about 40 percent cropland and pasture and 60 percent forest. The area disturbed by coal mining ranged from 1.9 to 11.3 percent during the investigation. The climate is classified as humid continental. Summers are mild to warm and humid, with occasional heavy thundershowers. Winters are generally cold with short periods of temperatures below 0°F. Precipitation is evenly distributed throughout the year. Annual precipitation during 1978-85 ranged from 33.0 in. in 1982 to 48.8 in. in 1984 and averaged 42.8 in.

#### General Geology and Coal Seams

Bedrock units in the Stony Fork Basin consist of shales, sandstones, limestones, and coals that belong to the Allegheny Group and the overlying Conemaugh Group of Pennsylvania age. Structurally, the units are folded, forming on the Preston anticline that lies about midway between the Chestnut Ridge anticline and the Laurel Hill anticline (Hickok and Moyer, 1971). Several coal seams are mined in the study area; the most important are the Brush Creek and Mahoning coals in the Glenshaw Formation of the Conemaugh Group and the Upper Kittanning coal of the Allegheny Group (fig. 2). Minor coal seams are in the Freeport Formation of the Allegheny Group. The Brush Creek coal lies 100 to 125 ft above the top of the Allegheny Group. The coal is 1 to 3 ft thick, and, in some places, overlain by several feet of black shale. The three Mahoning coals are from 0 to 5 ft thick and variable in extent. The upper coal is about 1 ft thick and the two lower coals are each about 2 ft thick, separated by as much as 6 ft of shale. The Upper Kittanning coal is 1 to 5 ft thick. The roof generally consists of sandy shale or thin-bedded sandstone, and the floor consists of black shale or clay (Hickok and Moyer, 1971). Limestone is present in the overburden and below the Upper Freeport coal seam. Pyrite lenses are found near the base of the Brush Creek seam and within the Mahoning and Upper Freeport seams.

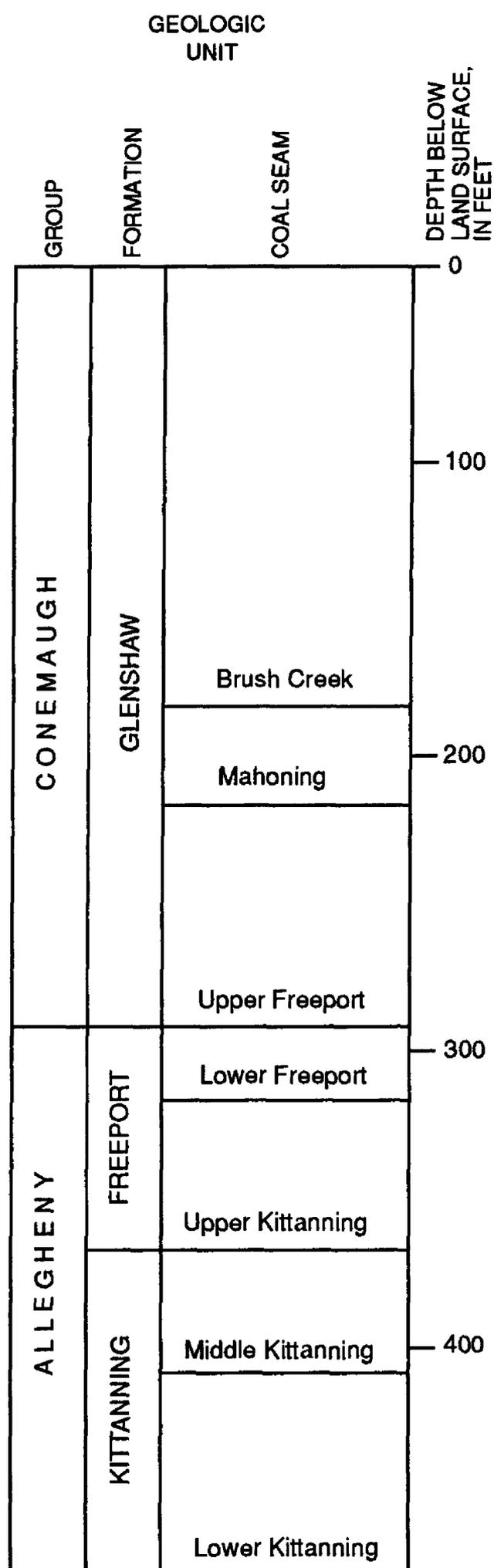
## Surface Mines and Mining Methods

Six mine sites are located in the area of investigation (fig. 3). The total area disturbed by surface mining increased from about 1.9 percent to about 11.3 percent (89 acres to 539 acres) of the basin between October 1977 and September 1985. Characteristics of the mines are given in table 1. Mine reclamation methods include backfilling and seeding disturbed areas.

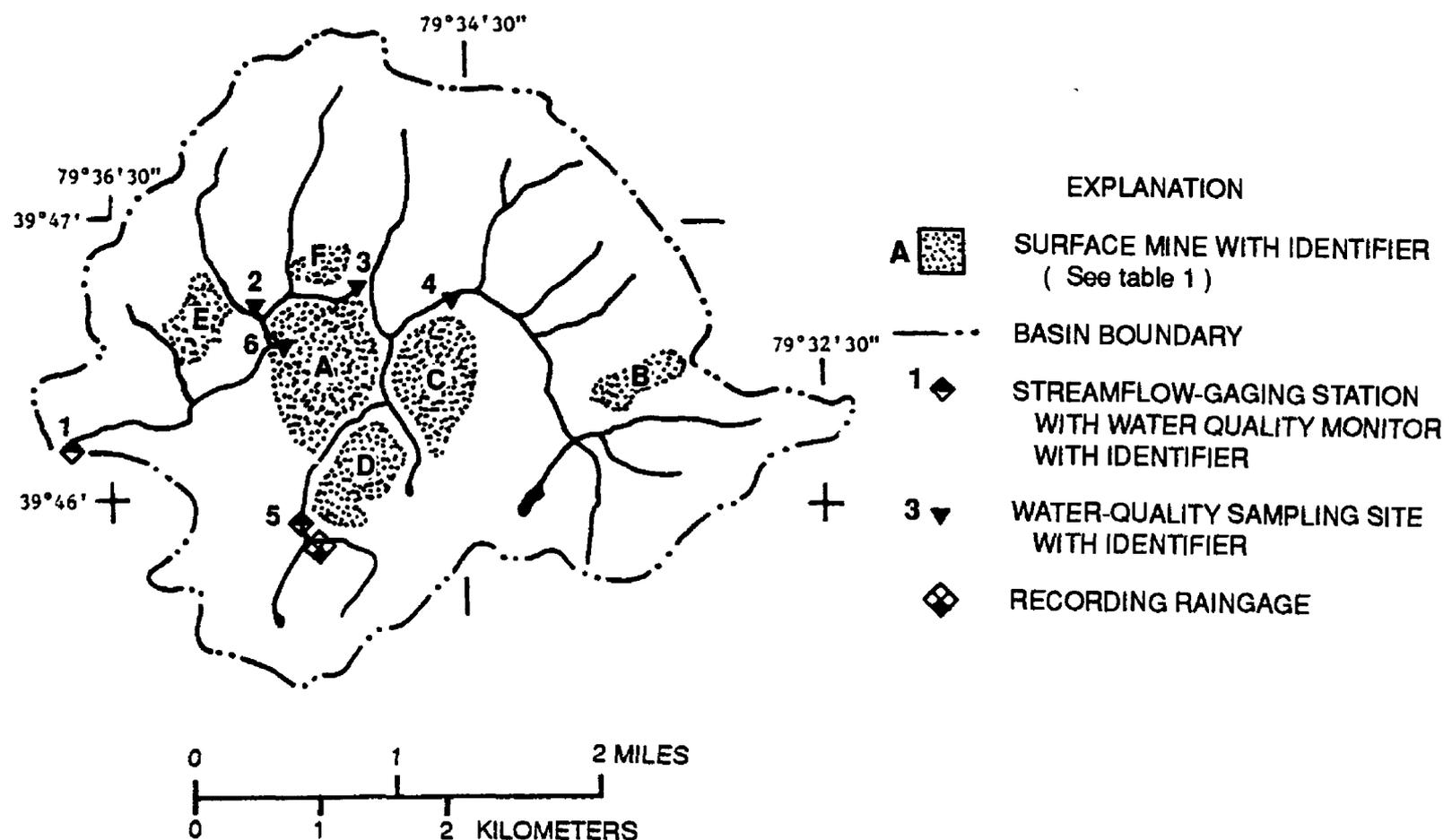
Each of the six mines in the Stony Fork Basin were active for at least 1 year during the 8-year study (table 1). Parts of mine A were intermittently active during the study, while other parts were backfilled and seeded. Mine B was active from May 1979 through December 1980. Mine C was opened in August 1983 and was operated continuously until October 1984 when reclamation backfilling and seeding was initiated. Reclamation was finished in March 1985. Mine D began operations in January 1985 and was still active in September 1985. Mine E was opened in March 1978 and mining continued until March 1979, when backfilling began. Backfilling was completed in September 1979, when seeding began. Operations at mine F began in 1975 and continued intermittently until June 1978. The mine was backfilled from June to September 1978, when the backfilled area was seeded with rye grass (Stump and Mastrilli, 1985, p. 5).

Contour and haul-back mining were the methods used in the basin. These methods are applicable because the mined coal beds have gentle slopes and thin overburden. In contour mining, overburden excavation proceeds along a constant land surface elevation following the topography of 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. Mining continues until removal of the overburden becomes too expensive. The high ridge of overburden along the down-slope perimeter of the mined area is subject to erosion, landslides, and weathering. Runoff and erosion were controlled by constructing a diversion at the base of the ridge to transport surface-water runoff to a sedimentation pond with enough retention time to allow suspended particles to settle.

In haul-back mining, the excavation is made perpendicular to contours of the land surface. 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. Generally, less overburden is exposed in haul-back mining than in contour mining. Erosion, landslide, and mineral-decomposition problems are reduced, and reclamation costs are less for haul-back than contour mining because the overburden material is handled only once. Runoff in haul-back mining is controlled by constructing a diversion and a sedimentation pond similar to those described for contour mining.



**Figure 2.** Typical geologic section showing relative positions of coal seams in the Stony Fork Basin.



**Figure 3.** Surface mines and data-collection sites in the Stony Fork Basin.

**Table 1.** Prior land use, mining methods, and period of mining for surface mines in the Stony Fork Basin

[Locations of mines are shown in figure 3.]

Surface mine	Prior land use or cover	Mining method	Period of mining
A	Pasture and forest	Contour	Sept.-Dec. 1977, Mar. 1978 - <sup>1</sup>
B	Forest	Haul-back	May 1979 - Dec. 1980
C	Forest	Contour	Aug. 1983 - Oct. 1984
D	Forest	Haul-back	Jan. 1985 - <sup>1</sup>
E	Forest	Contour	Mar. 1978 - Mar. 1979
F	Pasture	Contour	1975 - June 1978

<sup>1</sup> Still active at end of investigation.

### Previous Investigations

Hickok and Moyer (1971) described the geology and mineral resources of Fayette County. The U.S. Department of Agriculture, Soil Conservation Service (1973), identified the surface and subsurface soil characteristics and composition within Fayette County. Ward (1977) described the geographic and environmental characteristics of part of the Big Sandy Basin, which includes the Stony Fork Basin.

Stump and Mastrilli (1985) discussed the effects of surface mining on streamflow, suspended sediment, and water quality in the Stony Fork Basin from October 1977 through September 1980. Mastrilli and Stump (1986) reported on the effects of surface coal mining on suspended-sediment discharge in a small watershed in the Stony Fork Basin. Reed and others (1985) described the trap efficiency of a sediment-control pond below a block-cut mine in the watershed.

### Acknowledgment

Eugene Hess of the PaDER, Bureau of Mining and Reclamation, provided much technical advice throughout the investigation. His assistance was greatly appreciated.

## SAMPLING SITES AND METHODS OF DATA COLLECTION

Five stream sites and one mine-drainage discharge site (fig. 3) (table 2) were selected for data collection to monitor drainage areas that would be affected to different degrees by mining. Site 1, Stony Fork near Elliottsville, is downstream from all mining in the basin. Site 2, Stony Fork tributary number 4 near Elliottsville, is downstream from a pond that collects drainage from mine E. Site 3, Stony Fork at Bethel Chapel near Elliottsville, is downstream from mines B, C, and D. Site 4, Stony Fork near Farmington, is downstream from mine B. Site 5, Stony Fork tributary near Gibbon Glade is upstream from all mining. Site 6 is at the outflow of an abandoned underground mine on the northwestern perimeter of surface mine A. The 3.5-acre mine had collapsed and was subsequently backfilled in 1978 as the result of operations at mine A.

Field measurements at each site included streamflow, pH, specific conductance, temperature, alkalinity, and acidity. Streamflow was recorded every 15 minutes at sites 1 and 5 throughout the study and at site 4 from July 1980 through November 1981. Streamflow was computed by use of standard methods outlined by Rantz (1982). Stream temperature measurements were made by use of a calibrated, handheld mercury thermometer. Field pH and specific conductance were measured by use of standard field meters. All field meters were calibrated daily according to manufacturers' specifications prior to field measurements. Field alkalinity and acidity were determined by electrometric titration as described by Fishman and Friedman (1989). Hydrologic data collected at the six sites were published annually in U.S. Geological Survey Water-Data Reports (Lescinsky and others, 1978-85). During 1978-84, specific conductance, pH, and temperature were measured at 15-minute intervals with USGS flow-through, water-quality monitors at sites 1 and 5. These same constituents were measured monthly at sites 1 and 5 in 1985. Monthly water samples were collected at all sites for laboratory analyses of sulfate, iron, aluminum, manganese, and zinc. Semiannual samples for all sites were also analyzed in the laboratory for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and selenium. All laboratory analyses were done by the PaDER.

Suspended-sediment samples were collected with an automatic sequential pumping sampler activated by a rise in stage at sites 1 and 5 throughout the study. An automatic sampler also was used at site 4 from July 1980 through November 1981. Manual depth-integrated samples were collected monthly at site 4 after November 1981. Suspended-sediment samples also were collected monthly at sites 2, 3, and 6. At sites 1, 4, and 5, depth-integrated samples were collected manually at verticals along a cross section of the stream near the pump-sampler intake to compare method results. The depth-integrated samples were assumed to be representative, and the comparison between results was used to determine corrections applied to the pump-sample results. Sediment concentrations were determined at the USGS sediment laboratory in Harrisburg, Pa., by the filtered dry-weight method (Guy, 1969). Daily suspended-sediment concentrations and discharges for sites 1, 4, and 5 were calculated by the methods described by Porterfield (1972).

Precipitation was measured continuously at site 5 with a recording rain gage. Precipitation records from the National Weather Service station at Brandonville, W. Va. (7 mi south of the study area) were used for periods of missing record at site 5. Three precipitation-quality samples were collected during the study.

Benthic-invertebrate and fish samples were collected quarterly to determine mining effects on aquatic life. Data collection methods are described on page 29 of this report.

**Table 2. Data-collection sites in the Stony Fork Basin**

[Location of sites are shown in figure 3.]

Site number	U.S. Geological Survey station number	Station name	Drainage area (square miles)
1	03070455	Stony Fork near Elliottsville	7.44
2	03070435	Stony Fork tributary No. 4 near Elliottsville	.54
3	03070430	Stony Fork at Bethel Chapel near Elliottsville	4.85
4	03070415	Stony Fork near Farmington	2.50
5	03070420	Stony Fork tributary near Gibbon Glade	.93
6	03070440	Hagar mine discharge near Bauer Estate	—

## EFFECTS OF SURFACE MINING ON HYDROLOGY

Mining began in the basin in 1975. By the beginning of the study in October 1977, 89 acres of land were disturbed. Mining gradually progressed throughout the study period, and the acres of active mines, reclaimed land, and the total combined percentage of both for the basin increased through time (table 3).

Site 1 was the downstream site in the basin below all mining activity, and site 5 was above all mining activity. Streamflow and sediment data collected at both sites were compared to show the total effect of mining on those characteristics. Water-quality data from all mainstem sites (sites 1, 3, 4, and 5), from a tributary site (site 2), and from a mine discharge site (site 6) were compared to show how the mining activity affected the stream quality throughout the watershed.

**Table 3. Mining and reclamation activity in the Stony Fork Basin**

Water year	Mined area (acres)			Total mined area, percentage of basin
	Active	Reclaimed	Total	
1977	89	0	89	1.9
1978	136	43	179	3.8
1979	309	54	363	7.6
1980	186	196	382	8.0
1981	161	221	382	8.0
1982	118	264	382	8.0
1983	162	266	428	9.0
1984	160	301	461	9.7
1985	200	339	539	11.3

### Streamflow

Annual streamflow at site 1 appeared to be unaffected by mining from October 1977 through September 1985. The annual streamflow at sites 1 and 5 for water years 1978-85 differed by less than 5 percent for any year and by only 0.1 in. of the average for the study period (table 4). The difference in mean monthly streamflow between both sites for the same period generally was less than 0.1 in. The magnitudes of the differences shown in table 4 are within the error of streamflow measurement. The average streamflow at sites 1 and 5 was about 25 in. or 59 percent of the average precipitation.

**Table 4. Annual precipitation and streamflow at data-collection sites 1 and 5 in the Stony Fork Basin, 1978-85**

Water year	Precipitation (inches)	Streamflow				Percentage difference 100 - [(site 1/ site 5) × 100]
		Site 1		Site 5		
		Inches	Percentage of precipitation	Inches	Percentage of precipitation	
1978	47.0	27.7	59	28.8	61	+3.8
1979	47.5	28.4	60	27.5	58	-3.3
1980	45.6	25.4	56	25.9	57	+1.9
1981	41.2	24.5	59	25.3	61	+3.2
1982	33.0	21.7	66	20.9	63	-3.8
1983	36.7	21.0	57	21.9	60	+4.1
1984	48.8	26.6	55	25.9	53	-2.7
1985	36.4	22.7	62	22.7	62	.0
Average	42.0	24.8	59	24.9	59	+4

The annual streamflow at site 1 ranged from 21.0 in. during water year 1983 to 28.4 in. during water year 1979. The annual streamflow at site 5 ranged from 20.9 in. during water year 1982 to 28.8 in. during water year 1978. Streamflow measured at site 4 for the 1981 water year was 25.4 in., which was 0.9 in. greater than at site 1 and only 0.1 in. greater than at site 5.

### Suspended Sediment

Surface mining changes several factors affecting erosion rates and can increase the volume of sediment available for transport. Erosion is influenced by soil and rock properties, land slope, length of slope, climate, amount and intensity of rainfall, and the type and percentage of vegetation (Grim and Hill, 1974, p. 101). The particles are detached from the ground mostly by raindrop impact and water movement and transported down slope by flowing water (Haan and Barfield, 1978, p. 178). By increasing slopes, removing vegetative cover, and disturbing rock and soil, surface mining can accelerate erosion and increase the amount of suspended sediment in streams.

Table 5 shows the suspended-sediment discharges and yields at sites 1 and 5 for 1978-85. Sediment discharge is directly related to streamflow, and generally, most sediment is transported during high-flow conditions. At site 5, the maximum annual sediment discharge was in 1978, the year of maximum annual streamflow and maximum peak flow. However, at site 1, downstream of mines, the maximum annual sediment discharge was in 1984, which was not the year with the maximum annual streamflow (1979), nor the year with the maximum peak flow (1981). The maximum sediment discharge during this year suggests that sediment from surface mines was introduced in 1984. A large mine (surface mine C) opened in August 1983 and was in operation during 1984 (see table 1).

The highest monthly mean sediment yield at both stations for 1978-85 was in April each year and was caused by the high streamflow and runoff over thawed soils. Streamflow was also high in December, February, and March, but not as much sediment was transported during those months because erosion is limited in the frozen and snow-covered soils. Some high streamflows in those months were caused by snowmelt, which does not transport as much sediment as rainfall runoff.

**Table 5. Annual suspended-sediment discharge and yield at data-collection sites 1 and 5 in the Stony Fork Basin, 1978-85**

[ft<sup>3</sup>/s, cubic feet per second; ton/mi<sup>2</sup>, ton per square mile]

Water year	Site 1			Site 5			Suspended-sediment yield ratio (SSYR) (yield site 1 / yield site 5)
	Peak flow (ft <sup>3</sup> /s)	Suspended-sediment		Peak flow (ft <sup>3</sup> /s)	Suspended-sediment		
		Discharge (ton)	Yield (ton/mi <sup>2</sup> )		Discharge (ton)	Yield (ton/mi <sup>2</sup> )	
1978	372	1,913	257	126	448	481	0.53
1979	310	1,771	238	34	213	229	1.04
1980	272	2,375	319	62	275	296	1.08
1981	754	1,906	256	114	328	353	.73
1982	252	879	118	34	128	138	.86
1983	242	786	106	44	258	277	.38
1984	719	3,226	434	81	304	327	1.33
1985	302	1,184	159	63	228	246	.65
Average		1,755	236		273	293	.81
	Site 4 - 1981	172	69				

The suspended-sediment yields for sites 1 and 5 (table 5) are fairly low compared to yields from other areas in Pennsylvania. Measured suspended-sediment yields in other areas of Pennsylvania range from less than 100 (ton/mi<sup>2</sup>)/yr in primarily forested watersheds to 1,950 (ton/mi<sup>2</sup>)/yr for an intensively farmed watershed (Wetzel, 1982, p. 27). A suspended-sediment yield ratio (SSYR) was calculated to evaluate the effect of land-use change on suspended-sediment yields upstream and downstream of the mined area. The SSYR is the suspended-sediment yield of the downstream site (site 1) divided by the suspended-sediment yield for the upstream control site (site 5)(table 5). Because the downstream site is affected by mining, the SSYR would be expected to increase as the mined area increased throughout the basin. However, the ratio was less than or nearly equal to 1 in all years except 1984, a year when the opening of a new mine contributed to high sediment yields. One storm on April 4-5, 1984, was responsible for 64 percent of the annual suspended sediment discharged at site 1 and 27 percent of the annual suspended sediment discharged at site 5.

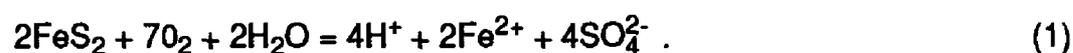
These data suggest that coal mining operations effectively controlled sediment runoff from their sites. Langbein and Schumm (1958) showed that sediment yields in several midwestern drainage basins are inversely proportional to the 0.15 power of the drainage area. If this generalized relation is applied to the Stony Fork Basin, the sediment yield for site 5 would be a factor of  $\left(\frac{1}{0.93}\right)^{0.15}$  or 1.01, and the sediment yield for site 1 would be a factor of  $\left(\frac{1}{7.44}\right)^{0.15}$  or 0.74. As a result, site 5 would be expected to yield 1.36 times the sediment of site 1. For 1978-85, the measured sediment yield at site 5 averaged 1.40 times the sediment yield at site 1.

Data from site 4 demonstrates effectiveness of an upstream sedimentation pond. The 1981 sediment record for the mined basin above site 4 showed a yield of 69 ton/mi<sup>2</sup>, which was well below the yield of 256 and 353 ton/mi<sup>2</sup> for sites 1 and 5, respectively. This pond was shown by Reed and others (1985) to have a trap efficiency of more than 98 percent for four of the five storms measured. The 10.8-acre mined area above the pond had a calculated annual sediment yield of 19,840 ton/mi<sup>2</sup>.

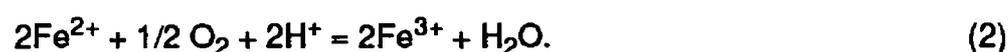
### Water Chemistry

The effects of surface mining on water chemistry were assessed by comparing the median annual concentrations of selected constituents for sites 1-6. Data from sites 1 and 5 are compared because they represent the control site (site 5) and the downstream site with the cumulative effects of all mining in the basin (site 1). Data from sites 2, 3, and 4 are compared because they represent sites with different mined areas during different periods throughout the study. Data from site 6 are plotted separately because they represent the direct effect of mine drainage from an underground mine that could affect water quality at site 1. Potential trends in specific conductance, pH, acidity, alkalinity, and concentrations of sulfate, iron, manganese, aluminum, zinc, and selected trace elements in stream samples from the six sites are identified. The progression of mining (table 3) in the Stony Fork Basin would be predicted to have a measurable effect on many of the water-quality constituents in surface water.

Most of the constituents discussed in this section are either directly or indirectly related to the oxidation of pyrite (FeS<sub>2</sub>), a mineral that is commonly present in coal and the adjacent rock strata. When the overburden is removed and the coal is mined, pyrite is exposed to oxygen and water, initiating the oxidation process and the production of acid mine drainage (AMD). The oxidation of pyrite is described by the following reaction in which pyrite, oxygen, and water form sulfuric acid and ferrous sulfate:



Oxidation of ferrous iron (Fe<sup>2+</sup>) produces ferric ions (Fe<sup>3+</sup>) according to the following reaction:



When the ferric ions react with water, an insoluble ferric hydroxide [Fe(OH)<sub>3</sub>], also referred to as “yellow boy,” and more acid are produced:



The above reactions produce elevated concentrations of the precipitate, insoluble ferric hydroxide [Fe(OH)<sub>3</sub>], dissolved sulfate (SO<sub>4</sub><sup>2-</sup>), and acid (H<sup>+</sup>). Secondary reactions of the acidic water dissolve many other constituents associated with coal deposits, such as manganese, aluminum, zinc and other trace elements. The highly mineralized water collects in mine impoundments and spoil where it eventually evaporates, percolates downward into underlying aquifers, or if uncontrolled, runs off into streams.

Table 6 lists the maximum contaminant levels (MCL's)<sup>3</sup> and the secondary maximum contaminant levels (SMCL's)<sup>4</sup> for drinking water for public-supply systems as established by the U.S. Environmental Protection Agency (USEPA) (1992). Although these standards were established for public-water supplies, they provide guidelines for the assessment of the surface-water quality.

**Table 6. U.S. Environmental Protection Agency maximum contaminant levels and secondary maximum contaminant levels for selected contaminants of drinking water for public supply systems**

[Levels in milligrams per liter except as indicated; --, no data]

Contaminant	Maximum contaminant level <sup>1</sup>	Secondary maximum contaminant level <sup>1</sup>
Arsenic (As)	0.05	—
Cadmium (Cd)	.005	—
Chromium (Cr)	.1	—
Lead (Pb)	.015 (action level)	—
Mercury (Hg)	.002	—
Nickel (Ni)	.1	—
Selenium (Se)	.05	—
Aluminum (Al)	—	0.05 to 0.2
Copper (Cu)	—	1
Iron (Fe)	—	.3
Manganese (Mn)	—	.05
pH	—	6.5 - 8.5
Sulfate (SO <sub>4</sub> )	—	250
Total dissolved solids	—	500
Zinc (Zn)	—	5

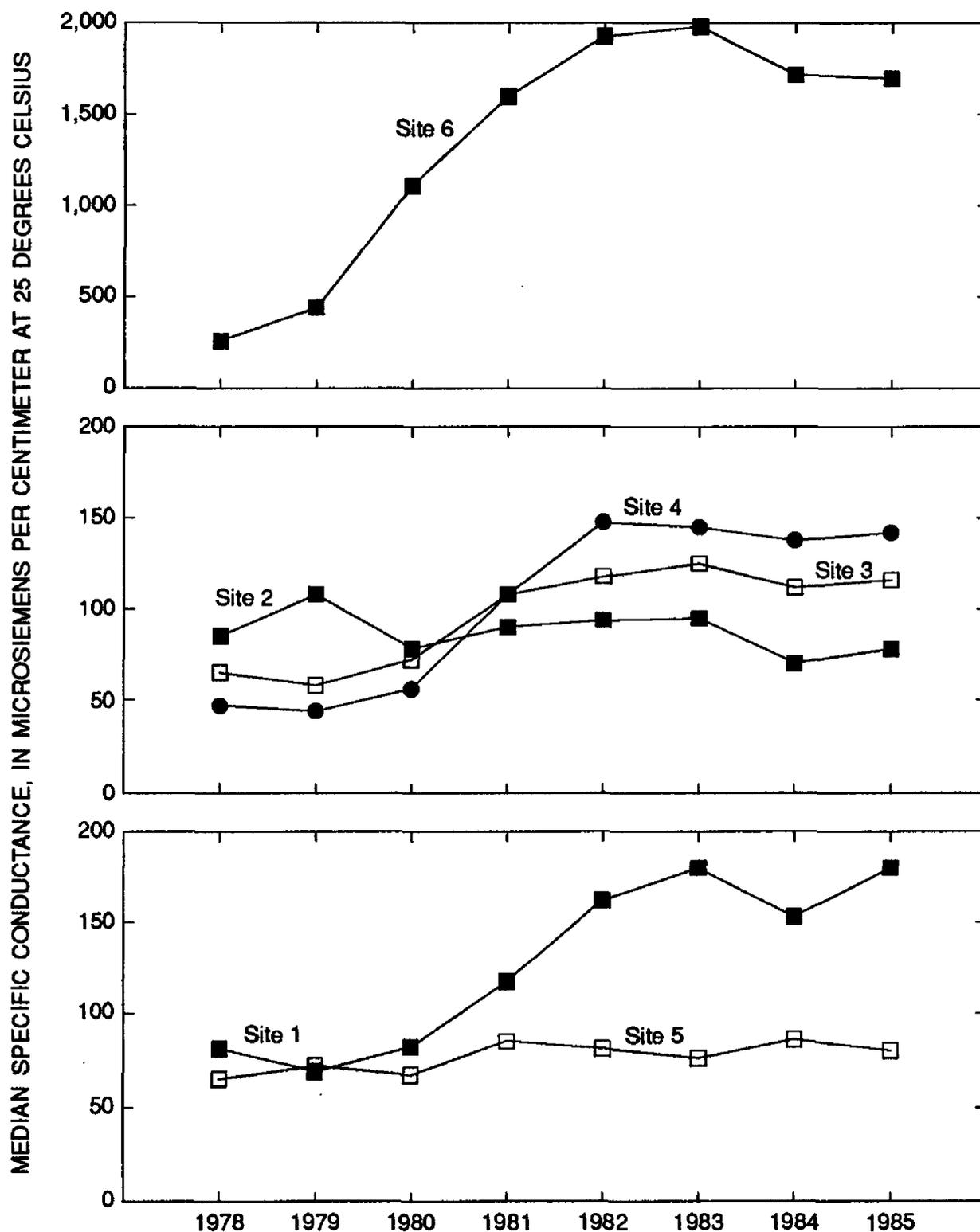
<sup>1</sup> U.S. Environmental Protection Agency, December 1992, Drinking Water Regulations and Health Advisories.

<sup>3</sup> Maximum contaminant levels (MCL's) are levels of drinking-water contaminants that could cause health effects if exceeded, and are enforceable by law.

<sup>4</sup> Secondary maximum contaminant levels (SMCL's) are levels of drinking-water contaminants that are not health related and are intended to protect public welfare by establishing unenforceable guidelines on the taste, odor, or color of drinking water.

### Specific Conductance

Specific conductance is directly related to the dissolved solids concentration. A generalized formula for this relation is  $KA=S$ , where  $K$  is the specific conductance in microsiemens per centimeter at 25°C,  $S$  is the dissolved solids concentration in milligrams per liter, and  $A$  is a factor that varies between 0.55 and 0.75, the higher values generally being associated with water containing elevated sulfate concentrations (Hem, 1985, p. 67). The annual median specific conductance increased noticeably throughout the study period at all sites except 2 and 5 (fig. 4). At site 2, a slight increase in specific conductance from 1978 to 1979 corresponds to the mining above the site in the same years, but the specific conductance decreased in 1980 and remained relatively constant through the remainder of the study. Specific conductance increased significantly at site 6, from a median of 255  $\mu\text{S}/\text{cm}$  in 1978 to a median of 1,980  $\mu\text{S}/\text{cm}$  in 1983. At sites 3 and 4, the specific conductance gradually increased from 1979 through 1982, and then remained relatively constant through 1985. The cumulative effects of the increases in specific conductance at sites 3, 4, and 6 can be seen in the increases at site 1; site 6 had the most significant effect on site 1.

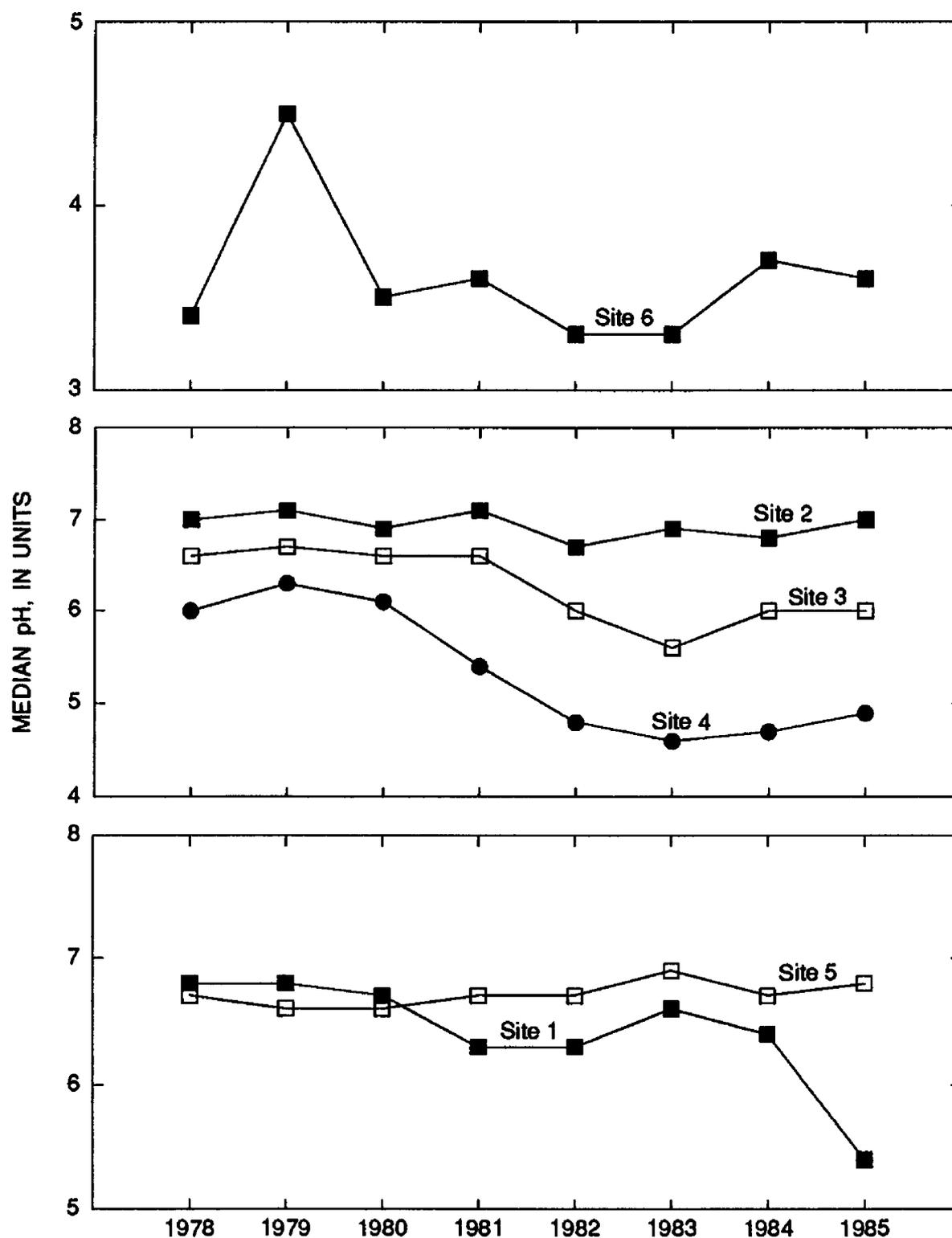


**Figure 4.** Annual median specific conductances for data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.

## pH

The pH of most natural streams generally ranges from 6.5 to 8.5 (Hem, 1985, p. 64). A pH less than 6.5 in mined areas commonly indicates the presence of AMD. Low-pH water can dissolve many of the minerals commonly associated with coal and pyrite, causing elevated concentrations of iron, manganese, aluminum, and zinc. The combined effects of low-pH water and elevated concentrations of metals can be toxic to many forms of aquatic life (Baker and Christensen, 1991).

The annual median pH ranged from 4.5 to 7.5 at the five stream sites and was consistently less than 4.5 at site 6 (fig. 5). Sites 2 and 5 had a median pH greater than 6.5, and the pH at both sites was relatively constant throughout the study. Site 2 drained an area treated with an acid-neutralizing substance. Sites 1, 3, and 4 show a decrease in pH as mining progressed throughout the basin. The pH trends at sites 3 and 4 were very similar. Both sites were mainstem sites and downstream of mine activity. From 1981 through 1985, the pH at site 4 was approximately one unit less than the pH at site 3. The median pH at site 6 was never greater than 4.5 and after 1979, the maximum measured pH never exceeded 4.0, which is indicative of untreated AMD. The most significant change in pH was at site 1 when the median pH decreased from 6.4 in 1984 to 5.4 in 1985.



**Figure 5.** Annual median pH for data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.

## Acidity

Acidity is the measurement of the capacity of water to neutralize a basic solution. Acidity, as used in this report, is primarily caused by the presence of hydrogen ions produced by the hydrolysis of the salts of strong acids and weak bases.

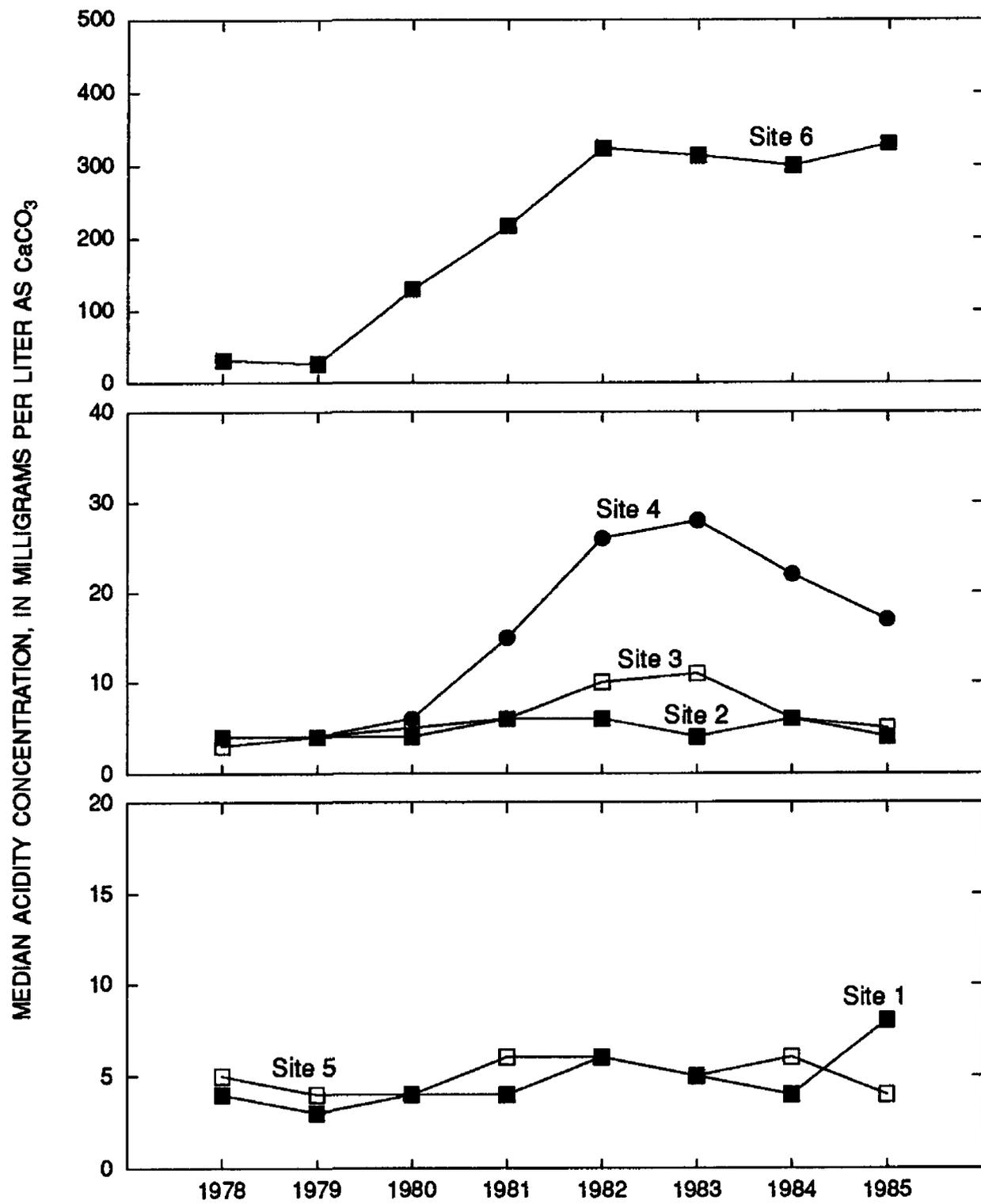
Acidity, as  $\text{CaCO}_3$ , ranged from 1 mg/L at stream sites to 420 mg/L at the mine-drainage site (site 6). The maximum acidity, excluding those at site 6, was 89 mg/L at site 4. Because acidity at the site unaffected by mining (site 5) was low and the annual median acidity remained low (4-6 mg/L) throughout the study period (fig. 6); any substantial increase in acidity at sites 1-4 was assumed to have been caused by mining.

Annual median acidity was low (3-6 mg/L) and almost constant at sites 1-5 during 1978-80 (fig. 6). The annual median acidity at sites 1 and 5 was very similar during 1978-84 and never exceeded 6 mg/L. In 1985, however, the median acidity at site 1 increased to 8 mg/L. This increase was caused by elevated acidities (20-58 mg/L) measured in July through September as a result of mine seepage upstream. In 1981-83, the annual median acidity at site 4 increased to 15, 26, and 28 mg/L, respectively, and then decreased to 22 and 17 mg/L in 1984 and 1985. Acidity at site 3 also increased during 1981-83 and then decreased in 1984, but the maximum annual median acidity was only 11 mg/L.

The increase in acidity at sites 3 and 4 is related to the mining upstream from the sites, but there is no correlation between the period of mining and when the acidity increased.

Acidity at site 6 was always greater than acidity at the other five sites. The annual median acidity at site 6 ranged from 26 mg/L in 1979 to 330 mg/L in 1985. The median acidity at site 6 was 45 mg/L during 1978-80 and 300 mg/L during 1981-85. The increases in acidity at sites 4 and 6 after 1981 seemed to have little effect on acidity at site 1 except perhaps during extremely low flow when the acidity at site 6 contributes a major percentage of the acidity at site 1. However, acidity at site 1 increased substantially in late 1985 because of sources between site 1 and site 3.

Figure 6 shows that the annual median acidity decreased in a downstream order at the mainstem sites (sites 4, 3, and 1). The increase in basin size and the corresponding increase in dilution from non-mined areas was probably the main cause for the decrease in acidity. The only exception was at site 1 where the acidity increased from 1984 to 1985 while the acidity at sites 3 and 4 was decreasing. The strong relative effect of site 6 on water quality at site 1 is demonstrated by the increase in acidity at both sites while acidities at sites 2, 3, and 4 were decreasing.

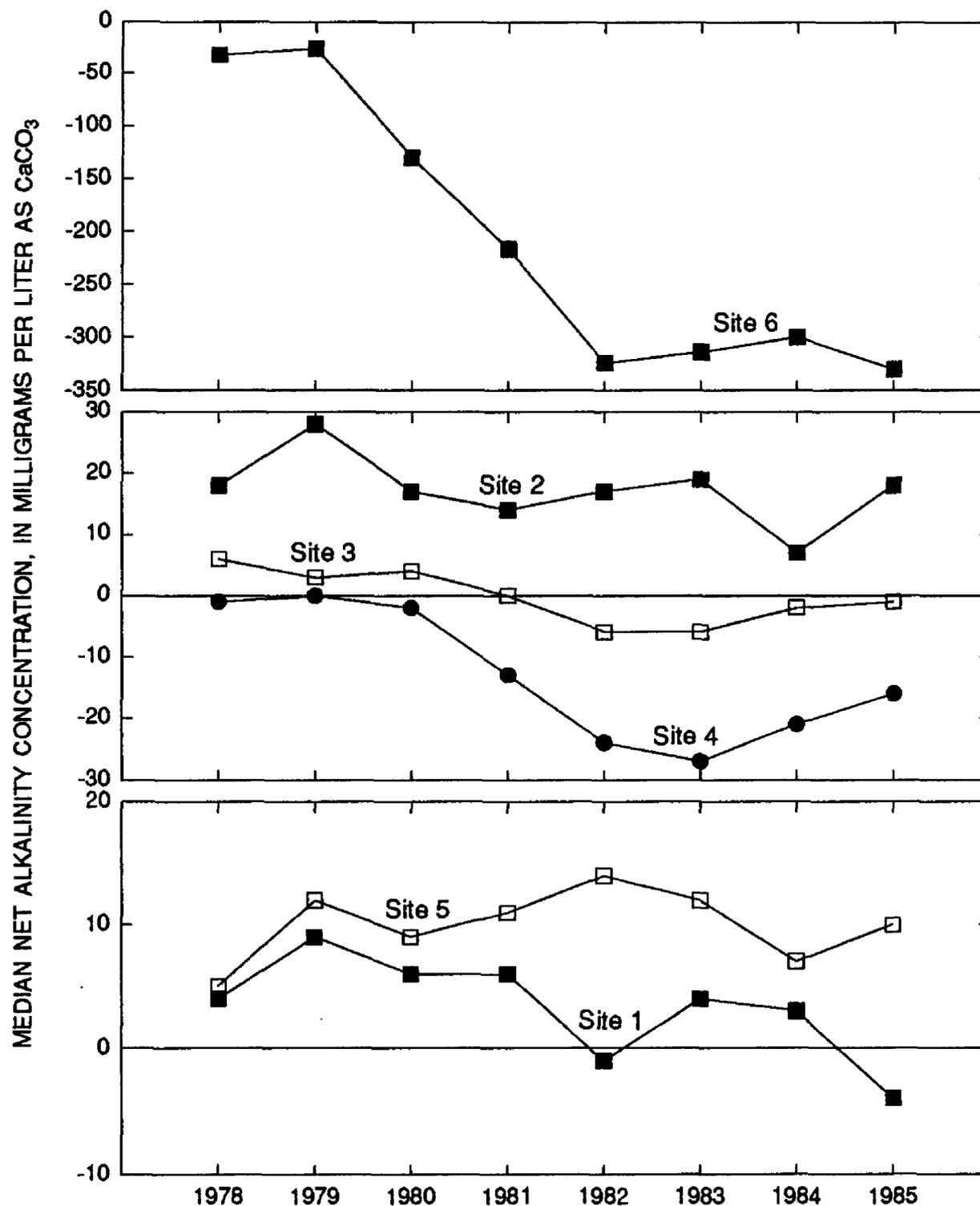


**Figure 6.** Annual median acidity, as CaCO<sub>3</sub>, for data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.

## Alkalinity

Alkalinity is a measurement of the capacity of water to neutralize acid. The maximum alkalinity measured as  $\text{CaCO}_3$  was 118 mg/L at site 2, and the minimum was 0 mg/L at sites 1, 4, and 6. Annual median alkalinity ranged from 4 to 12 mg/L at site 1 and from 10 to 20 mg/L at site 5, indicating that the water from unmined areas has more acid-neutralizing capacity than water from mined areas.

Net alkalinity is calculated by subtracting acidity from alkalinity. A positive net alkalinity indicates that the water is more alkaline than acid; a negative net alkalinity indicates that it is more acid than alkaline. The annual median net alkalinity decreased at all sites except 2 and 5 and was consistently greater than zero only at sites 2 and 5 (fig. 7). The water at site 2 was the most alkaline, probably because the mine pond above the site was treated with acid-neutralizing substances. The median net alkalinity at site 4 was negative during 1978-85. The patterns for net alkalinity at sites 3 and 4 are somewhat similar for 1978-85, but net alkalinity is greater at the downstream site (site 3), indicating that water at site 4 is being neutralized as it flows downstream. Net alkalinity in 1978-80 was almost constant at these two sites. Decreases in 1981-83 were followed by increases in 1984 and 1985. At site 1, median net alkalinity was positive in all years except 1982 and 1985. Net alkalinity at site 5 ranged from +5 to +14 mg/L and was always greater than net alkalinity at site 1. The difference in net alkalinity between sites 1 and 5 increased after 1980, indicating that increases in mined area affects water quality at site 1.



**Figure 7.** Annual median net alkalinity, as  $\text{CaCO}_3$ , for data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.

## Sulfate

Elevated concentrations of dissolved sulfate in the basin are the result of the oxidation of pyrite found in the coal deposits and spoils. When coal is mined, pyrite is exposed to water and air accelerating the oxidation process that produces sulfate, iron, and hydrogen ions in AMD. If the stream receiving AMD is sufficiently alkaline, the incoming acidic water may be neutralized rapidly. However, neutralization by natural processes or treatment with an alkaline agent does not change the concentration of sulfate. Therefore, sulfate persists as an indicator of mine drainage.

Figure 8 shows the annual median concentrations of dissolved sulfate measured at sites 1 through 6 for 1978-85. The maximum concentrations of sulfate (up to 1,400 mg/L) were measured at site 6, which is the outflow of an abandoned underground mine. At site 6, the annual median concentration of dissolved sulfate gradually increased from a low of 45 mg/L in 1978 to a maximum of 1,100 mg/L in 1983. Although the discharge at site 6 was generally low compared to the discharge in the mainstem, the elevated sulfate concentrations contributed to increases in the sulfate concentrations at site 1. Sulfate concentrations at sites 2 and 5 remained low (less than 20 mg/L) throughout the study. The median sulfate concentration of 17 streamflow samples collected at site 2 in water year 1977 was 9.0 mg/L compared to the annual median concentration of 13 mg/L for 1978, the year mining began at mine E. Annual median concentrations of dissolved sulfate at sites 4, 3, and 1, which are all mainstem sites, began to increase in 1981 and followed similar patterns throughout the study. Concentrations at site 1 were generally greater than at the other two sites because of the elevated sulfate concentrations in inflow from site 6. Concentrations at site 4 were slightly greater than at site 3 because of dilution by inflows with low concentrations.

## Iron

Iron is one of the main constituents of pyrite, and when pyrite oxidizes, ferrous ions ( $\text{Fe}^{2+}$ ) and ferric ions ( $\text{Fe}^{3+}$ ) are produced (eqs. 1 and 2). The solubility of iron in water is strongly influenced by pH and redox potential, Eh (Hem, 1985, p. 80); the lower the pH, the more soluble the iron, given a range of redox potential. Under oxidizing conditions, the ferrous ions can be oxidized to the ferric state (eq. 3). The ferric ions react with water to form relatively insoluble ferric hydroxide ( $\text{Fe}(\text{OH})_3$ ), which precipitates as "yellow boy" and coats the stream bottoms. This precipitate became more apparent in the Stony Fork Basin as coal mining expanded.

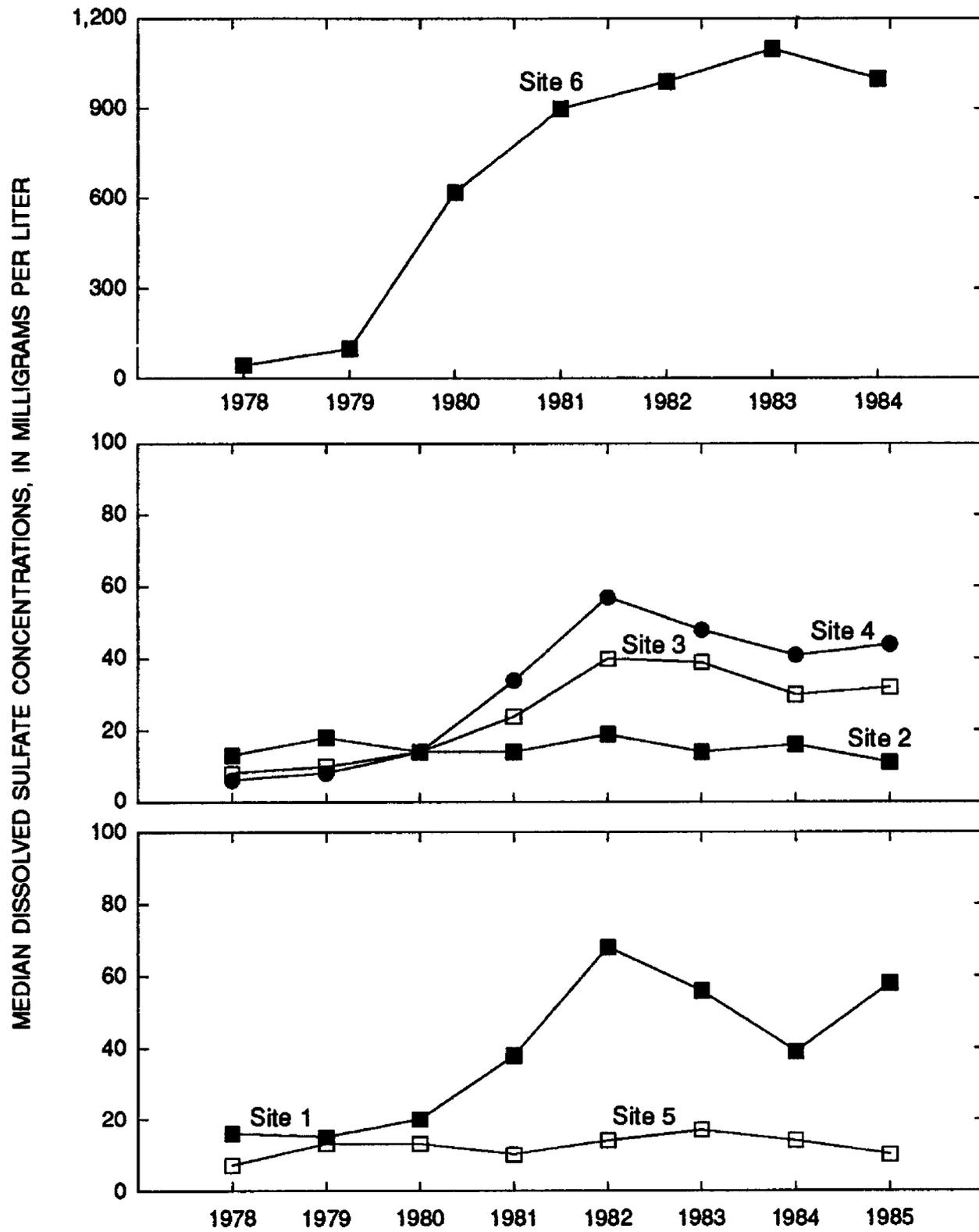
Measured concentrations of dissolved<sup>5</sup> iron ranged from a low of 10  $\mu\text{g}/\text{L}$  at site 1 to a maximum of 56,000  $\mu\text{g}/\text{L}$  at site 6. Most of the iron in the site 6 discharge is dissolved. Measured concentrations of total dissolved plus suspended<sup>6</sup> iron ranged from a low of 100  $\mu\text{g}/\text{L}$  at site 1 to a maximum of 56,000  $\mu\text{g}/\text{L}$  at site 6. At site 6, annual median concentrations of dissolved and total iron increased from 1979 through 1985 (figs. 9 and 10). The increases were greatest in 1980 and 1981 and were more gradual from 1982 through 1985. At sites 2, 3, and 4, the annual median concentrations of dissolved iron followed a similar pattern from 1981 through 1984, reaching a maximum in 1982, but tended to be more variable from 1978 through 1980 and in 1985 (fig. 9). The lowest concentrations of dissolved iron were measured at site 1, which was downstream of all mining, and the concentrations were considerably lower at site 1 than at site 5, the upstream site unaffected by mining. The low dissolved iron concentrations at site 1 were the result of dilution by the elevated streamflow. The pH consistently increased from mainstem site 4 to mainstem site 3 (fig. 5), and much of the dissolved iron probably precipitated because of increasing pH conditions before it reached site 1. About half or more of the total iron at sites 1-5 is in the dissolved phase; the remainder is suspended. The annual median concentrations of total iron at sites 1, 2, and 5 followed a similar pattern, but the concentrations at site 2 were much greater than at sites 1 and 5 (fig. 10).

The drainage area at site 1 is eight times greater than the drainage area at site 5; therefore, the total-iron discharge at site 1 could be more than the iron discharge at site 5 because of the difference in the size of the drainage areas. Total-iron discharges at sites 1 and 5, estimated by multiplying annual median concentrations and median water discharges, were 2.6 and 7.2 ton, respectively, during 1980. Total iron per unit area was less in streamflow at site 1 (0.35 ton/ $\text{mi}^2$ ) than at site 5 (7.7 ton/ $\text{mi}^2$ ).

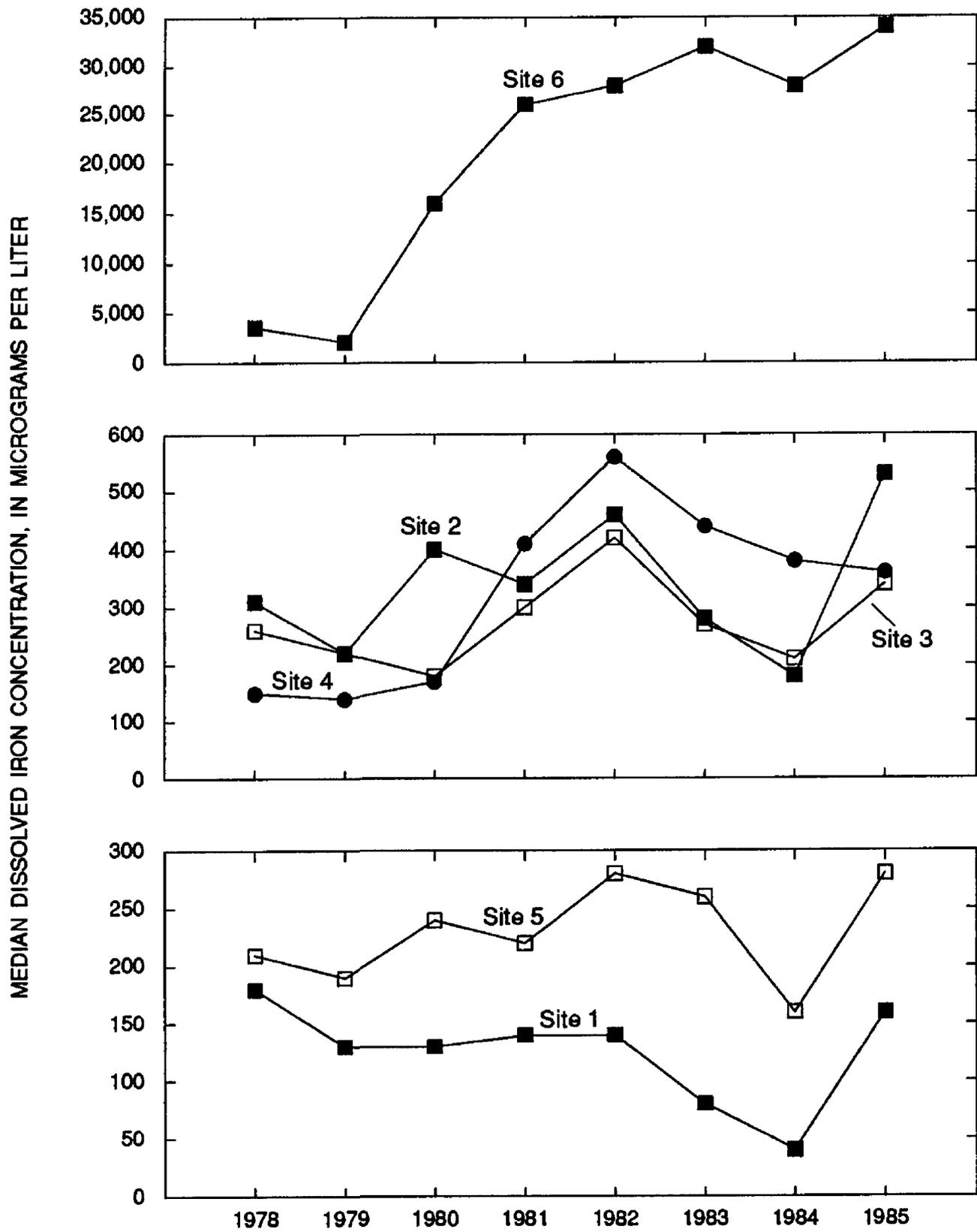
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<sup>5</sup> Dissolved refers to that material in a representative water sample which passes through a 0.45  $\mu\text{m}$  membrane filter.

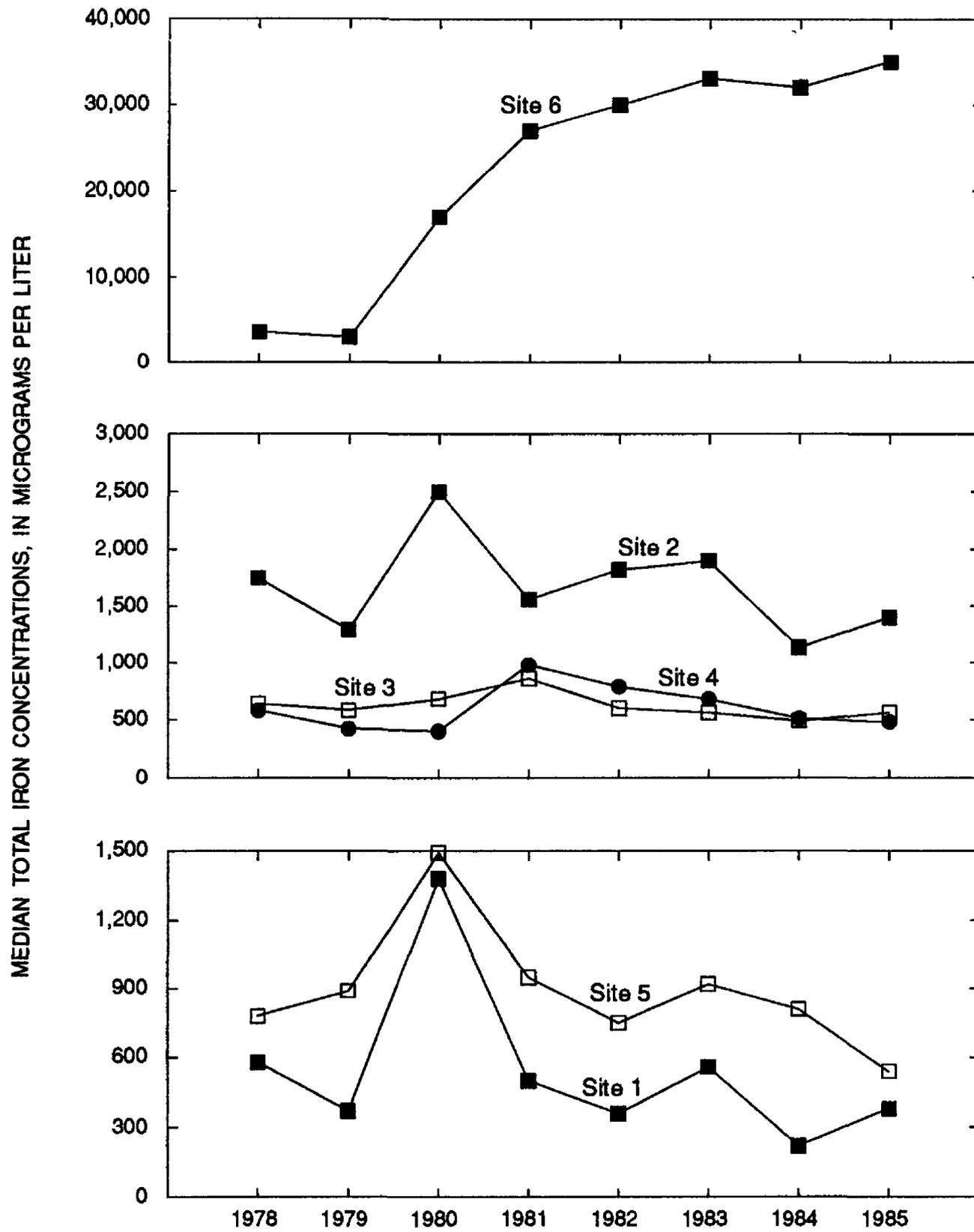
<sup>6</sup> Suspended refers to the concentration of undissolved material in a water-sediment mixture. It is associated with the material retained on a 0.45  $\mu\text{m}$  filter.



**Figure 8.** Annual median dissolved-sulfate concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.



**Figure 9.** Annual median dissolved-iron concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.



**Figure 10.** Annual median total-iron concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85.

## Manganese

Manganese is present naturally in various salts and minerals and frequently is found in association with iron compounds. It is undesirable in water supplies because it tends to precipitate, depositing black oxide stains. In streams receiving AMD, concentrations of dissolved manganese commonly exceed 1,000  $\mu\text{g}/\text{L}$  (Hem, 1985, p. 88). In mined areas, the oxidation of pyrite consumes oxygen and can cause a reducing environment that increases the solubility of manganese. Manganese usually persists in streams for greater distances downstream in AMD than does iron (Hem, 1985, p. 88). As the acidity of the stream is gradually neutralized, iron precipitates as ferric hydroxide before manganese is removed from solution.

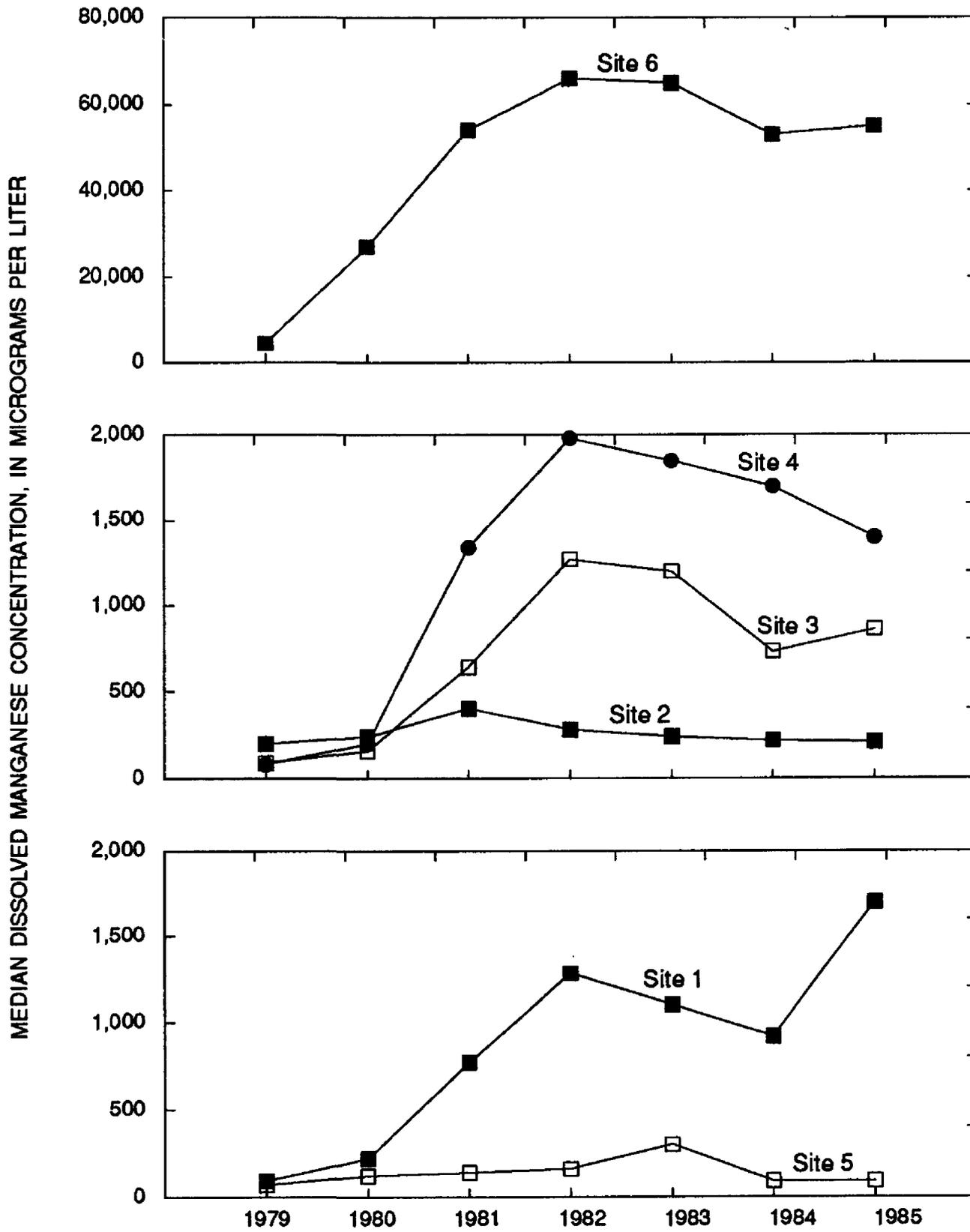
In the Stony Fork Basin, elevated concentrations of dissolved manganese were measured—up to 72,000  $\mu\text{g}/\text{L}$  at site 6 and up to 5,300  $\mu\text{g}/\text{L}$  at site 4. Concentrations greater than 1,000  $\mu\text{g}/\text{L}$  were common at sites 1 and 3. Annual median concentrations of dissolved and total manganese are shown in figures 11 and 12, respectively, for sites 1 through 6. Manganese transported at all six sites was mostly dissolved. Manganese concentrations at all mainstem sites (sites 4, 3 and 1) except site 5, increased significantly from 1980 through 1985. Figure 13 is a logarithmic plot of dissolved-manganese discharge as a function of streamflow for site 1 for 1979 and 1983. The regression lines show that, in 1983, a streamflow of 10  $\text{ft}^3/\text{s}$  carried 10 times the amount of manganese carried by a streamflow of 10  $\text{ft}^3/\text{s}$  in 1979. Although the data plotted are from monthly instantaneous samples, the regression lines are indicative of increased manganese as a result of increased mining upstream.

## Aluminum

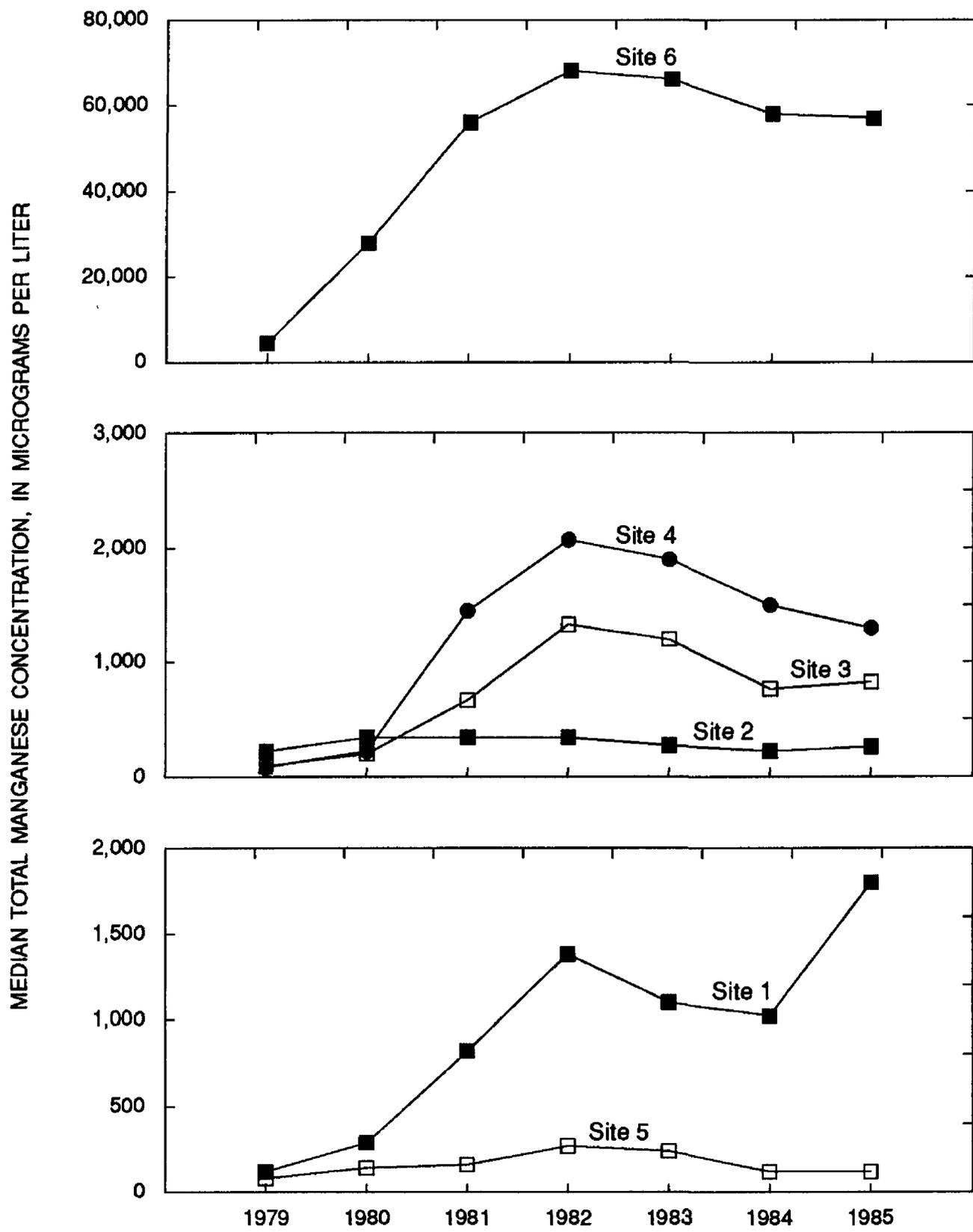
Aluminum is the third most abundant element in the earth's outer crust, but is rarely detected in solution in natural waters in concentrations greater than a few tenths of a milligram per liter. Common aluminum-bearing minerals generally have a solubility minima at pH 6. Below pH 6, aluminum concentrations are inversely related to pH. Below pH 5, concentrations of dissolved aluminum can be high enough to be toxic to aquatic organisms (Baker and Christensen, 1991). Drainage from acid mine spoils is suspected of causing aluminum poisoning in some native and cultivated plants (Gough and others, 1979, p. 5). Concentrations of dissolved aluminum ranged from less than 10  $\mu\text{g}/\text{L}$  at sites 1, 4 and 5 to 20,000  $\mu\text{g}/\text{L}$  at site 6. Total-recoverable aluminum concentrations ranged from less than 10  $\mu\text{g}/\text{L}$  at site 1 to more than 30,000  $\mu\text{g}/\text{L}$  at site 5. It is interesting to note that the minimum concentration of total aluminum was measured at site 1, which is downstream of all mining, and the maximum concentration was measured at site 5, which is above all mining. Annual median concentrations of dissolved and total aluminum are shown in figures 14 and 15. From 1979 through 1984, the annual median concentrations of dissolved aluminum were relatively low and constant at sites 1, 2 and 5. From 1984 to 1985, the median concentration of dissolved aluminum increased significantly at site 1 and corresponded to a significant drop in the annual median pH at that same site (see fig. 5).

Except for the mine seep at site 6, the annual median concentrations of dissolved aluminum at site 4 were greater than the other four sites. The increase in dissolved aluminum at site 4 after 1980 is related to mining upstream and the concurrent decrease in pH at the site (fig. 5). The area disturbed by mining above site 4 increased from 12 to 50 acres between July 1980 and November 1981 (Mastrilli and Stump, 1986, p. 6). Further downstream at site 3, the annual median concentration of dissolved aluminum increased after 1981, but not as much as at site 4.

The pH of Stony Fork appears to be important in controlling the amount of dissolved and total aluminum present in the stream. As the pH in the mainstem increased from site 4 to site 1 (fig. 5), the concentrations of dissolved aluminum decreased significantly (fig. 14). The decrease in aluminum concentration downstream was the result of dilution and of precipitation of the dissolved phase. Total aluminum concentrations also decreased downstream because of dilution, precipitation, and deposition to streambed sediments. Site 5 was above all mining and the pH remained relatively constant as did the concentrations of dissolved aluminum.



**Figure 11.** Annual median dissolved-manganese concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1979-85.



**Figure 12.** Annual median total-manganese concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1979-85.

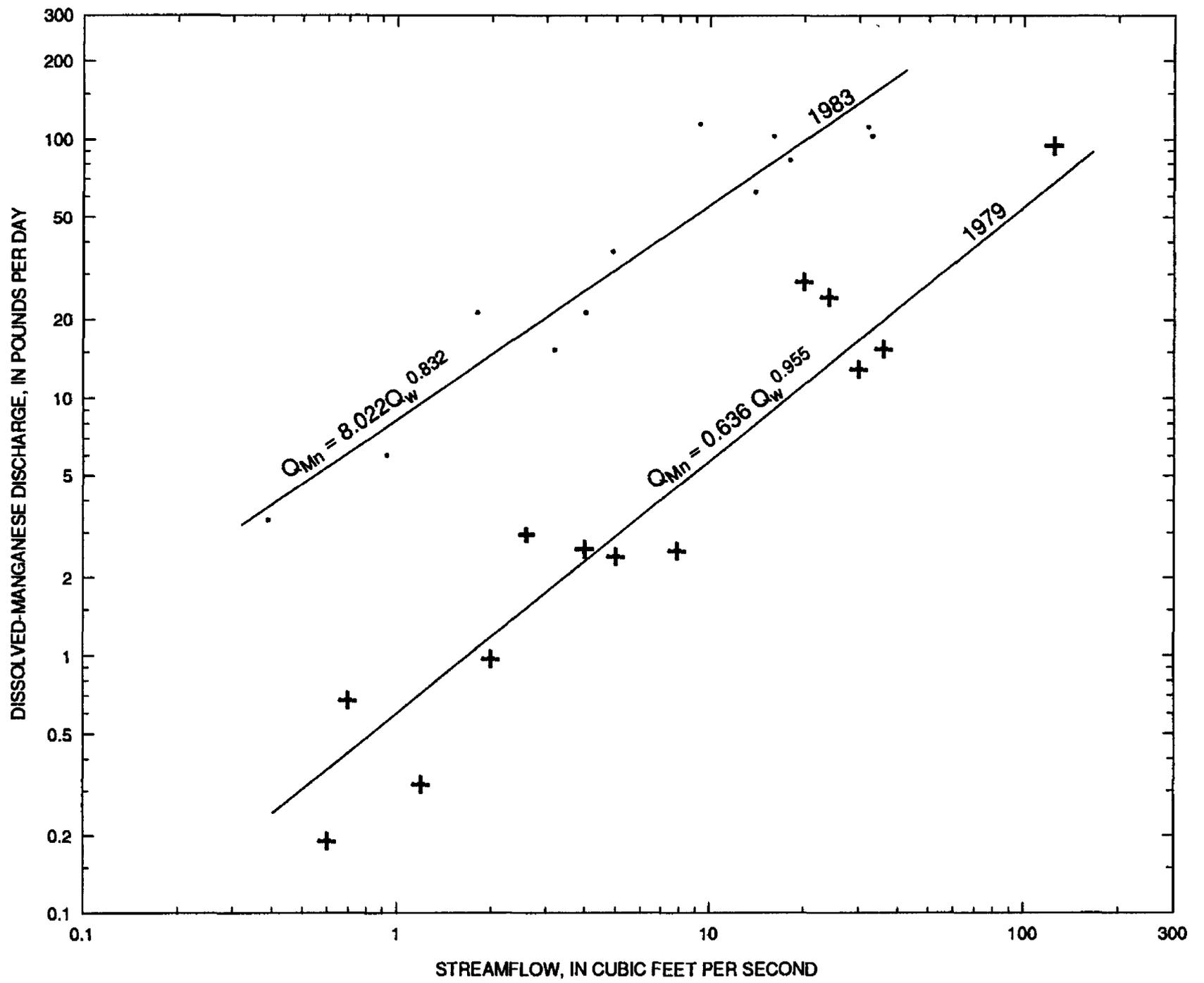
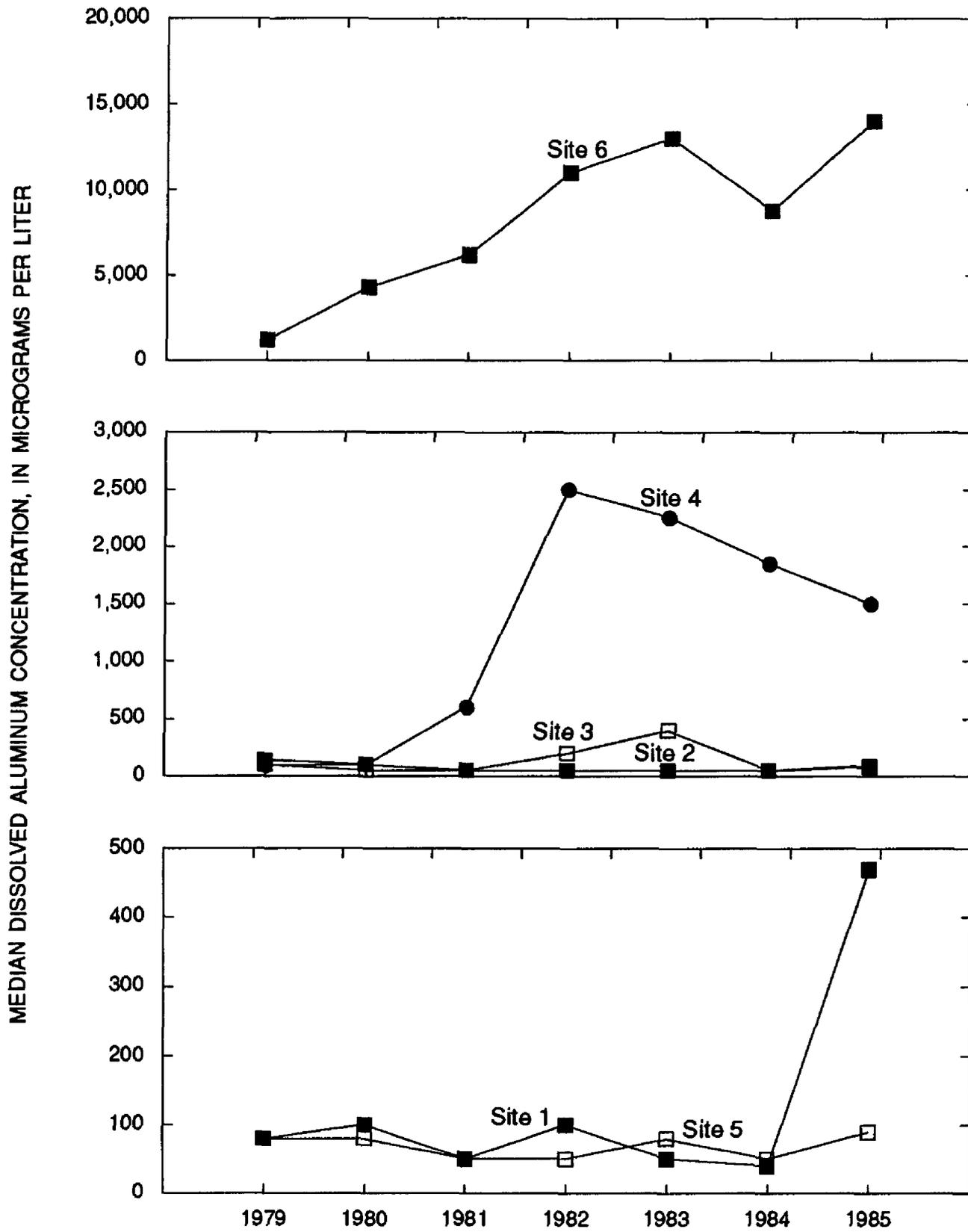
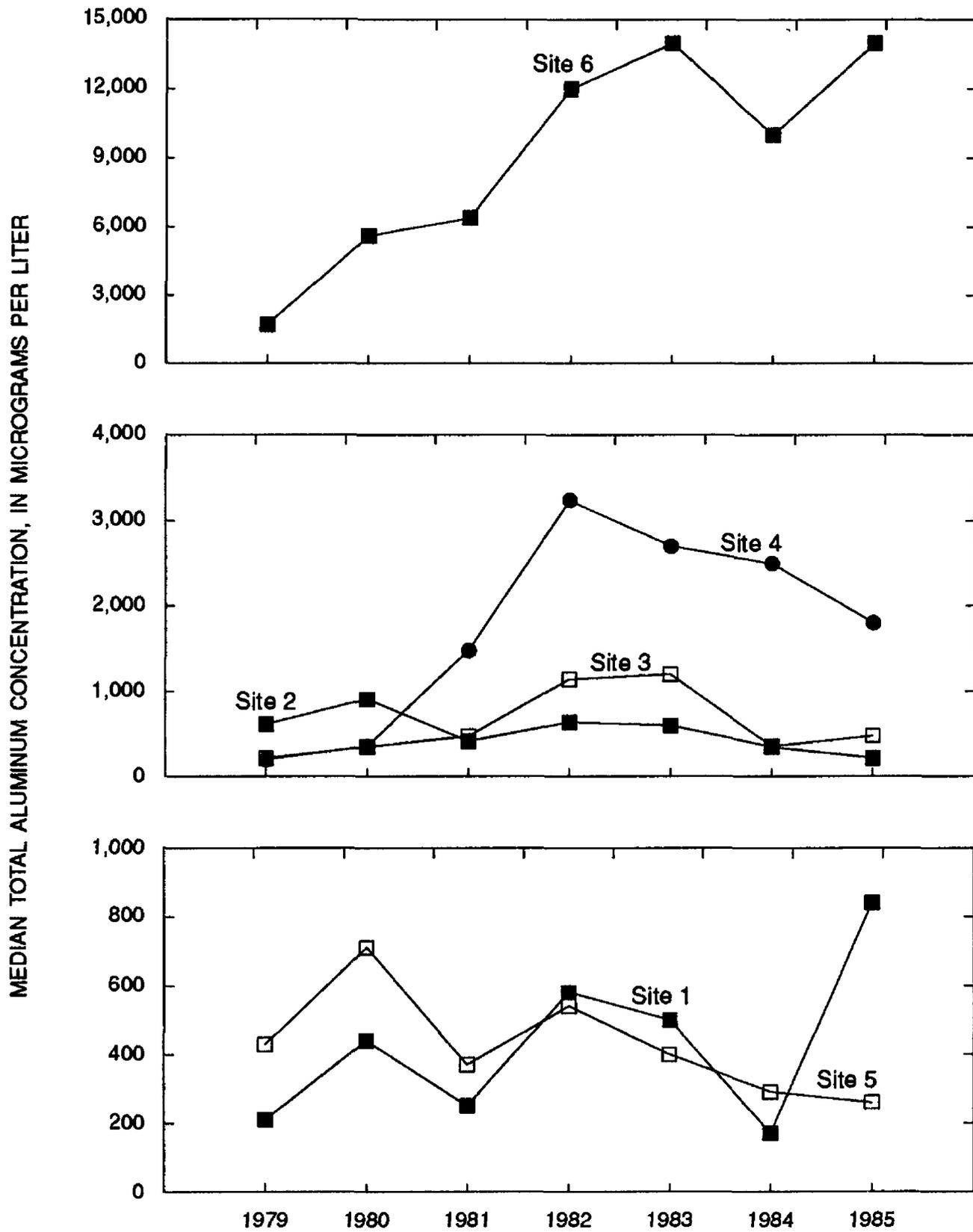


Figure 13. Dissolved-manganese discharge at site 1 as a function of streamflow for 1979 and 1983.



**Figure 14.** Annual median dissolved-aluminum concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1979-85.



**Figure 15.** Annual median total-aluminum concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1979-85.

## Zinc

Streams affected by AMD commonly contain zinc concentrations greater than 100 µg/L (Hem, 1985, p. 142), but they generally do not exceed the concentrations of iron, manganese, or aluminum. In the Stony Fork Basin, dissolved and total zinc concentrations at sites directly affected by mine drainage (sites 4 and 6) were consistently greater than 100 µg/L (figs. 16 and 17). Most of the zinc is in the dissolved phase. Zinc concentrations at the mainstem sites 4, 3, and 1 increased in a similar pattern after 1980; concentrations decreased downstream as a result of dilution. The annual median concentration of dissolved zinc at site 1 was less than 100 µg/L in 1979-84, but the median increased to 180 µg/L in 1985 when concentrations in 8 of the 12 stream samples exceeded 100 µg/L. Because the increase in zinc concentration at site 1 from 1984 to 1985 was not observed at sites 3 and 4, zinc may have been introduced between site 3 and site 1 during that year. Annual median concentrations of dissolved zinc at site 5, which was above all mining, remained constant throughout the study at 20 µg/L.

## Trace Elements

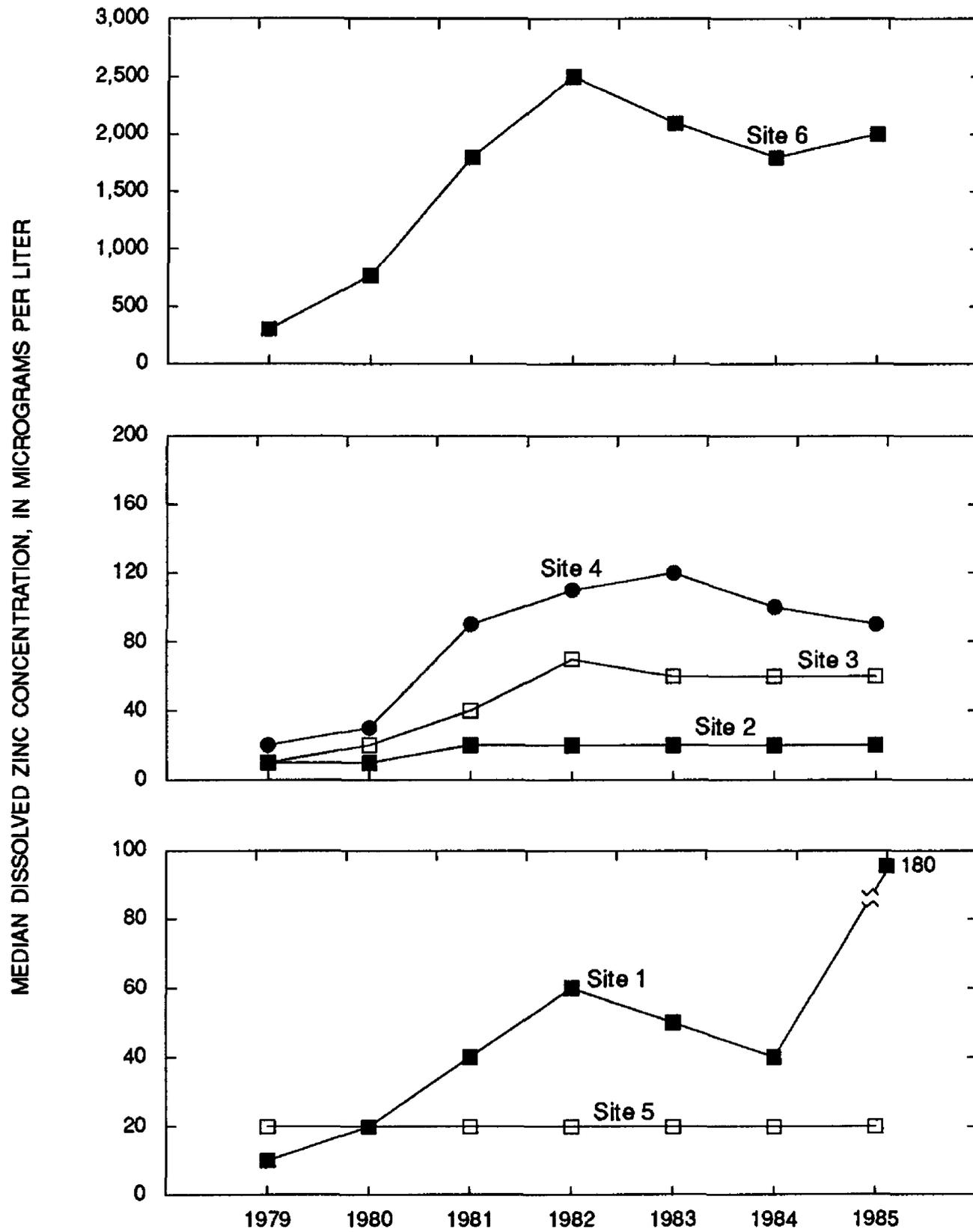
Trace elements commonly are present in extremely small concentrations in water because of their low abundance in the earth's crust and (or) low solubility. Stream samples were collected and analyzed for selected trace elements at least annually throughout the study except in 1981, when no samples were collected. The trace elements analyzed for included arsenic, cadmium, chromium, copper, lead, mercury, nickel and selenium. Table 6 gives the USEPA MCL's and SMCL's for these trace elements. Dissolved arsenic, mercury, and selenium were not detected in any samples, and concentrations of other trace elements generally were low except for nickel. Concentrations of dissolved chromium and lead did not exceed 10 µg/L. All stream samples except one (from site 6) contained less than 10 µg/L of dissolved cadmium. Concentrations of dissolved copper did not exceed 10 µg/L in samples from sites 1-5. At site 6, 8 of 13 samples had concentrations of dissolved copper greater than 10 µg/L, but the maximum measured concentration was 60 µg/L, well below the USEPA SMCL.

Concentrations of dissolved nickel exceeding 10 µg/L were detected in samples from all the sites (table 7). The median concentration of nickel in North American rivers described by Durum and Haffty (1963) is 10 µg/L. At sites 2 and 5, the maximum concentration of dissolved nickel measured did not exceed 20 µg/L. In 1982, the concentrations of dissolved nickel at sites 1 and 3 seem to have been affected by the elevated concentrations at site 4 that may be the result of the mining above site 4. The elevated concentrations of dissolved nickel at site 6 indicate that mines can be the source of nickel in streams.

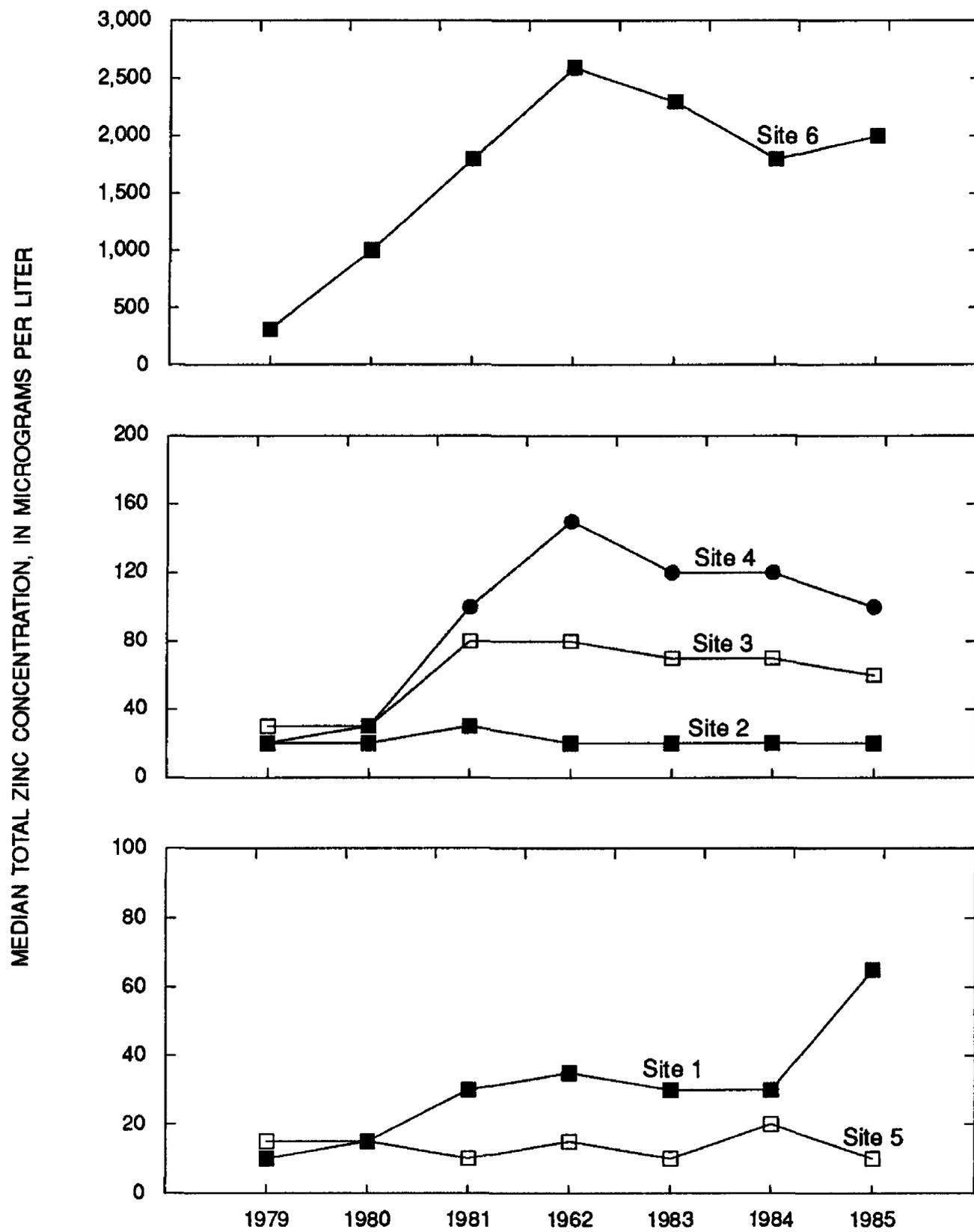
**Table 7.** Concentrations of dissolved nickel greater than 10 micrograms per liter measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1978-85

[14 analyses were done at each site except for site 6, which had 12 analysis; concentrations are in micrograms per liter; --, no data]

Site	Dissolved-nickel concentrations						
	1978	1979	1980	1982	1983	1984	1985
1	--	20	--	50	--	20	--
	--	--	--	--	--	20	--
2	20	20	--	--	--	--	--
3	--	--	--	50	--	20	--
	--	--	--	--	--	--	--
4	20	20	--	80	--	20	20
	--	--	--	--	--	50	--
5	20	20	--	--	--	--	--
6	--	60	520	1,600	1,700	1,300	--
	--	170	--	1,600	1,200	1,100	--



**Figure 16.** Annual median dissolved-zinc concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1979-85.



**Figure 17.** Annual median total-zinc concentrations measured at data-collection sites 1 through 6 in the Stony Fork Basin, 1979-85.

## Precipitation Chemistry

Precipitation in Pennsylvania tends to be acidic (Lynch and others, 1992), which can accelerate mineral weathering. The results of the chemical analyses of three precipitation samples collected near site 1 are shown in table 8. The samples had very little, if any, buffering capacity. The precipitation acidity was very similar to the stream acidity. The low pH of the samples suggests that acid rain may be partly responsible for depressions in pH in the stream during storm runoff (Stump and Mastrilli, 1985, p. 12). Sulfate concentrations and specific conductances were low. Except for zinc, concentrations of metals in the precipitation were much less than the measured stream concentrations. Zinc concentrations in precipitation and in the stream at site 5 were very similar.

**Table 8.** Results of chemical analyses of precipitation samples collected near data-collection site 1 in the Stony Fork Basin during 1984

[ $\mu\text{g/L}$ , micrograms per liter;  $\mu\text{S/cm}$ , microsiemens per centimeter at 25 degrees Celsius;  $\text{mg/L}$ , milligrams per liter]

Constituent	April 14, 1984	July 11, 1984	November 11, 1984
Laboratory pH (units)	4.4	3.8	4.7
Specific conductance ( $\mu\text{S/cm}$ )	50	50	50
Acidity, as $\text{CaCO}_3$ ( $\text{mg/L}$ )	10	25	11
Alkalinity, as $\text{CaCO}_3$ ( $\text{mg/L}$ )	0	0	6
Sulfate ( $\text{SO}_4$ ) ( $\text{mg/L}$ )	5	10	5
Total iron (Fe) ( $\mu\text{g/L}$ )	50	100	50
Total manganese (Mn) ( $\mu\text{g/L}$ )	10	50	40
Total aluminum (Al) ( $\mu\text{g/L}$ )	60	60	80
Total zinc (Zn) ( $\mu\text{g/L}$ )	50	40	50

# AQUATIC BIOLOGY

by Thomas Proch, Pennsylvania Department of Environmental Resources

## Introduction

Benthic-macroinvertebrate communities are sensitive to water quality and fairly immobile. As a result, they can indicate the time-integrated effects of water quality that might not be shown by discrete chemical samples. If a transient toxic chemical or other contaminant destroys any macroinvertebrates, the reestablishment of the community typically takes weeks or months. A water sample collected during this post-contamination period would probably show no evidence of contamination. Although benthic macroinvertebrates can serve as indicators of contamination of a stream, they generally do not provide information on the nature of the contaminant itself.

The purpose of the aquatic biological study in the Stony Fork Basin was to assess the effects of mining on the stream biota and to determine how much of the watershed can be mined before effects are observed. Invertebrates and fish were collected seasonally—in February, May, August, and November—from 1977 through 1984.

## Data Collection and Analytical Methods

Sites 1, 3, and 5 were selected for biological study on the basis of accessibility, similarity of substrate, and proximity to the mining activity. Site 5 served as a control.

Invertebrate samples at each site were collected at permanently marked transects and composed of three 1.0 ft units that were composited. This process was repeated to obtain a true replicate. All samples were processed in the field by washing in a U.S. standard number 30 sieve and removing large pieces of debris from the sample. The contents of the sieve were placed in containers and preserved with either a 70-percent ethanol or a 10-percent formalin solution. Each container was sealed, labeled, and transported to the laboratory for sorting and identification of the macroinvertebrates. Identifications were made to the generic level except for the annelids and Diptera, which were identified to class and family, respectively. Standard taxonomic texts by Merritt and Cummins (1984), Pennak (1978), Wiggins (1977), Hitchcock (1974), Edmunds and others (1976), and McCafferty (1981) were used. The diversity index (H) was calculated for each sample by use of Brillouin's formula (Brillouin, 1962).

Fish were collected by electrofishing for 15 minutes with a portable, gasoline-powered, direct-current generator at the same locations and frequencies as the invertebrates, although no replicates were collected. All stunned fishes were netted, placed in buckets of stream water, counted, and identified in the field. The generator output was 150 watts and the output voltage was adjusted to obtain maximum current at that power level. Fish species counts were converted by the square root transformation prior to analysis.

Macroinvertebrate and fish data were analyzed by use of a 3-way factorial analysis of variance (ANOVA) design. This design enabled comparisons among years and year groups, and at the same time, control for seasons and sites. The factors in the design were years (8 levels), seasons (4 levels), and sites (3 levels). The personal computer version of the Complete Statistical System by Statsoft, Inc.<sup>7</sup> was used for the analysis.

## Effects of Mining on Benthic Invertebrates and Fish

Surface mining in the Stony Fork Basin has severely affected stream invertebrate and fish populations. As mining increased, fish species and invertebrate diversities decreased rapidly at sites 1 and 3, reflecting a change in water quality. By 1984, the mean number (on an annual basis) of taxonomic groups of invertebrates at sites 1 and 3 had decreased 45 and 71 percent, respectively, from populations measured in 1977 (table 9). However, populations at the control site did not significantly change during the same

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<sup>7</sup> The use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

period. ANOVA showed that diversities decreased significantly ( $P < 0.001$ ) between 1977 and 1984 at sites 1 and 3 relative to the diversity at the control (site 5). This difference was consistent among seasons ( $P < 0.001$ ) and among all combinations of years after 1978 ( $P < 0.001$ ). The analysis showed no difference in diversity among years at site 5, but showed differences in diversity among seasons ( $P < 0.05$ ). Differences among seasons are expected because diversity changes as organisms mature and emerge. The diversity at sites affected by mining was not significantly different among the years 1977-79, yet comparisons of diversity among these years and the years 1980-84 showed significant differences ( $P < 0.001$ ). Mean diversity was much less at the conclusion of the study than at the beginning.

**Table 9.** Mean number of invertebrate taxonomic groups in the Stony Fork Basin

Year	Number of invertebrate taxonomic groups		
	Site 1	Site 3	Site 5
1977	19.5	18.8	13.9
1978	19.5	18.6	12.9
1979	21.3	22.3	13.6
1980	17.5	19.8	14.1
1981	18.5	5.0	14.9
1982	18.3	9.9	14.1
1983	15.5	7.1	14.6
1984	10.8	5.5	14.0

The mean number of fish species (on an annual basis) decreased 81 and 88 percent at sites 1 and 3, respectively, between 1977 and 1984 (table 10). Little or no change occurred at the control site during the same period. By use of the square root transformation of species counts, ANOVA showed that there were significant differences ( $P < 0.001$ ) in the mean species number among the years of study, but this result was dependent on the location. Species means at sites 1 and 3 were significantly less ( $P < 0.001$ ) among years, but those at site 5 (control) were not. Further analysis showed that the mean number of species at all sites were similar during the period 1977-79, but were significantly different ( $P < 0.001$ ) for any combination of the years 1980 through 1984.

**Table 10.** Mean number of fish species in the Stony Fork Basin

Year	Number of fish species		
	Site 1	Site 3	Site 5
1977	7.75	6.25	4.50
1978	9.75	9.25	5.00
1979	9.00	8.25	5.25
1980	7.00	6.25	4.50
1981	6.00	5.25	4.25
1982	4.50	3.00	4.25
1983	2.25	.75	4.25
1984	1.50	.75	4.25

### Conclusions

The effects of surface mining on the macroinvertebrates and fishes of Stony Fork were substantial. It took approximately 2 years for any deleterious effects to emerge, but once species numbers began to decline, they did so rapidly. The pivotal point was in 1979 when approximately 4 percent of the basin was being mined. Further mining quickly eliminated most fish and many macroinvertebrate species. No recovery had taken place at the time the study was concluded in November 1984.

## SUMMARY AND CONCLUSIONS

The area in the Stony Fork Basin disturbed by surface mining increased from about 1.9 percent to about 11.3 percent during 1977-85. Streamflow, suspended-sediment, water-quality, and biologic data collected at one monitoring site upstream and five sites downstream from mined areas were analyzed to determine the effects of mining on the stream. Streamflow measured at the streamflow-gaging stations below the mining (site 1) and above the mining (site 5) was not significantly different, accounting for differences in drainage areas; the lack of difference indicated that mining probably did not affect annual streamflow. The suspended-sediment yields at site 1 were not consistently greater than those at site 5, indicating that mining did not significantly increase sediment yields at downstream site 1 except in 1984. A storm on April 4-5, 1984, was responsible for 64 percent of the sediment transported past site 1 for that year. Equal or smaller sediment yields at site 1 compared to site 5 were probably the result of the larger drainage area above site 1 coupled with the effective sediment-control measures used by the mining companies throughout the basin.

The annual median pH at a stream site below all mining (site 1) decreased after mining while the annual median pH at a stream site above all mining (site 5) remained almost constant through the study. Measured pH ranged from 4.2 to 7.7 and from 5.5 to 7.9 at sites 1 and 5, respectively. The pH at two sites on the mainstem of Stony Fork (sites 3 and 4) also decreased during the study. Specific conductance generally varies inversely with streamflow; specific conductance increased at sites 1, 3, 4, and 6 at all streamflows after mining.

Mining throughout the basin increased concentrations of sulfate, manganese, aluminum and zinc on the mainstem sites on the basis of comparisons to water quality unaffected by mining at site 5. Elevated concentrations of sulfate, iron, manganese, aluminum, zinc, and hydrogen ions (low pH) are associated with AMD. Although the discharge from the mine seep at site 6 was low, the extremely elevated concentrations of those constituents associated with AMD increased the concentrations of those constituents at site 1.

Concentrations of dissolved and total iron at site 5 were generally greater than the concentrations at site 1 because of dilution at site 1. Surface mining throughout the basin did not significantly increase iron concentrations in the streamflow. The increasing pH from site 4 to site 1 had a significant effect on concentrations of dissolved-aluminum. As the pH increased below site 4 on the mainstem, concentrations of dissolved aluminum decreased as the dissolved phase precipitated to the suspended phase and (or) to streambed sediments.

Manganese remained mostly in the dissolved phase and concentrations at mainstem sites 4, 3, and 1 increased significantly from 1979 to 1983. Regression analyses showed a 10-fold increase in concentrations of dissolved-manganese in 1983 at a discharge of 10 ft<sup>3</sup>/s compared to the same streamflow in 1979.

The trace elements arsenic, cadmium, copper, lead, mercury, and selenium were rarely detected in the basin and all concentrations of the detected trace elements were well below the USEPA MCL's and SMCL's. Elevated concentrations of nickel were measured at the mainstem sites 4, 3, and 1 and at the mine discharge site (site 6) and were probably related to mining. There is no SMCL for nickel.

Surface mining throughout the Stony Fork Basin significantly affected benthic invertebrate diversities and fish populations. From 1977 to 1984, the mean annual number of taxonomic groups of invertebrates at sites 1 and 3 had decreased 45 and 71 percent, respectively, and the mean annual number of species of fish decreased 81 and 88 percent, respectively. No significant changes were measured at site 5.

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