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EFFECTS OF SURFACE MINING ON WATER QUALITY IN A SMALL WATERSHED, SULLIVAN COUNTY, INDIANA

By James G. Peters

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

Multiply inch-pound units	By	To obtain metric units
acre	0.4047	hectare (ha)
British thermal unit (Btu)	252.0	calorie (cal)
British thermal unit per pound (Btu/lb)	0.5555	calorie per gram (cal/g)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1892	meter per kilometer (m/km)
inch (in.)	2.540	centimeter (cm)
million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)

DATUM

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

TRADE NAMES

Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

ABBREVIATIONS

Abbreviation	Description
Btu	British thermal unit
Btu/lb	British thermal unit per pound
°C and DEG C	degree Celsius
e	base of the natural logarithm, 2.71828
ft	foot
ft/mi	foot per mile
ft^3/s and FT3/S	cubic foot per second
in.	inch
mg/kg	milligram per kilogram
mg/L and MG/L	milligram per liter
Mgal/d	million gallons per day
mi^2	square mile
μG/G	microgram per gram
μg/L and UG/L	microgram per liter
μmho/cm and UMHO/CM	micromho per centimeter at 25° Celsius
NGVD of 1929	National Geodetic Vertical Datum of 1929
NPDES	National Pollution Discharge Elimination System
PH	pH
ppm	part per million
U.S.	United States
yr	year

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ABSTRACT

The water quality in an unnamed tributary to Spencer Creek upstream and downstream from a surface mine and in South Lake adjacent to the mine were monitored during a 5-year study (1975-79) in the 1,210-acre watershed of the tributary.

Compared with the background values, pH and concentrations of all major dissolved ions and dissolved, suspended, and streambed metals generally increased in Spencer Creek tributary downstream from the mine. Median dissolved-sodium and sulfate concentrations increased as much as eighteenfold and fourteenfold, respectively, and median dissolved-manganese and suspended aluminum concentrations increased as much as sevenfold and more than twofold. Concentrations of suspended metals decreased more than 50 percent after installation of sediment ponds by the mine operator. During high streamflow, concentrations of major ions at background and at mined sites on Spencer Creek tributary decreased, but dissolved- and suspended-metal concentrations increased downstream from the mine.

South Lake exhibited seasonal stratification and mixing characteristics of other lakes at a similar latitude. However, the bottom 3 feet of the water column demonstrated persistent chemical stratification. Phytoplankton populations of the lake varied seasonally, and the population density patterns resembled those in other lakes at latitudes similar to that of South Lake.

INTRODUCTION

As the world's supply of petroleum decreases and its price increases, domestic coal reserves become an increasingly important part of the Nation's energy resources. Despite the problems associated with mining, transporting, and burning coal, it is abundant. U.S. coal reserves could provide three times as much energy as Middle East oil. Conservative projections indicate that these reserves could satisfy an expanding U.S. energy market for at least 70 yr (Noyes, 1978, p. 3-4).

As interest in coal increases, so does the concern about the environmental impact associated with mining it. An evaluation of coal mining is complicated by variation in climate, geology, and mining practices. These practices vary widely, not only among different areas but also among the many mining operations within each area. Thus, as more information is collected from various locations, the interaction of these factors can be better evaluated.

The purpose of the study was to examine effects of surface mining and simultaneous reclamation on a stream draining the affected area in southwestern Indiana and on a last-cut lake adjacent to the watershed. Results of the study are compared with those of similar studies in other parts of the country.

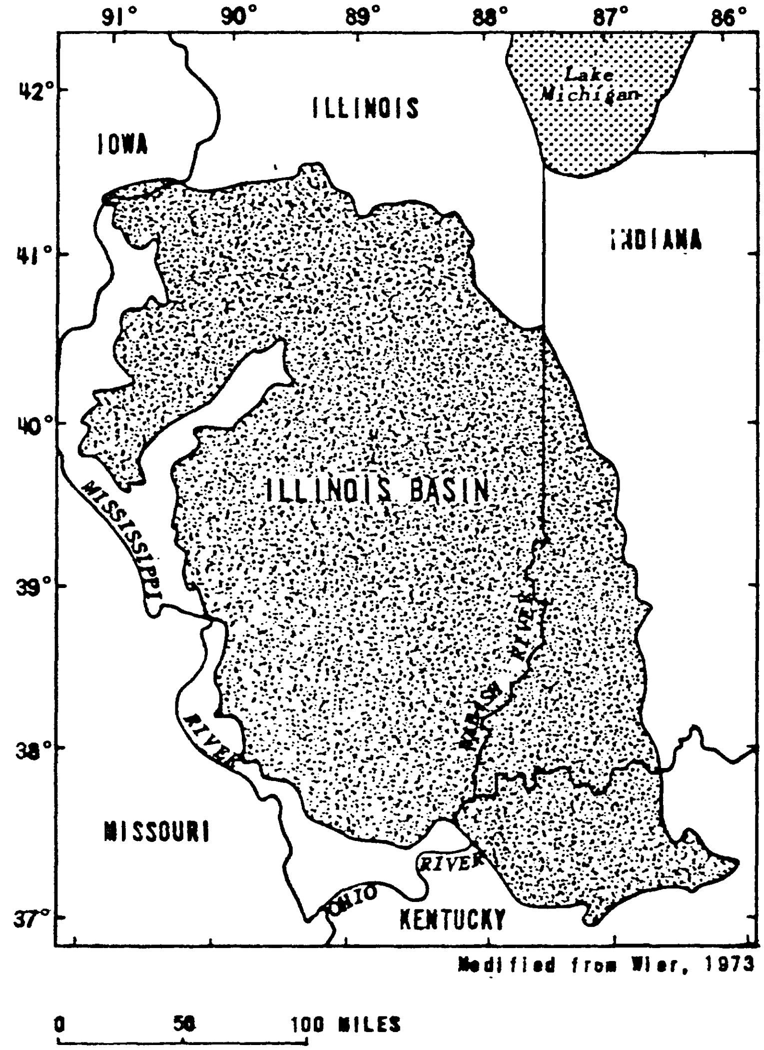
BACKGROUND

Coal is the major energy resource in Indiana and has been produced in the State for the last 150 yr. Ninety-seven percent of all electricity in Indiana is produced by coal-burning steam generators. Indiana ranks fourth among States using coal for energy production (Wier, 1973, p. 1). Coal is commercially available only in the southwestern part of the State in the Pennsylvanian System. This area is in the eastern part of the Illinois Basin, a large bedrock depression that extends south into Kentucky and west over most of Illinois (fig. 1). The Indiana part of the basin is a 6,500-mi^2 area equal to about one-sixth of the State's total area.

The first commercial mining in Indiana began in the early 1830's, along the Ohio River. Production steadily increased to 30 million tons annually at the end of World War I (Wier, 1964, p. 3). After a decline during the 1930's, production reached another peak of 28 million tons in 1944. From 1954 through 1970, about 15 million tons were produced annually, but, in 1971, production rose to 21 million tons (Wier, 1973).

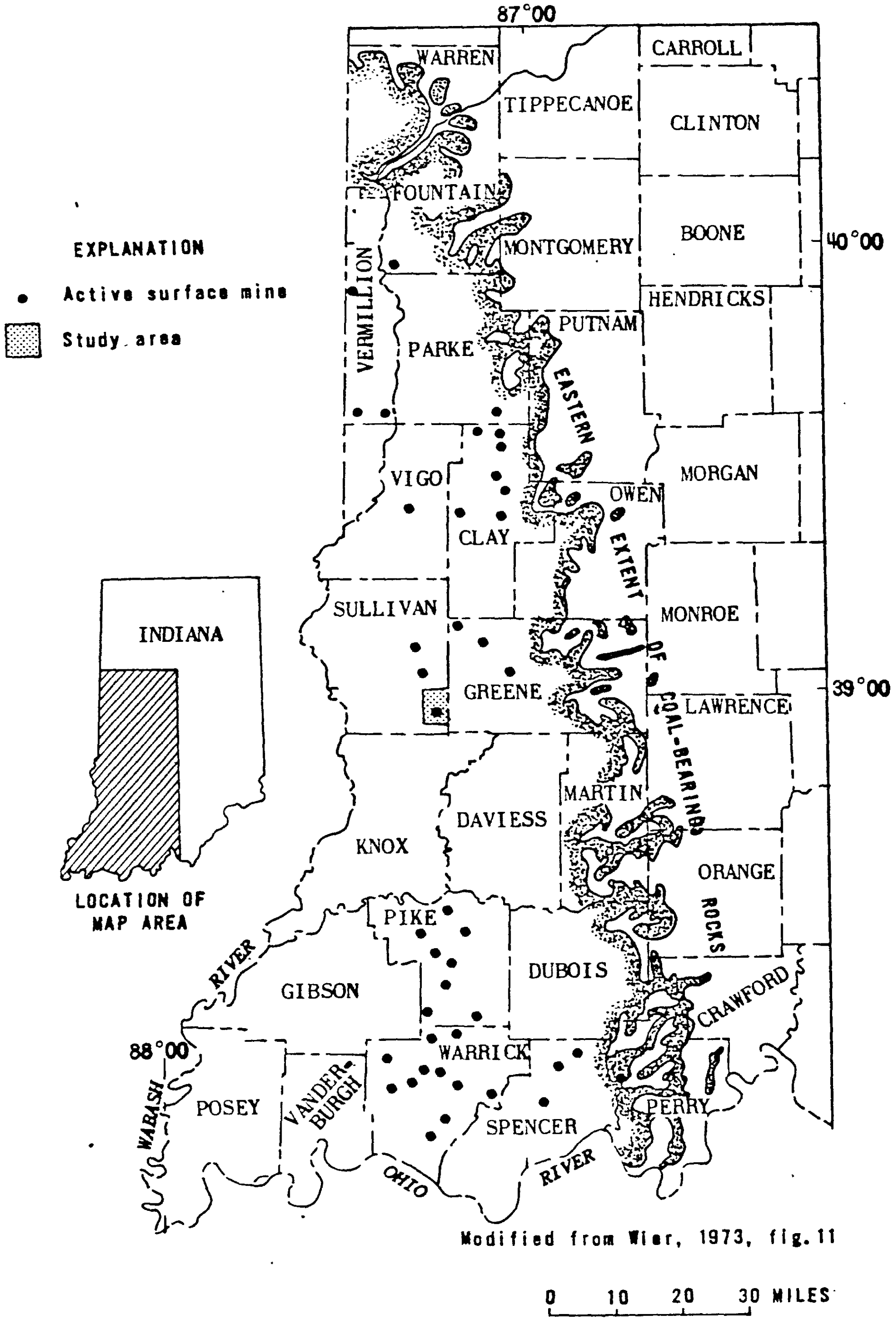
Since the early 1950's, surface mining has been the predominant mining method in Indiana. By 1971, about 90 percent of the State's coal production came from surface mines (Wier, 1973, p. 22). Powell (1972, p. 1) estimated that, by 1972, 156 mi^2 of land surface in southwestern Indiana had been disturbed by surface mining. This area represents about 2 percent of the land area in that part of the State. Currently (1979), most of the surface mining in Indiana is done mainly in 11 counties in southwestern Indiana (fig. 2).

Though 13 States have greater coal reserves, Indiana has about 33 billion tons. Reserves recoverable by 1970 technology have been estimated to total about 17.5 billion tons. This tonnage is impressive compared with the 1.3 billion tons that was mined in Indiana between 1812 and 1970 (Wier, 1973, p. 32).



Modified from Wier, 1973

Figure 1. -- Areal extent of the Illinois Basin in Indiana and adjacent States.



Modified from Wier, 1973, fig. 11

Figure 2.-- Locations of active surface mines and the study area.

DESCRIPTION OF STUDY AREA

Physical Features

The study area is along the east boundary of Sullivan County, Ind., in the coal-mining region of southwestern Indiana (fig. 2). This area includes the Wabash Lowlands physiographic unit, which is characterized by wide alluvial plains and aggraded valleys. According to Schneider (1966, p. 48), the elevation of this broad lowland tract averages about 500 ft above the NGVD of 1929. The surface is relatively flat and relief rarely exceeds 75 ft (Malott, 1922, p. 104).

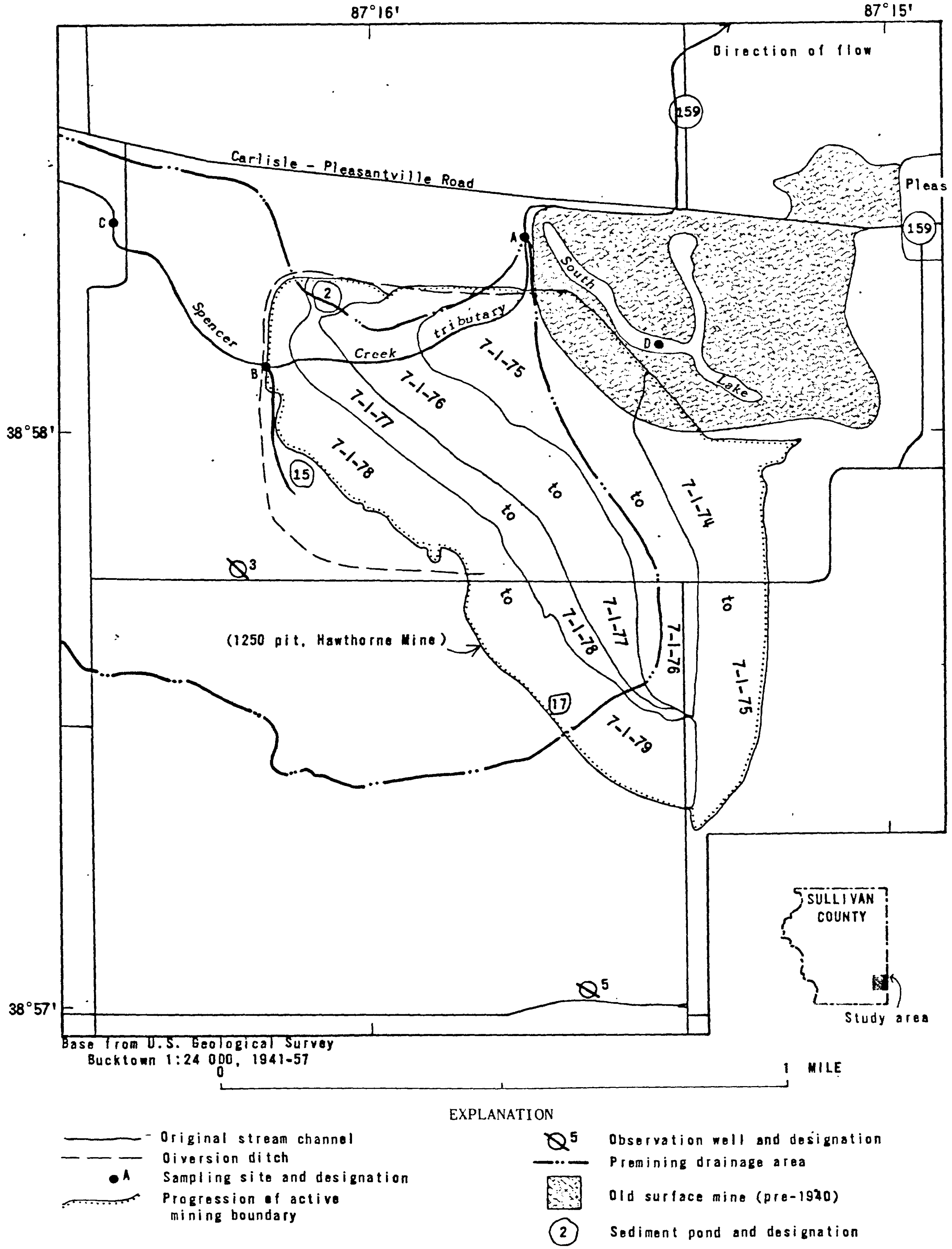
The study area consists of a small drainage basin and an adjacent lake (fig. 3). The premining surface area of the basin, 1,210 acres, was drained by an intermittent tributary to Spencer Creek--part of the White River drainage. Upstream from the mine, the stream drained agricultural land, a small part of which was forested.

South Lake was formed before 1940, when ground-water seepage and surface drainage filled the last cut of a surface-mining operation. The surface area of South Lake is roughly 20 acres, and the depth of the lake is 22.0 ft at sampling site D. The steeply sloping banks, composed of unreclaimed spoil material, are similar to those of most older last-cut lakes. The natural revegetation surrounding the lake is composed mainly of Virginia pine (*Pinus virginiana*), white pine (*Pinus strobus*), and scrub oak (*Quercus ilicifolia*). The litter layer beneath the vegetation is thin or absent in many places.

The lake, which is used primarily for recreation, is periodically stocked with various game fish that provide excellent fishing opportunities (Curtis F. Todd, property manager, Greene-Sullivan State Forest, Jasonville, Ind., oral commun., 1980). Nongasoline-power boats are permitted on the lake.

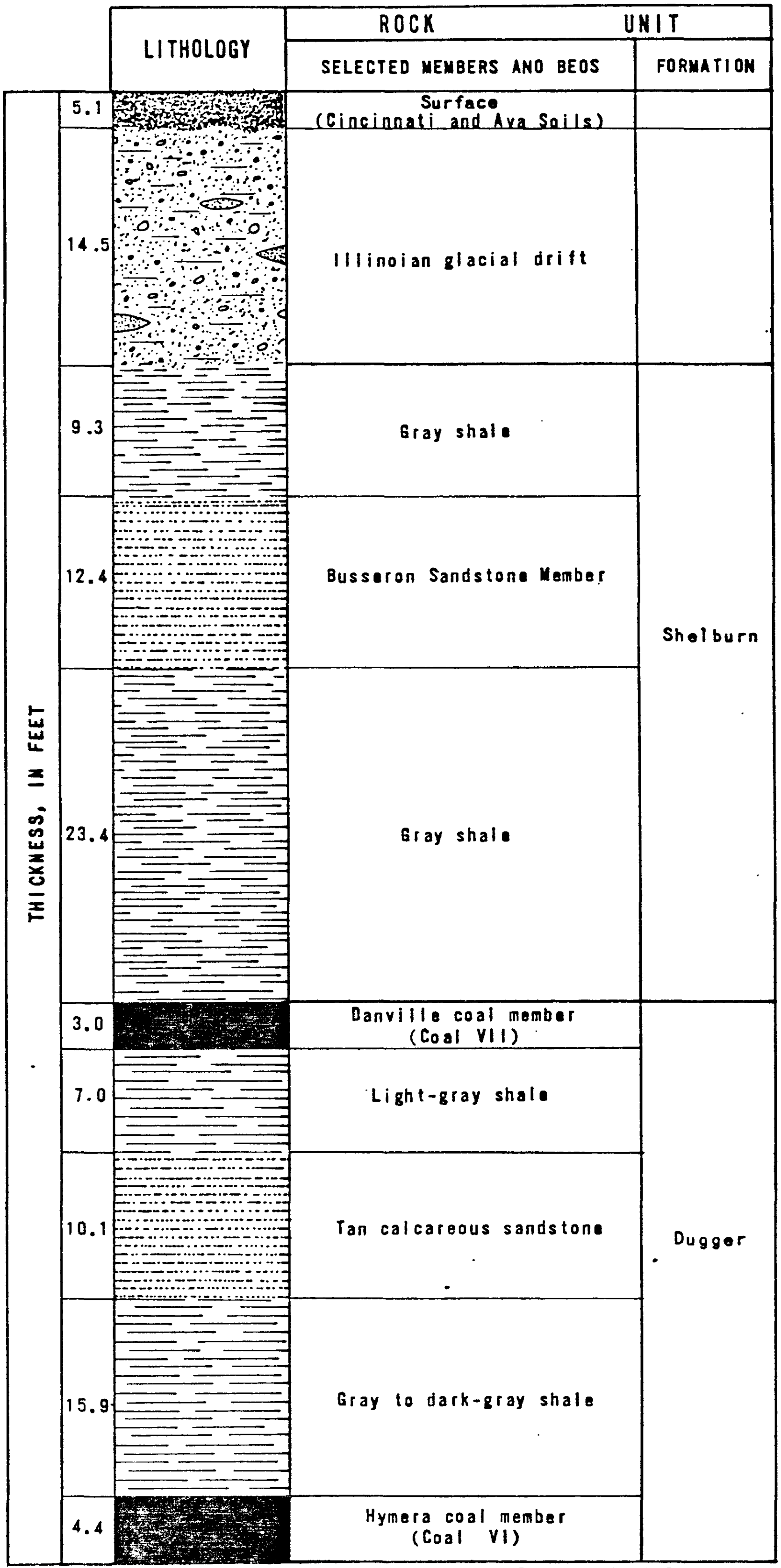
Geology

The bedrock of Middle Pennsylvanian age forms a plunging anticline that dips southwest 10 to 30 ft/mi (Gutschick, 1966, p. 10). Its upper part is composed of 45 ft of gray shale and yellow sandstone (fig. 4). Directly below is the Dugger Formation, whose thickness ranges from 73 to 185 ft and averages 130 ft (Shaver and others, 1970, p. 49). The upper boundary of the Dugger Formation is the uppermost of two commercially mined coal seams--the Danville coal member (coal VII, local usage). Forming the base of this coal member is a light-gray shale underlain by flatbedded tan calcareous sandstone. Below the sandstone is gray to dark-gray shale that overlies the lower commercial coal seam--the Hymera coal member (coal VI, local usage).



Base from U.S. Geological Survey
Bucktown 1:24 000, 1941-57

Figure 3.-- Chronological progression of mining and sampling sites in the study area, Sullivan County, Ind. (progression of mining information from Peabody Coal Company, 1979a).



THICKNESS, IN FEET	LITHOLOGY	ROCK UNIT: SELECTED MEMBERS AND BEDS	ROCK UNIT: FORMATION
5.1		Surface (Cincinnati and Ava Soils)	
14.5		Illinoian glacial drift	
9.3		Gray shale	Shelburn
12.4		Busseron Sandstone Member	
23.4		Gray shale	
3.0		Danville coal member (Coal VII)	Dugger
7.0		Light-gray shale	
10.1		Tan calcareous sandstone	
15.9		Gray to dark-gray shale	
4.4		Hymera coal member (Coal VI)	

Modified from Peabody Coal Co., 1979a

Figure 4.-- Representative geologic column in the study area.

Thus, the bedrock associated with the two commercial coal seams is composed mainly of clay minerals in the form of thin and thickbedded shales. In general, the dark-gray to black shales are thin bedded, and the light-gray shales are thick bedded. The clay minerals are composed mainly of illite and kaolinite (Austin, 1975, p. 27-28).

Both coal seams are composed of a bright-banded (Shaver and others, 1970, p. 41 and 75) high-volatile bituminous coal (Wier, 1951). Thickness of the Danville coal member (coal VII) ranges from 0.2 to 6.5 ft and averages 3.3 ft in Sullivan County (Shaver and others, 1970, p. 41). Clay and shale occur in thin partings, and films of clay are in vertical joints. Pyrite and marcasite, as well as projections of coal called stringers, extending upward from the top of the seam, occur locally (Shaver and others, 1970, p. 41). The stringers are separated from the main coal body by sandstone or silty shale (Wier, 1951).

Thickness of the Hymera coal member (coal VI) ranges from 0.5 to 11.0 ft (Shaver and others, 1970, p. 75). The coal is distinguished by two shale and pyrite partings about 8 in. apart in the upper third of the bed (Wier, 1951). Descriptive characteristics of the two types of coal are presented in table 1.

Table 1.--Characteristics of Danville coal (coal VII) and Hymera coal (coal VI) in Indiana (Wier, 1973, p. 12-14)

Coal	Heat output (Btu/lb)	Ash content (percent by weight)	Sulfur content (percent by weight)
Coal VII	1,230	13.0	2.1
Coal VI	1,260	13.0	2.3

The study area lies within the Illinoian glacial province. Till, comprised of quartz, calcite, dolomite, and clay, overlies the bedrock to a depth of about 15 ft (fig. 4). The clays include illite, chlorite, and mixed-layer clay materials (Austin, 1975, p. 30).

Soils are developed upon residuum formed from the weathering of the till (Ulrich, 1966, p. 81-82). They are represented mainly by the Cincinnati and the Ava soil series (Kelly, 1971, maps 67 and 72). These upland soils, deep and well drained to moderately well drained, consist of a surface layer of dark-grayish-brown and yellow-brown silt and a subsoil that is yellowish-brown silty clay loam (Kelly, 1971, p. 2).

Mining During the Study Period

Except as otherwise stated, the term "mining," as used in this report, includes not only the activities associated with coal removal but also reclamation of the land.

The Hawthorn Mine is operated by the Peabody Coal Company. The mine has two pits, but only one, the 1250 pit (fig. 3), was involved in this study. The stripping machine used was a dragline with a 32-cubic-yard bucket. Recent mining at the 1250 pit began before 1973. However, mining before July 1974 was east of the Spencer Creek tributary watershed.

Mining permits are effective from July 1 of the permit year through June 30 of the following year. During permit year 1974, mining within the watershed was minimal. However, sampling records indicate that water from the 1250 pit was pumped to this drainage area during permit year 1974 (water-quality sampling records, National Pollution Discharge Elimination System file, Indiana State Board of Health, Indianapolis, Ind.). Also, fine particles of coal were noted at site A during the initial sampling in May 1975.

During the summer of 1975, a diversion ditch was constructed around the west boundary of the area of the 1250 pit. Water from the pit was pumped through the diversion ditch to the Spencer Creek tributary drainage. Also during the summer, mining began in the Spencer Creek tributary drainage watershed. In the latter part of permit year 1975, the first sediment pond (pond 2, fig. 3) was constructed in the northwest corner of the mining area. About 33 acres of the drainage area was disturbed by mining during permit year 1975.

During permit year 1976 and thereafter, all pit pumpage entering Spencer Creek tributary flowed through a sediment pond 2. Also during this period, an additional 63 acres within the watershed was disturbed by mining.

From December 1977 through March 1978, no coal was mined at the 1250 pit. Only a 38-acre area was disturbed by mining in permit year 1977.

Beginning in May 1978, a change in mining regulations provided for saving and stockpiling topsoil, which increased the area disturbed by mining. In August 1978, a second sediment pond (pond 15, fig. 3) was constructed at the west boundary of the mining operations. Pond 15 was designed to treat both surface runoff and pit pumpage. Ponds 2 and 15 were used alternately during permit year 1978, depending on the location of the mining in the pit. Water-quality and discharge data for the two sediment ponds are presented in table 2, after References. A third sediment pond (pond 17, fig. 3) drained out of the tributary watershed and was not considered in the study. Mining disturbed 106.5 acres in permit year 1978.

Before the summer of 1979, two observation wells for monitoring water quality were drilled by the Peabody Coal Company in the vicinity of the 1250 pit. Well 3 is immediately west of the active mining operation, and well 5 is about 1 mi southeast of well 3 (fig. 3). These wells were sampled by Peabody personnel, first on June 26, 1979, and again on September 11, 1979. Water-quality data for the wells are presented in table 3, after References.

A summary of the area disturbed by mining and the amount of coal production for the 1250 pit is presented in table 4. Total coal production for Indiana from 1974 to 1978 was 122.8 million tons. Production at the 1250 pit during this period was about 1.9 million tons, which was about 2 percent of the State's production. (See Indiana Bureau of Mines and Mining, 1974-78.)

Table 4.--Disturbed surface area and coal production during the study period at the 1250 pit, Hawthorn Mine, Sullivan County, Ind.

Permit year	Total new disturbed area[1] (acres)	Calendar year	Coal production (tons)		
			Coal VII[2]	Coal VI[2]	Total
1974	62.0	1974	227,800	297,000	524,800
1975	82.0	1975	252,600	243,000	495,600
1976	63.0	1976	200,000	216,600	416,600
1977	38.0	1977	144,700	206,200	350,900
1978	106.5	1978	110,200	239,900	350,100
	-----	1979	238,600	297,300	535,900
Total	351.5				2,673,900

[1] From Indiana Department of Natural Resources, Mining Permit Form R-101, Division of Reclamation, Jasonville, Ind.

[2] Kurt M. Belton, Engineering Manager, Peabody Coal Co., oral commun., 1980.

Reclamation of the disturbed areas was started shortly after coal removal. Each area was generally graded within a year after the initial disturbance. From 1974 to 1977, the spoil piles were graded to a gently rolling topography that trapped part of the surface runoff. Seeding of grasses and legumes and, in some areas, the planting of trees followed grading a year later (Peabody Coal Co., 1979b). In May 1978, reclamation grading was changed so that topography was returned to the approximate original contour. Revegatation consisted primarily of planting grasses, legumes, and annual grains.

Information on mining was supplied to the author by Joyce Fitzgerald, Nancy Alumbaugh, Joe Ellis, and Forrest Crow (Indiana Division, Peabody Coal Co., written and oral communs., 1979-80).

COLLECTION OF DATA

Spencer Creek Tributary

Two sampling sites were initially selected on the Spencer Creek tributary. Site A (fig. 3), downstream from the mine, had a premining drainage area of approximately 1,210 acres. Site B, upstream from earlier mining, was selected to provide background data. In March 1977, progression of mining required that background data be collected at a new site (site C). Upstream land use was virtually identical for sites B and C, and the combined data were used for comparisons with data from the mined site. The drainage areas for sites B and C were 128 acres and 51 acres, respectively. Throughout the report, site A is referred to as the mined site and sites B and C as the background sites.

South Lake was sampled at site D (fig. 3) at approximately the middle of the lake.

Field parameters--water temperature, pH, specific conductance, and dissolved oxygen--were measured at stream sites during all sampling surveys. The parameters were measured with multi-parameter water-quality instruments, which were calibrated in the field at the start of each sampling day. For several samplings, alkalinity measured in the field was compared with alkalinity measured in the laboratory. No notable differences were detected.

Water and streambed samples from stream sites were collected by point-sampling techniques. This method was assumed to provide representative sampling because the flows were very small and complete mixing of the water column was virtually assured.

All water and streambed samples were prepared in the field for shipment to the U.S. Geological Survey Central Laboratory in Doraville, Ga. Analysis of water samples included measurement of concentrations of major cations and anions, dissolved and total metals, dissolved and total organic carbon, dissolved and total solids, and hardness. Analysis of streambed samples included measurement of weight of metals sorbed on streambed material relative to weight of sample. Methods of chemical analysis used are listed in U.S. Geological Survey (1979). Instantaneous streamflow was measured directly by a current meter during several surveys. For the remaining surveys, streamflow was approximated from estimates of depth, width, and velocity of flow.

South Lake

The lake was sampled from a small rowboat. Water samples were collected at several depths with a Kemmerer-type water sampler. In addition to most water-quality parameters mentioned for the stream sites, phytoplankton samples were collected at South Lake. Total cell count and percentage of total cells within each class of phytoplankton were determined for these samples. During selected surveys, field parameters were measured at various depths for use in constructing vertical lake profiles.

DISCUSSION OF RESULTS

All data collected by the U.S. Geological Survey during the study are presented in tables 5, 6, and 7. Some of the data has been analyzed and has been interpreted. Tables and illustrations used for descriptive purposes are also included in the text. The data are presented in this way to permit further analysis by the reader if desired.

All data collected by the Geological Survey were examined to determine whether the various concentrations of each constituent at each site were normally distributed. In this determination, the author used the Kolmogorav-Smirnov test for normality of data, described by Haan (1977, p. 176), and tables developed by Lilliefors (1967, p. 400). Calculations were done by the SAS computer system for data analysis (SAS Institute, Inc., 1979). Most of the data were not normally distributed. Transformation of the data to log base e did not significantly improve the results. Thus, nonparametric methods were used for data analysis and interpretation. Medians were used as the measure of central tendency, and maximum and minimum values were presented to define the extremes of the sample values. No quantitative measure of confidence was assigned to the results.

Spencer Creek Tributary

Field Measurements

The descriptive statistics for field measurements at the Spencer Creek tributary sites are presented in table 8. The maximum temperature recorded at site A was 13° C higher than that at the background sites. Because flow was sufficient for sampling at the background sites only during winter and spring, a low bias was introduced to stream temperatures measured at these sites. Stream temperature was measured 10 times at the background sites and 31 times at the mined site. For the 10 days that temperature was measured at both background and mined sites, the median temperature was 12.6° C at the two background sites and 13.1° C at the mined site.

The only streamflow measurements at the background sites were 0.6 and 2.6 ft^3/s, at site B. Corresponding flows at the mined site were 12.1 and 25.8 ft^3/s. Streamflow was measured 15 times at the mined site. The maximum recorded flow was 25.8 ft^3/s, but the median flow was only 0.4 ft^3/s. The large difference between these values indicates that flows were generally much lower than 25.8 ft^3/s. Only three of the 15 measurements were greater than 2.0 ft^3/s.

Dissolved-oxygen concentration did not change noticeably from upstream at the background sites to downstream at the mined site. The difference in median concentrations was only 0.2 mg/L. The high concentrations at both sites (tables 5 and 6) suggest that oxidizing conditions prevailed throughout the reach of Spencer Creek tributary that was studied.

Values of pH, both upstream and downstream from the mine, were generally close to neutrality. More importantly, pH tended to increase downstream from the mine. All minimum, maximum, and median pH values for site A were somewhat higher than analogous values at sites B or C.

Median specific conductance downstream from the mine was nearly 9 times that at the background sites. Maximum specific conductance at the mined site was 4,560 μmho/cm at 25° C and at the background site was 480 μmho/cm at 25° C. The difference indicates that mining released large amounts of dissolved constituents to the stream. Similar increases in dissolved-solids concentration downstream from the mine confirms this assumption (table 9). Median and maximum dissolved-solids concentrations increased from 199 and 278 mg/L, respectively, at the background sites, to 1,860 and 3,690 mg/L, respectively, at the mined site.

Brown and others (1970, p. 145) stated that, for most waters, dissolved-solids concentration, in milligrams per liter, can be adequately estimated from specific conductance, in micromhos per centimeter at 25° C, by multiplying the latter by 0.65. The median ratio of dissolved solids to specific conductance was 0.65 for the background sites. However, at the mined site,

Table 8.--Values of field measurements at background and mined sites, Spencer Creek tributary, Sullivan County, Ind., 1975-79

Field measurements	Number of measurements	Minimum	Maximum	Median
Sites B and C (background sites)				
Temperature (°C)	10	0.6	19.9	12.6
pH	10	5.6	8.2	7.0
Specific conductance (µmho/cm at 25° C)	10	48	480	272
Dissolved oxygen (mg/L)	10	5.5	14.2	8.9
Streamflow (ft^3/s)	2	.6	2.6	-----
Site A (mined site)				
Temperature (°C)	31	0.2	32.9	14.4
pH	31	6.7	8.5	7.9
Specific conductance (µmho/cm at 25° C)	31	132	4,560	2,375
Dissolved oxygen (mg/L)	29	2.7	14.5	8.7
Streamflow (ft^3/s)	15	.0	25.8	.4

Table 9.--Concentrations of major ions and dissolved solids at background and mined sites, Spencer Creek tributary, Sullivan County, Ind., 1975-79

Dissolved constituents and dissolved-solids concentrations	Number of measurements	Minimum	Maximum	Median
		(milligrams per liter)		
Sites B and C (background sites)				
Sodium	10	1.7	11	20
Potassium	10	1.9	2.5	4.9
Calcium	10	7.3	39	25
Magnesium	10	3.1	19	12
Chloride	10	2.8	14	7.4
Bicarbonate	10	12.2	114	62
Sulfate	10	21	120	77
Dissolved solids	10	6.2	278	199
Site A (mined site)				
Sodium	31	11	800	360
Potassium	31	2.4	9.7	5.4
Calcium	31	12	250	102
Magnesium	31	5.4	140	67
Chloride	31	3.1	29	13.5
Bicarbonate	31	23.2	611	276
Sulfate	31	44	2,200	1,100
Dissolved solids	31	107	3,690	1,860

the median ratio increased to 0.77. Curtis (1977) found an increase in the ratio after mining on two watersheds in Kentucky. Higher ratios are predicted for waters with high sulfate concentrations (Hem, 1970, p. 99) such as at the mined site.

Major Dissolved Ions

A knowledge of the concentration of the major ions in a stream is helpful in evaluating the geochemical environment of the stream's drainage area. In the Spencer Creek tributary, concentrations of major cations and anions consistently increased to above-background concentrations at the mined site (table 9). Because of the importance of these increases, a brief discussion of the more significant mechanisms involved in ion availability and transport is appropriate.

Surface mining fragments bedrock material and exposes it to increased weathering, which results in higher concentrations of dissolved solids in water draining the area. Weathering is more effective in breaking down overburden material if hydrogen ions react with alumino-silicate minerals such as the illite and kaolinite prevalent in Indiana shales. The resulting breakdown in the clay matrix releases cations to water draining the spoil piles (Freeze and Cherry, 1979, p. 270.).

Exposure of overburden material during the mining operation also speeds up the oxidation of iron sulfides (pyrite and marcasite) and creates a potential for acid production. The oxidation is a two-step process involving both the iron and sulfur (Barnes and Romberger, 1968):

$$2\ FeS_2 + 2\ H_2O + 7\ O_2\ (g) \rightleftarrows 2\ Fe^{+2} + 4H^+ + 4\ SO_4{}^{-2} \qquad (1)$$

$$4\ Fe^{+2} + 10\ H_2O + O_2\ (g) \rightleftarrows 4\ Fe(OH)_3 + 8H^+ \qquad (2)$$

Evidence indicates that the ferric ion (Fe^{+3}) reacting directly with iron sulfide (FeS_2) can also oxidize sulfur (Garrels and Thompson, 1960).

$$FeS_2 + 8\ H_2O + 14\ Fe^{+3} \rightleftarrows 15\ Fe^{+2} + 2\ SO_4{}^{-2} + 16\ H^+ \qquad (3)$$

Though the reaction in equation 3 proceeds very rapidly, the large requirement for ferric iron reduces its importance in the natural system (Barnes and Romberger, 1968). Reactions 1 and 2 indicate that, for each molecule of iron sulfide that is oxidized, 4 equivalents of acidity are ultimately released--2 from the oxidation of sulfur and 2 from the oxidation of iron (Singer and Stumm, 1968). These reactions unquestionably provide the major source of hydrogen ions in mine drainage (Barnes and Romberger, 1968, p. 374).

Musser (1965) listed three requirements for the production of acid in spoil piles and its subsequent transport to streams: (1) iron sulfides in overburden and coal, (2) sufficient rainfall and runoff, and (3) low natural alkalinity in streams. Mining in geologic formations containing significant amounts of carbonate material might produce enough buffering capacity to offset acid production in the spoil piles. There is an increase in both the alkalinity and the pH of acidic water passing over carbonate material such as that in the overburden at the Hawthorn Mine (Jennett and Foil, 1979).

Cation exchange is another mechanism that might reduce hydrogen ion concentration in spoil drainage between the time of acid production in the spoil piles and subsequent movement of the water to the stream. Cation exchange is the ability of one cation to replace another cation that has been sorbed by a negatively charged clay particle. In general, divalent cations replace monovalent cations. However, hydrogen ions, though monovalent, have a high charge density that provides replacing power equal to divalent or even trivalent ions (Grim, 1953, p. 146). Hydrogen ions tend to be preferentially sorbed by clay particles while releasing other cations into solution. Thus, the ion exchange of hydrogen ions released through iron sulfide oxidation would tend to increase pH and concentrations of other cations in streams.

The preceding discussion should be useful in interpreting changes to ionic concentration in the Spencer Creek tributary. At all the background water-sampling sites, calcium was the dominant cation. Median concentrations of sodium, magnesium, and potassium followed in decreasing order (table 9).

The cation concentrations, whose medians ranged from 4.9 mg/L (for potassium) to 25 mg/L (for calcium), are generally associated with soft to moderately hard water (Durfor and Becker, 1964, p. 27).

Anion concentrations at background sites were generally dominated by sulfate, although on April 23, 1976, and May 14, 1976, bicarbonate concentrations were greater (table 5). Median concentrations of sulfate and bicarbonate were 77 and 62 mg/L, respectively (table 9). Chloride concentration, which was never more than 10 percent of the total anion concentration at the background sites and was usually a much lower percentage, had a median concentration of only 7.4 mg/L.

Most of the sulfate at the background water-sampling sites probably resulted from the slow oxidation of pyrite (equations 1 and 2) commonly found in the study area (Don L. Eggert, Geologist, Indiana State Geological Survey, oral commun., 1980). Background concentrations of bicarbonate probably resulted from the dissolution of carbonate minerals in the glacial material and underlying shales.

Concentrations of all cations at the mined site (table 9) exceeded those at background sites. The increase in median potassium concentration was the least increase of all median cation concentrations; median calcium concentration increased about fourfold, and median magnesium concentration increased more than fivefold.

Among both cations and anions, sodium demonstrated the most notable increase in median concentration, eighteenfold, from background to the mined site. In terms of maximum concentration, the increase was more than seventyfold. Increases in sodium concentration in streams draining mined areas have been reported for Kentucky, but the increases are less than those in Spencer Creek tributary. Dyer and Curtis (1977) reported that sodium concentrations from mined watersheds were about twice as great as those from unmined watersheds. They also reported that sodium concentration accounted for less than 10 percent of the total cation concentrations from mined watersheds.

Exchange of calcium for sodium on the clays is a possible explanation for the large increases in sodium concentrations for streams associated with mining in the study area. Hanshaw (1964) indicated that sodium ions might tend to be preferentially adsorbed by compacted clays but that clays, when broken up and dispersed in water (such as during mining), tend to release sodium ions and preferentially adsorb calcium ions. This evidence is supported by cation-exchange mechanisms; that is, divalent ions tend to replace monovalent ions on clay particles. Also, among cations of the same valence, the greater the diameter the greater the replacing power (Blatt and Murray, 1972, p. 246-247). A grouping of cations in decreasing order of exchangeability is called a lyotropic series. For the major cations, this series can be written as:

$$\mathrm{Ca} > \mathrm{Mg} > \mathrm{K} > \mathrm{Na}.$$

The grouping indicates that calcium can easily replace sodium on clay particles. Sodium is more soluble than calcium and, once in solution, tends to remain dissolved (Hem, 1970, p. 145). Thus, during mining, an increase in sodium concentration in streams draining the area is likely.

Data for water samples collected from observation well 3 (table 3) indicate a higher concentration of sodium than calcium in the ground water. Data reported by Watkins and Jordan (1962, p. 318) indicate similar findings. Ground water could have provided the source of sodium ions for adsorption on clay particles.

Among the anions, the median chloride concentration at the mined site was nearly twice that of background concentration (table 9). The median bicarbonate concentration at the mined site was more than four times that of the background concentration.

Of all the anions, greatest increase in the median concentration was the fourteenfold increase over the median background concentration for sulfate. The increase in sulfate indicates that pyrite was being oxidized in the spoil piles and was being leached into the Spencer Creek tributary. Sulfate concentration, which has also increased in response to mining and other earth moving at six watersheds in Kentucky, was generally less than 15 mg/L before mining and a maximum of 625 mg/L after mining (Dyer and Curtis, 1977). Further, the dominance of sulfate increased as the percentage of mined area on a watershed increased in West Virginia (Corbett, 1977). Thus, the sulfate concentrations of Spencer Creek tributary were somewhat higher than concentrations for other streams draining mined and unmined watersheds.

The increase in sulfate concentration at site A was not accompanied by a decrease in pH. In fact, minimum, median, and maximum pH were actually higher at the mined site than at the background sites (table 8). As noted previously, bicarbonate concentrations at the mined site were also higher than background values. Thus, buffering from bicarbonate concentration was probably partly responsible for pH being higher at the mined site than at the background sites.

Increases in bicarbonate concentrations (from those at background sites to those at the mining site) were less than increases in sulfate concentrations, and, thus, the increase in pH at the mined site may not be due to buffering alone. Dyer and Curtis (1977) noted increases in stream pH after mining and concluded that carbonate buffering partly explains the results but that cation exchange between hydrogen ions and calcium, magnesium, sodium, and potassium accounts for some of the increase. Thus cation exchange tends to increase the pH and the concentrations of other cations.

The milliequivalent concentrations of major cations and anions are presented in patterns suggested by Stiff (1951). Concentrations of major cations and anions for representative samples of stream water collected at the background and mined sites are presented in figure 5. Samples having the median dissolved-solids concentrations were assumed to be representative.

The ionic composition of water is often qualitatively represented by a "water type." Figure 5 indicates that the water type of the representative water sample from the background site is a mixed cation-mixed anion type and that the water type of the representative sample from the mined site is a mixed cation and sulfate water type.

In Pennsylvania, Biesecker and George (1966) concluded that sulfate concentrations greater than 20 ppm can be used as an index to mining whether the environment is alkaline or acidic. Sulfate has this versatility because, unlike most other constituents, concentrations are relatively insensitive to changes in pH (Corbett, 1977). The present study showed that sulfate concentrations less than 44 mg/L indicate background conditions and that concentrations greater than 120 mg/L indicate mining.

Campbell and Lind (1969) suggested that the ratio of sulfate to bicarbonate concentrations can be used to indicate mining. The sulfate-to-bicarbonate ratio at the background sites on the Spencer Creek tributary ranged from 0.88 to 2.04. At the mined site, the ratio ranged from 1.64 to 7.05. Thus, for the present study, ratios greater than 2.04 indicate the influence of mining, whereas ratios less than 1.64 indicate background concentrations.

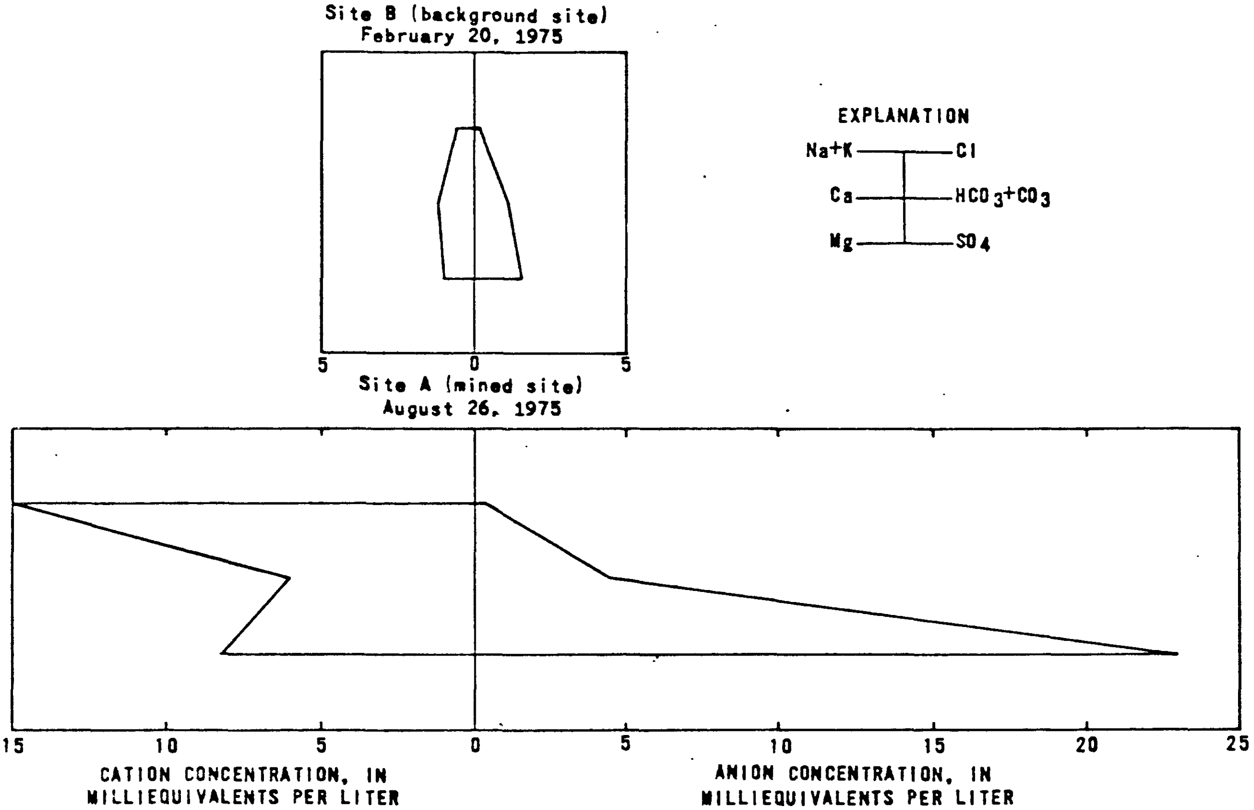


Figure 5. -- Patterns representing analyses of water samples collected at background and mined sites, Spencer Creek tributary.

Dissolved and Suspended Metals

Rocks associated with coal-bearing formations contain metals (Corbett, 1977; Caruccio, 1972; Noyes, 1978, p. 116-117). Aluminum, iron, and manganese contents are generally greater than those of other metals.

Aluminum oxide is abundant in the alumina-silicate clays in the study area. Aluminum oxide is generally about one-third the total composition of kaolinite and about one-fourth that of illite (Grim, 1953, p. 370 and 372). Iron is released through the exposure and the oxidation of iron sulfides. Manganese is widely distributed in rocks and soils and is more soluble at the pH and oxidation conditions in the study area than iron is (Hem, 1970, p. 119, 126, and 128).

Trace metals are generally found in coal and the overburden material associated with it. Trace-metal contents of coal, pyrite, and clays from several sources are presented in table 10.

Concentrations of ten different metals in surface water at the background and the mined sites on Spencer Creek tributary were determined. Water samples were analyzed for both dissolved and total metals. Suspended-metal concentrations were calculated by subtracting dissolved concentrations from total concentrations. Additionally, the quantities of metals sorbed on streambed materials were measured.

Maximum dissolved concentrations of the ten trace metals were greater at the mined site than at background sites (table 11). Median concentrations of aluminum, cobalt, manganese, nickel, and zinc were greater at the mined site than at the background sites. Median and maximum concentrations of dissolved manganese were 285 and 1,800 mg/L, respectively, at the mined site and were an order of magnitude greater than concentrations of dissolved iron and aluminum.

The U.S. Environmental Protection Agency's (1976) recommended maximum concentrations of selected dissolved metals in domestic drinking-water supplies and concentrations of those metals in Spencer Creek tributary are listed in table 11. Though the tributary is not used for domestic water supply, the information provides a useful point of reference with which to compare the water quality of the tributary.

Median and maximum dissolved-manganese concentrations at the mined site and maximum dissolved-manganese concentration at the background site exceeded maximum concentrations recommended for domestic drinking water. Maximum concentrations of dissolved nickel at both the background and the mined sites, as well as the median concentration at the mined site, exceeded the drinking-water standard. Maximum dissolved-iron concentration at the mined site also exceeded the drinking-water standards.

Because metal ions have a positive charge, they are attracted electrostatically to fine clay particles having a net negative charge. In low pH water, this association usually represents an insignificant transport mechanism for metals (Gang and Langmuir, 1974); but in a well-buffered system with neutral pH, the sorption of metals on suspended sediment can be significant. Precipitation, co-precipatation, and chelation can also remove ions from solution.

Concentrations of suspended iron and aluminum in the Spencer Creek tributary were noticeably greater than concentrations of other metals at both the background and mined sites (table 12). Maximum and median concentrations of all suspended metals above the detection limit were greater at the mined site than at the background sites. Concentrations of suspended aluminum, chromium, iron, and manganese were much greater at the mined site (table 12).

Suspended material was an important transport mechanism for metals in Spencer Creek tributary because suspended-metal concentrations (table 12)

Table 10.--Trace-metal content of selected pyrites, bituminous coals, and associated shales

[Adapted from table 2, Gang and Langmuir, 1974, p. 47, who obtained data on pyrites from Fleischer (1955); on bituminous coals from O'Gorman (1971), and on shales from Degens and others (1957); unit of measure, part per million; ND, below detection limit]

Trace metal	Pyrites		Coal samples						Shale samples					
	Maximum content	Typical content range							Fresh	Brackish			Marine	
			1	2	3	4	5	6	1	2	3	4	5	6
Chromium	-------	----------	260	200	220	220	100	490	150	150	70	40	60	70
Copper	60,000	<10-10,000	425	125	76	300	310	430	70	90	80	80	80	80
Lead	5,000	200-1,000	38	112	23	210	100	170	40	20	35	30	40	40
Zinc	45,000	500-10,000	72	190	62	310	160	410	ND	ND	ND	ND	ND	ND
Cobalt	>25,000	100-5,000	26	100	320	290	100	26	ND	10	ND	ND	20	10
Nickel	25,000	10-1,000	95	170	61	185	105	135	30	30	15	30	80	40

Table 11.--Maximum concentrations of dissolved metals for domestic drinking-water supply and minimum, maximum, and median concentrations of dissolved metals at background and mined sites, Spencer Creek tributary, Sullivan County, Ind., 1975-79

[Unit of measure, microgram per liter]

Dissolved metal	Number of measurements	Minimum	Maximum	Median	Maximum concentrations recommended for domestic drinking water supply[1]
Sites B and C (background sites)					
Aluminum	10	10	200	20	-----
Cadmium	6	<1	1	<1	10
Chromium	8	<1	10	10	50
Cobalt	7	<1	2	<1	-----
Copper	8	<1	2	<1	1,000
Iron	10	20	100	30	300
Lead	7	<1	2	<1	50
Manganese	10	10	250	40	50
Nickel	8	<1	15	2	2
Zinc	8	<10	10	<1	5,000
Site A (mined site)					
Aluminum	29	<10	310	30	-----
Cadmium	23	<1	2	<1	10
Chromium	25	<1	20	10	50
Cobalt	25	<1	11	1	-----
Copper	26	<1	20	<1	1,000
Iron	31	<10	350	20	300
Lead	25	<1	12	<1	50
Manganese	31	10	1,800	285	50
Nickel	26	<1	64	8	2
Zinc	26	<10	50	10	5,000

[1] From U.S. Environmental Protection Agency (1976).

Table 12.--Concentrations of suspended metals at background and mined sites, Spencer Creek tributary, Sullivan County, Ind., 1975-79

[Unit of measure, microgram per liter]

Dissolved metal	Number of observations	Minimum	Maximum	Median
		Sites B and C (background sites)		
Aluminum	10	<10	4,900	160
Cadmium	--	---	------	---
Chromium	8	<1	10	<1
Cobalt	6	<1	2	<1
Copper	8	<1	20	<1
Iron	10	60	9,020	370
Lead	7	<10	2	<10
Manganese	10	<1	300	10
Nickel	8	<10	21	<10
Zinc	8	<10	40	<10
		Site A (mined site)		
Aluminum	28	30	28,000	610
Cadmium	23	<1	1	<1
Chromium	24	<1	340	7
Cobalt	23	<1	22	<1
Copper	26	<10	50	7
Iron	30	70	39,980	990
Lead	24	<10	30	<10
Manganese	30	<1	1,050	30
Nickel	26	<10	270	<10
Zinc	26	<10	100	10

generally equaled or exceeded dissolved concentrations (table 11) at background and mined sites. An example is the dominance of suspended iron over dissolved iron. In a well-oxygenated aqueous environment, at near neutral pH, ferrous iron rapidly oxidizes to ferric iron (Wilmoth and others, 1974). Because the ferric ion forms complexes much more readily than ferrous ion (Stumm and Morgan, 1970, p. 53), most of the iron is adsorbed by clay particles or transported as a flock, which produce the high suspended-iron concentrations. Suspended-iron concentrations were higher than dissolved-iron concentrations for all surveys at both sites (tables 5 and 6).

In contrast to the median concentrations of most other metals, the median dissolved-manganese concentration was greater than the median suspended-manganese concentration at both background and mined sites. Because the solubility of manganese is greater than that of other metals at the pH and oxidation conditions during the study, dissolved-manganese concentrations exceeded those of suspended manganese during 80 and 86 percent of the surveys at the background and mined sites, respectively (tables 5 and 6).

The author attempted to determine the phase (dissolved or suspended) in which the metals were most effectively transported. Transport effectiveness is defined as metals load per unit solids load and is calculated by dividing the concentrations of individual dissolved and suspended metals by the concentrations of total dissolved and total suspended solids, respectively. These ratios were then converted to the unit milligram per kilogram (part per million), which is a convenient unit commonly used in literature. Suspended-solids data were limited to two surveys at the background sites and four surveys at the mined site (table 13).

Ratios for suspended metals were usually greater than those for dissolved metals at both mined and background sites. Of the 42 pairs of ratios calculated, 32 showed that, for each unit of solids, more metals were transported in the suspended phase than in the dissolved phase. Thus, even though suspended-solids concentrations were low compared to dissolved-solids concentrations, metals were generally transported more effectively (that is, higher metals load per unit solids) in the suspended phase than in the dissolved phase.

The concentrations of suspended copper, nickel, and zinc at the mined site were greater than those at the background sites. The ratio of suspended metals to suspended solids for each of these three metals was generally greater at the mined site. However, few data are available, and no reliable conclusions on metals enrichment of sediment from mining operations are possible.

The probable effect of the sediment ponds on reducing suspended-sediment concentrations can be demonstrated from suspended-metal data. Median concentrations of suspended iron, aluminum, and manganese, by permit year, are presented in figure 6. Suspended concentrations for each of the three metals were maximums in permit year 1975, the only period when coal was mined within the study area and pit pumpage discharge was not treated in sediment ponds. Though the size of land-disturbed areas within the drainage area was increased each permit year after 1975, sediment concentrations were reduced

Table 13.--Ratios of concentrations of dissolved metals to dissolved solids and of suspended metals to suspended solids for background and mined sites, Spencer Creek tributary, Sullivan County, Ind.

[Ratios based on milligram per kilogram; site A, mined; site C, background]

Sampling site and date	Type of ratio	Aluminum	Chromium	Copper	Iron	Manganese	Nickel	Zinc
Site C (3/21/78)	Dissolved[1]	[1]350.9	[1]17.5	[1]17.5	[1]350.9	[1]263.2	[1]17.5	[1]87.7
	Suspended[2]	[2]13,913.0	[2]115.9	[2].0	[2]2,550.7	[2]579.7	[2]29.0	[2,3].0
Site C (5-18-78)	Dissolved[1]	100.0	[3].0	[3].0	500.0	1,250.0	75.0	50.0
	Suspended[2]	[3].0	526.3	[3].0	23,684.0	1,052.6	[3].0	[3].0
Site A (3-21-78)	Dissolved[1]	138.7	[3].0	2.7	221.9	499.3	15.2	13.9
	Suspended[2]	71,429.0	64.9	77.9	128,831.0	2,013.0	110.4	257.7
Site A (3-22-78)	Dissolved[1]	27.8	2.8	[3].0	27.8	527.8	18.5	[3].0
	Suspended[2]	12,857.0	50.0	21.4	214.3	71.4	42.9	142.9
Site A (5-18-78)	Dissolved[1]	110.9	[3].0	2.2	266.1	310.4	[3].0	22.2
	Suspended[2]	12,000.0	500.0	[3].0	23,000.0	500.0	400.0	[3].0
Site A (7-13-78)	Dissolved[1]	17.5	[3].0	.6	2.9	137.4	8.5	2.9
	Suspended[2]	350,000.0	375.0	212.5	111.1	4,888.9	287.5	500.0

[1] Ratio of dissolved metal to dissolved solids.

[2] Ratio of suspended metal to suspended solids.

[3] Zero values indicate that the metal concentration was less than the detection limit.

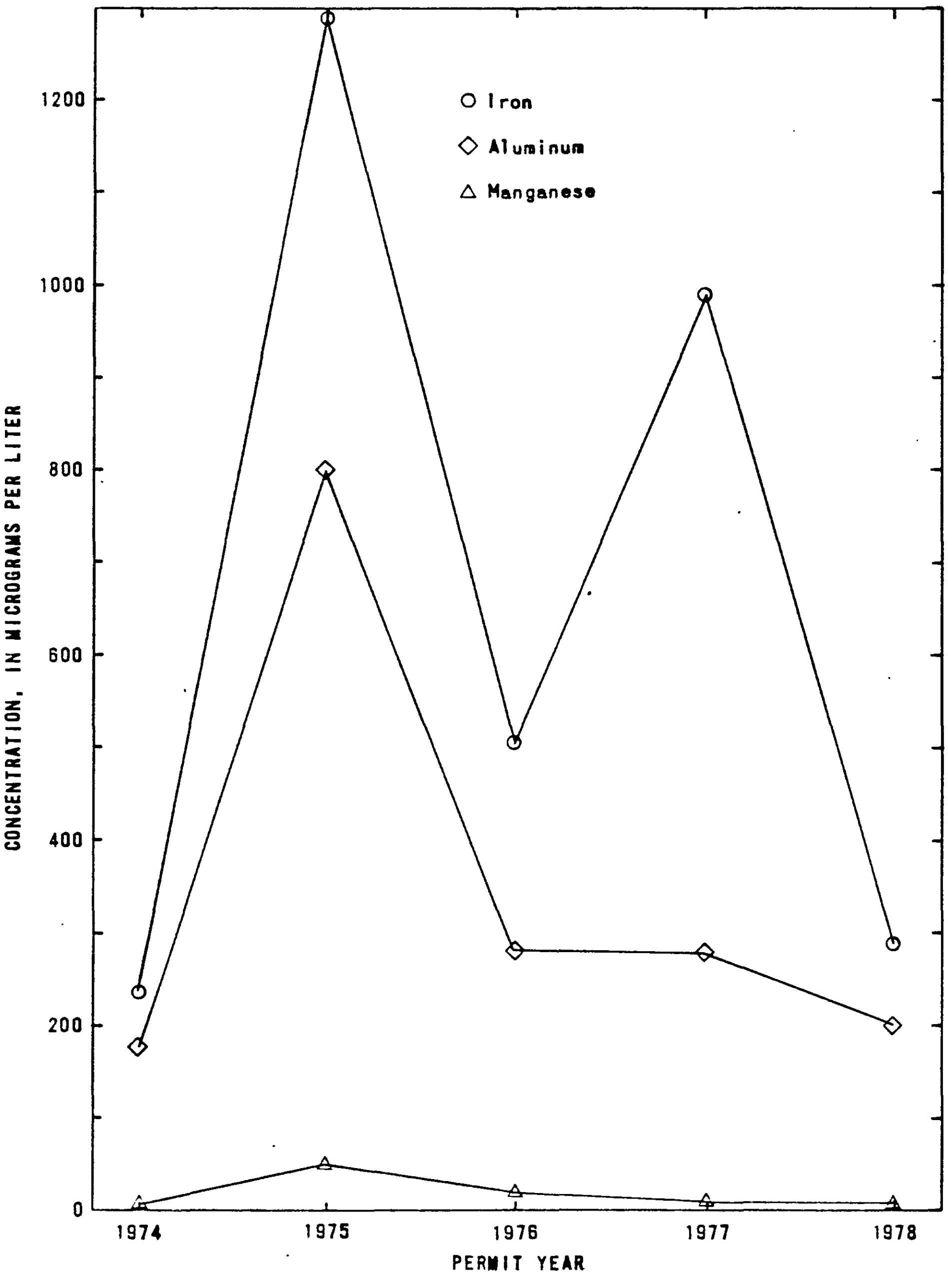


Figure 6. -- Median concentrations of suspended iron, aluminum, and manganese for each permit year (July 1-June 30) at mined site, Spencer Creek tributary.

substantially, presumably by the use of sediment ponds. Average reductions in median-sediment concentrations after sediment ponds were installed were 54, 68, and 73 percent for iron, aluminum, and manganese, respectively.

Streambed Materials

When collecting samples of streambed material for determining quantities of metals sorbed to the sediment, the author attempted to collect a representative sample across the stream bottom. However, the distribution of sediment-particle sizes from one survey to the next and from one site to another probably varied. Because samples were not divided into particle-size classes, quantitative comparisons among the sites or among the different surveys could not be made. However, the amounts of different metals within individual samples were compared, and the presence or absence of metals in a sample was noted.

Quantity of iron sorbed on streambed materials was the highest of all metals associated with streambed materials in the Spencer Creek tributary (table 14), and quantities of aluminum and manganese were consistently high. Quantity of cadmium sorbed was the lowest of all the metals. Mining did not seem to be affecting amounts of metals sorbed on streambed materials.

Specific Conductance and Mining

The effect of the progression of mining and reclamation on water quality was examined by plotting specific conductance and concentrations of dissolved solids and sulfate against permit year. The trends of these three variables were the same for each of the five permit years from 1974 to 1978 (fig. 7). Because of its ease of measurement, specific conductance is perhaps the most convenient indicator of mining (Curtis, 1977). Median specific conductance values used in this section were calculated from data in table 6.

There was no mining within the drainage area of site A during permit year 1974, but the Spencer Creek tributary basin did receive pit discharge upstream from site A during that time. Median specific conductance during this period was 2,045 µmho/cm at 25° C.

Mining began in the Spencer Creek tributary basin during permit year 1975 and disturbed 33 acres within the drainage area. Pit discharges entered the stream by way of the recently completed drainage ditch. Median specific conductance during the mining period increased 27 percent over that for the previous permit year to 2,590 µmho/cm.

Table 14.--Quantities of metals sorbed on streambed materials at background and mined sites, Spencer Creek tributary, Sullivan County, Ind., 1975-79

[Unit of measure, milligram per kilogram]

Metal	Number of measurements	Minimum	Maximum	Median
Sites B and C (background sites)				
Aluminum	9	940	4,500	2,950
Cadmium	7	>1	10	>1
Chromium	8	3	90	8
Cobalt	7	10	860	17
Copper	8	4	340	7
Iron	9	2,300	26,000	12,500
Lead	7	10	1,000	19
Manganese	9	180	2,200	760
Nickel	8	10	670	18
Zinc	8	10	31	17
Site A (mined site)				
Aluminum	30	10	5,300	2,400
Cadmium	27	>1	200	1
Chromium	28	4	140	10
Cobalt	27	>1	420	14
Copper	23	4	200	9
Iron	30	1,400	39,000	12,000
Lead	27	10	480	16
Manganese	30	18	14,000	800
Nickel	26	9	440	20
Zinc	28	9	59	21

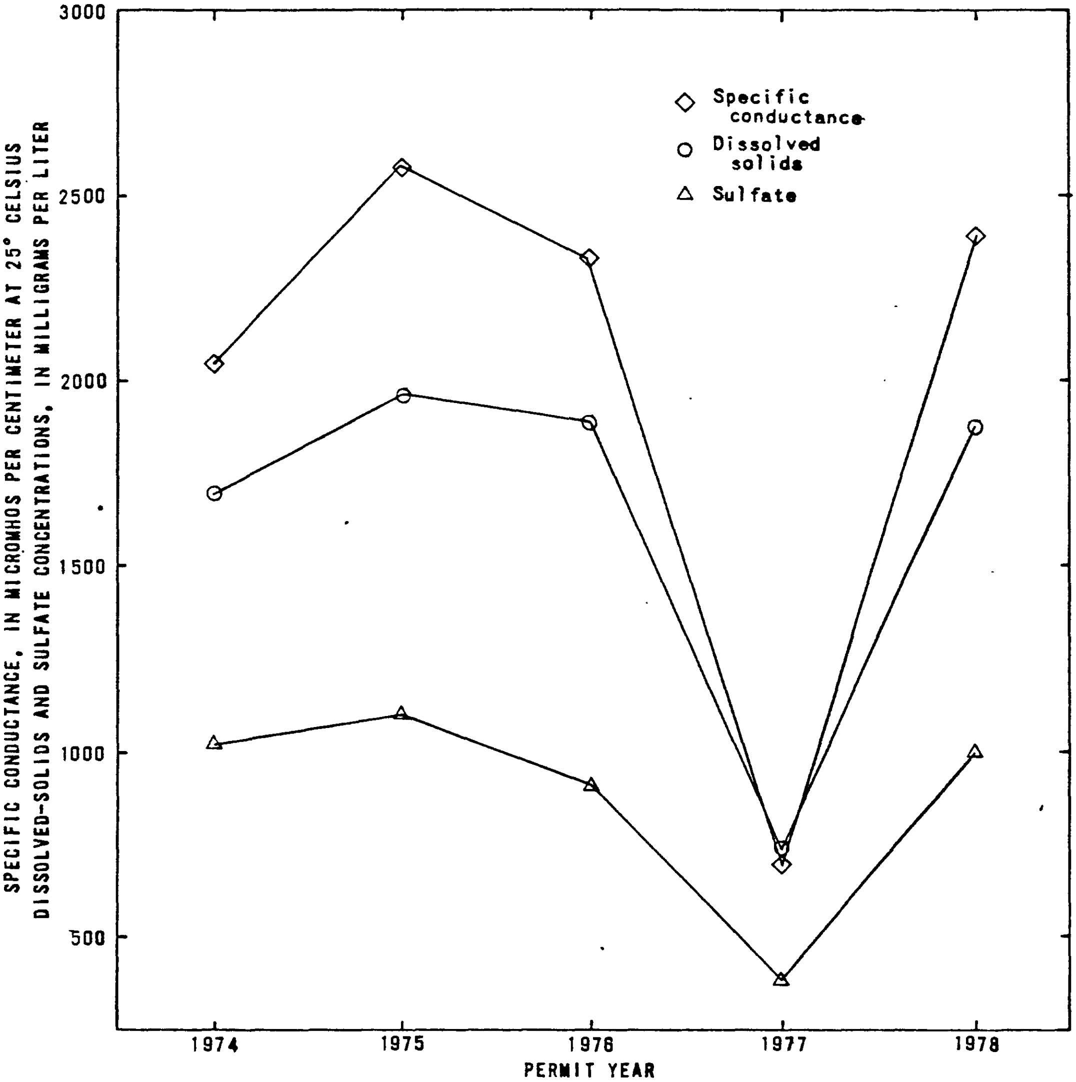


Figure 7. -- Median specific conductance and concentrations of dissolved solids and sulfate for each permit year (July 1-June 30) at mined site, Spencer Creek tributary.

During the 1976 permit year, median specific conductance was 2,330 μmho/cm, although the disturbed area within the basin nearly doubled. Throughout permit year 1976, pit discharges flowed through sediment pond 2 (fig. 3). The detention time within the basin probably permitted increased adsorption and flocculation of dissolved chemical constituents and thereby reduced their concentration in the receiving stream.

During permit year 1977, mining was noticeably reduced. Disturbed acreage decreased from 63 acres in the previous year to 38 acres. No coal was mined from December 1977 to March 1978, though pumping from the pit probably continued. Median specific conductance dropped to 705 μmho/cm, the lowest median value detected during the study period.

In permit year 1978, the area of land disturbed in a single year by mining reached a new maximum, 106.5 acres. Median specific conductance increased over that for the previous year to 2,359 μmho/cm.

The influence of streamflow on specific conductance from year to year was not considered in this study. Thus, the preceding results are only tentative. However, in a qualitative way, specific conductance can probably be used as an indicator of mining. For the study, this variable apparently integrated the varying effects of disturbed-land area, pit-discharge volume, presence or absence of sediment ponds, and reclamation.

In West Virginia, Corbett (1977) found that the concentrations of dissolved constituents increase as the areal extent of mining increases in a basin having unreclaimed spoil piles. Median specific conductance in Spencer Creek tributary increased about 20 percent between 1974 and 1978 (fig. 7), a period when the cumulative mined area increased 82 percent. Generally, coal mining disturbed less than 7 percent additional watershed each year, and reclamation quickly followed the coal removal. Regrading was completed about 1 yr after initial disturbance, and seeding and planting were completed in the next year. The timely reclamation of the disturbed land as well as the small part of the watershed subjected to mining might have contributed to the small increase in specific conductance.

The high median concentration for suspended iron in permit year 1977 cannot be explained by the author. This high concentration may have been an anomaly because the concentrations of suspended aluminum or manganese were not comparably high.

Streamflow

Stream discharge was measured directly only 10 times at the mined site and 2 times at the background sites. During the other surveys, discharge was estimated from stream width, depth, and estimates of flow velocity. Median flow at each site was used to separate flows into low- or high-flow categories.

Decreases in both sulfate concentration and specific conductance from low to high flow at both the mined site and the background sites (fig. 8) implies dilution.

The relation of concentrations of dissolved metals to flow (fig. 9) differed from the relation of dissolved solids and specific conductance to flow (fig. 8.) At the background sites, the median dissolved-manganese concentration was much lower during high flow than during low flow, owing to dilution. However, the equal median dissolved-iron concentrations for low and high flows indicate an effect other than dilution. At the mined site, median concentrations for both dissolved iron and dissolved manganese were higher at high flow than at low flow. One explanation for this condition is that salts deposited during low flow were dissolved at high flow. This salt-leaching process was apparently more prevalent at the mined site than at the background sites and more effective at dissolving metals than major cations and anions. In a study in northwestern Pennsylvania, Gang and Langmuir (1974, p. 51) found that dilution tends to decrease constituent concentrations in streams affected by mining but that salt leaching at increasing rates of runoff tends to increase iron and probably other metal concentrations. They also stated that the amount of leached material is dependent on the time between leaching periods and on runoff volume and that this dependence is a complication in analyzing the effects of salt leaching.

The effect of flow on suspended metal concentrations at the background sites was apparently different from that at the mined sites. Upstream from mining, median concentrations for both suspended iron and manganese decreased with increasing flow (fig. 10). The effect was more obvious for manganese than for iron. Median suspended-manganese concentration at high flow was less than the detection limit. Dilution of suspended sediment at high flow indicated that sediment reaching the stream from the forested and pastured lands at the background sites was minimal.

By contrast, median concentrations of suspended iron and manganese for the mined site were much greater at high flow than at low flow. Greater surface runoff, streambed scour, and the higher probability of pit pumping during rainstorms probably contributed to the higher concentrations. Compared with concentrations during low flow, concentrations of suspended iron and manganese during high flow increased about 400 and 250 percent, respectively. Increases in the actual mass (load) of metals transported during high flow would be even greater.

South Lake

Water-quality data for South Lake are presented in table 7. South Lake was generally very clear during the study period, though during the survey on November 16, 1977, the lake's milky-green color reduced light penetration, perhaps owing to algal bloom during fall turnover. Secchi disk measurements of light penetration in lake water for the study period ranged from 2.05 to 8.25 ft.

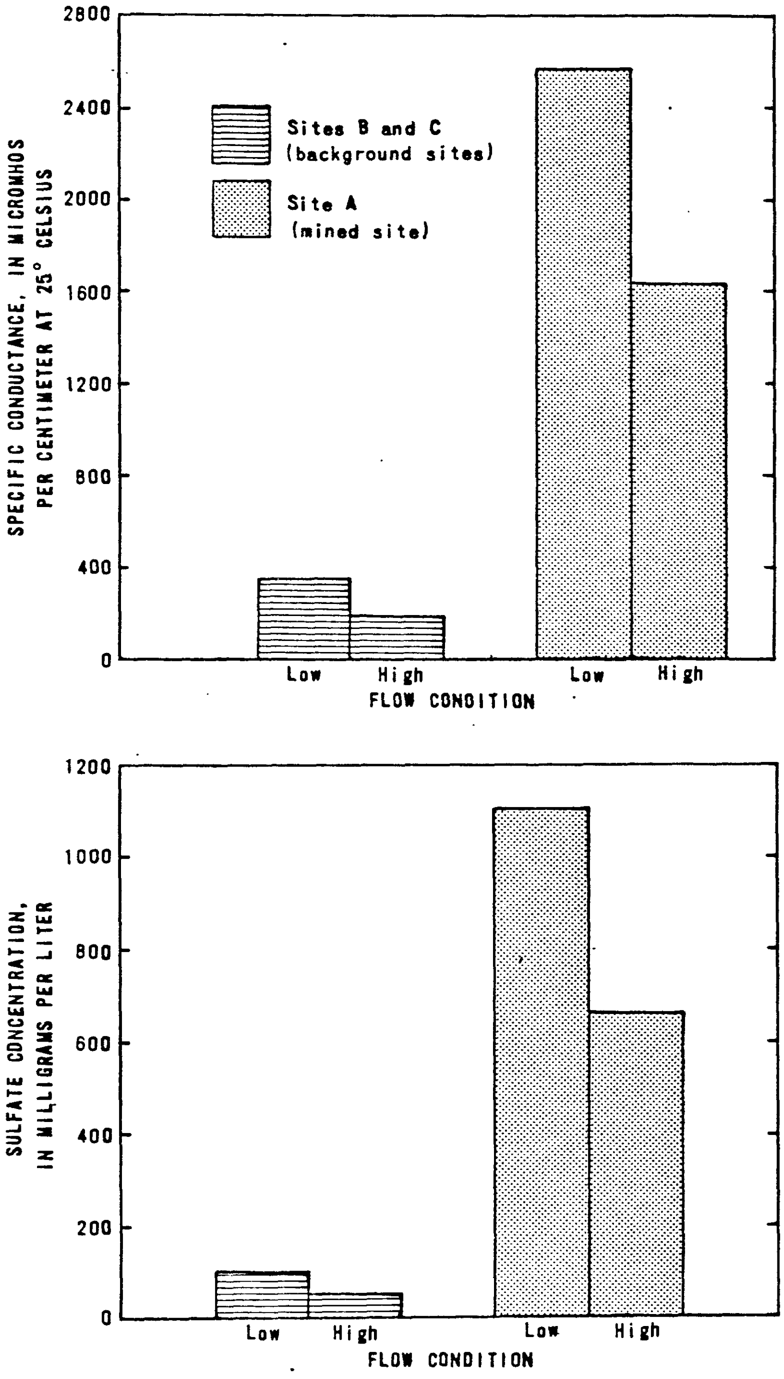


Figure 8. -- Median sulfate concentrations and specific conductances for low and high flows at background and mined sites, Spencer Creek tributary, 1975-79.

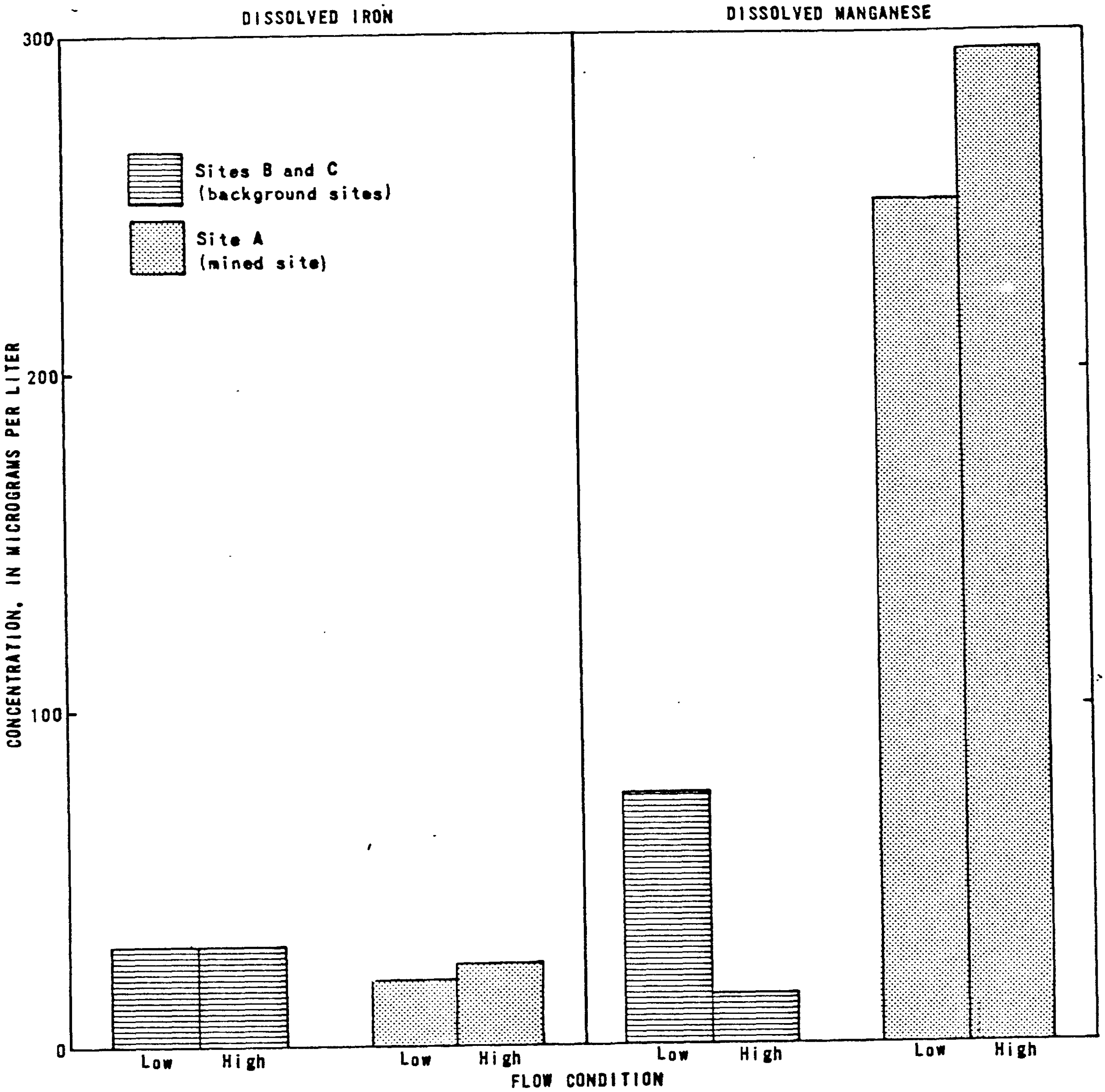


Figure 9.-- Median dissolved-iron and dissolved-manganese concentrations for low and high flows at background and mined sites, Spencer Creek tributary, 1975-79.

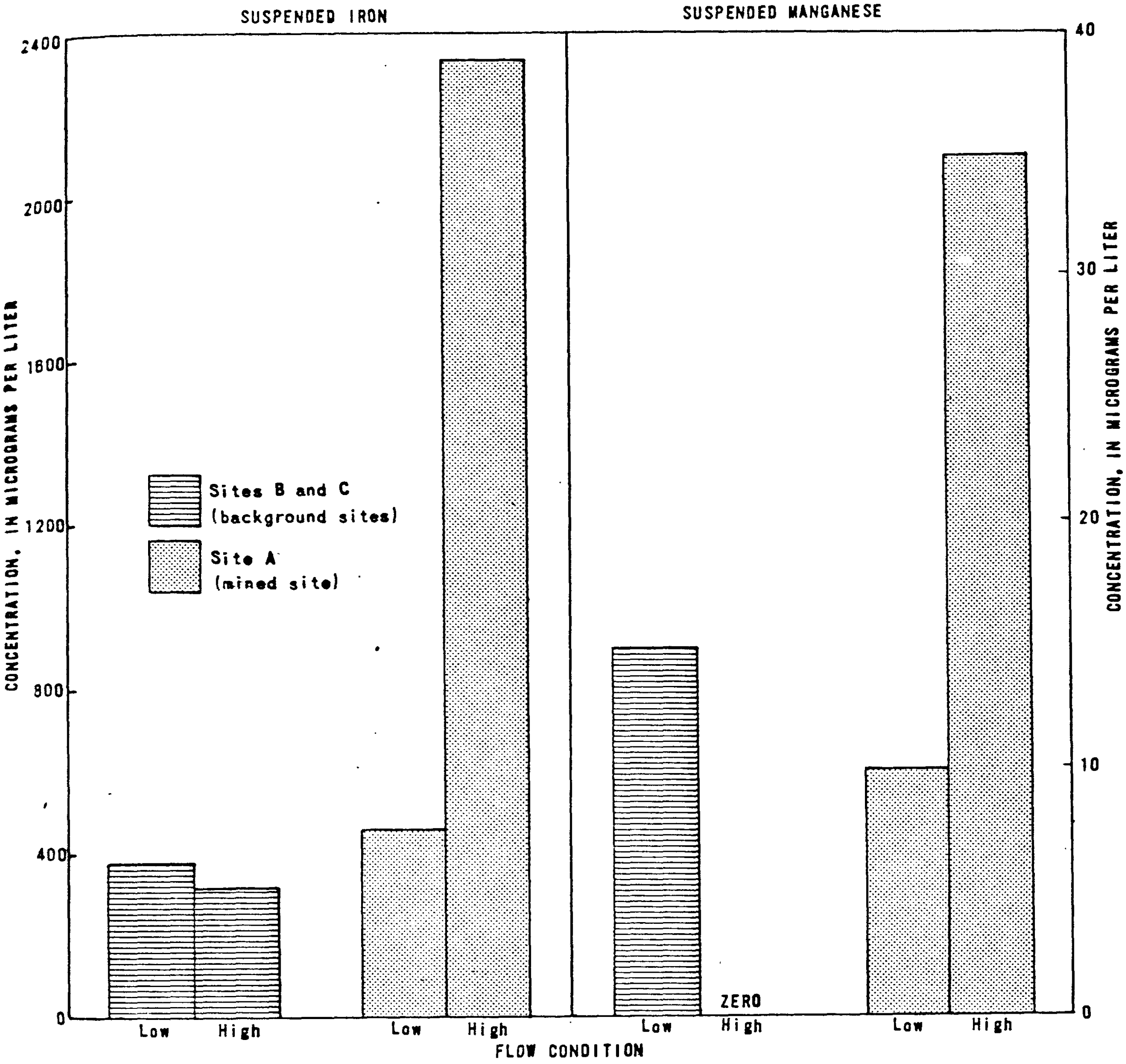


Figure 10.-- Median suspended-iron and suspended-manganese concentrations for low and high flows at background and mined sites, Spencer Creek tributary, 1975-79.

Vertical Profiles

South Lake exhibited many of the characteristics of a temperate, dimictic lake. During each of the four winters of the study period, the lake had been at least partly frozen. Vertical temperature and specific-conductance profiles of the lake (fig. 11) during different seasons indicate thermal stratification during the summer and winter and chemical stratification near the bottom of the lake during most of the year. Temperature profiles also indicate vernal and autumnal turnovers. Rate of temperature decrease was a maximum in the bottom 10 ft of the lake. The summer dissolved-oxygen profile shows a marked increase in dissolved-oxygen concentration, compared with those of the other seasons, to 18.3 mg/L at a depth of 13 ft. This depth was apparently preferentially selected by phytoplankton, which increased the concentration of dissolved oxygen through photosynthesis. Lack of mixing during summer tended to produce a buildup of dissolved-oxygen concentration. Below a depth of 13 ft, specific conductance increased and dissolved-oxygen concentration and pH decreased, which indicated a reducing environment for increasing the ionic concentrations.

The autumn profiles in figure 11 indicate that the water in the upper part of the lake was being mixed. All variables except pH were generally uniform with depth down to 17 ft. Below this depth, the lake was apparently chemically stratified. Dissolved-oxygen concentration decreased, and specific conductance increased. These changes indicated that reducing conditions near the lake bottom produce increases in concentrations of solutes and, thus, in density of water.

During the winter, the upper part of the lake was thermally stratified to a depth of 17 ft, as indicated by the water temperatures of less than 4° C above this depth. Other factors being equal, water reaches its maximum density at approximately 4° C. Below 17 ft, the water temperature was greater than 4° C. If temperature alone controlled the density of water near the lake bottom, this water would be less dense than the 4° C water above it and would rise. However, the specific conductance at this depth (greater than that of the water above) indicates that the density gradient was probably controlled chemically rather than thermodynamically.

The spring profiles represent lake conditions soon after the spring turnover period. The higher temperature of the water at the surface indicates that thermal stratification of the lake is beginning. The profiles for dissolved oxygen, specific conductance, and pH were still mostly vertical in mid-March but were beginning to approach profiles more characteristic of the summer period.

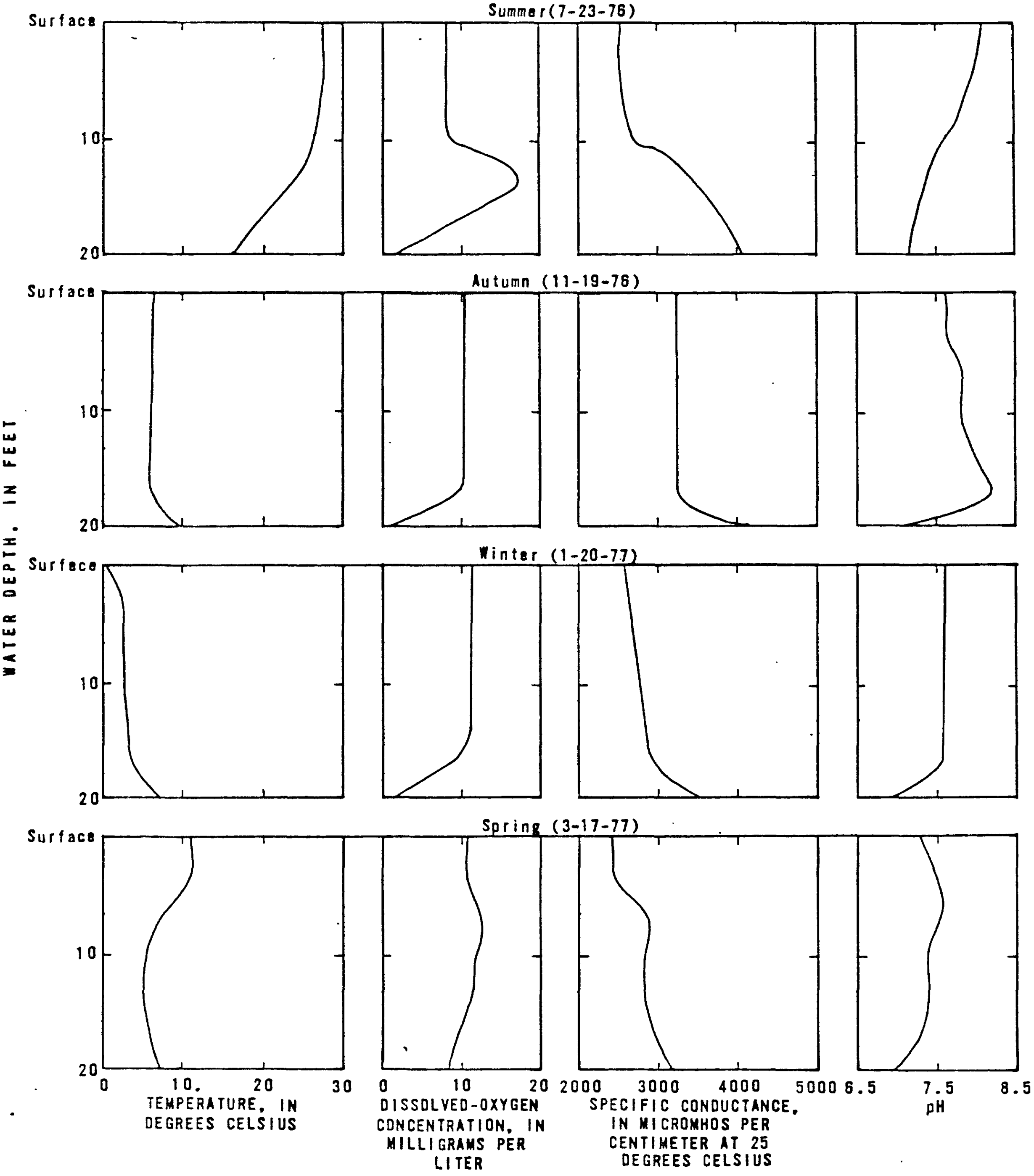


Figure 11.-- Relation of water depth to temperature, dissolved-oxygen concentration, specific conductance, and pH for each season, South Lake.

Phytoplankton

Samples for determining type and density of phytoplankton were collected during selected surveys on South Lake (table 15). Phytoplankton are minute, floating plants (mostly algae) distributed in lakes as deep as light penetrates. In lentic systems, phytoplankton are generally much more important than rooted aquatic plants in producing organic material for the ecosystem (Odum, 1971, p. 12). Many factors affect the distribution of phytoplankton in lakes, but the effects of these factors could not be quantified because of insufficient data. Nonetheless, the data suggest certain trends.

Generally, the populations of phytoplankton were smallest in winter. Reduced light intensity, from ice cover and low solar angle, as well as near-freezing water temperature tend to inhibit phytoplankton populations in temperate dimictic lakes (Wetzel, 1975, p. 322). On the basis of the percentage of total phytoplankton cells in the samples, yellow-brown algae (Chrystophyta) or euglenoids (Euglenophyta) generally dominated the winter populations. Green (Chlorophyta) and blue-green (Cyanophyta) algae were rare in winter. Both kinds of algae prefer higher water temperature than that of winter, and their numbers of active cells generally decrease markedly in winter (Welch, 1952, p. 255). The green algae were the most prevalent phylum during the summer. The blue-green algae tended to increase in late summer and early fall, a common tendency in lakes within the latitudes of Indiana (Wetzel, 1975, p. 323).

Diatoms (Chrysophyta) were present during all seasons but were most prevalent in spring and fall. Vernal and autumnal maxima for phytoplankton populations, in general, and diatoms, in particular, are characteristic of temperate lakes (Hutchinson, 1967, p. 401-405).

Water Quality

Water-quality samples collected at a depth of 1 ft indicated that the water in South Lake is consistently a mixed cation and sulfate water type. Figure 12 is a representative Stiff (1951) pattern of major ions. The pattern illustrates the high sulfate concentrations consistently measured in South Lake.

Table 15.--Sampling depth and phytoplankton counts, South Lake, Sullivan County, Ind.

Date of sampling	Time of sampling[1]	Depth of sample (ft)	Dominant organism[2]			Percent of total cells	Total cell count (cells/mL)
			Common name	Phylum	Class		
5-13-75	1400	1.0	Dinoflagellates	Pyrrhophyta	Dinophyceae	43	170
			Diatoms	Chrysophyta	Bacillariophyceae	22	
			Yellow-brown algae	Chrysophyta	Chrysophyceae	17	
6-17-75	1330	1.0	Yellow-brown algae	Chrysophyta	Chrysophyceae	94	5,800
7-16-75	1130	1.0	Blue-green algae	Cyanophyta	Myxophyceae	52	1,600
			Diatoms	Chrysophyta	Basillariophyceae	25	
			Green algae	Chlorophyta	Chlorophyceae	19	
8-27-75	0930	1.0	Green algae	Chlorophyta	Chlorophyceae	69	1,500
			Diatoms	Chrysophyta	Bacillariophyceae	24	
9-24-75	1100	1.0	Green algae	Chlorophyta	Chlorophyceae	47	3,700
			Blue-green algae	Cyanophyta	Myxophyceae	19	
10-18-75	1030	1.0	Green algae	Chlorophyta	Chlorophyceae	73	2,800
			Yellow-brown algae	Chrysophyta	Chrysophyceae	16	
2-20-76	1600	1.0	Euglenoids	Euglenophyta	Cryptophyceae	81	950
			Diatoms	Chrysophyta	Bacillariophyceae	16	
3-25-76	1300	1.0	Diatoms	Chrysophyta	Bacillariophyceae	58	330
			Yellow-brown algae	Chrysophyta	Chyrysophyceae	17	
3-25-76	1315	9.1	Green algae	Chlorophyta	Chlorophyaceae	91	1,900
6-16-76	1130	1.0	Blue-green algae	Cyanophyta	Myxophyceae	48	930
7-16-76	1600	1.0	Green algae	Chlorophyta	Chlorophyceae	100	45,000
7-16-76	1605	9.1	Green algae	Chlorophyta	Chlorophyceae	97	21,000

Table 15.--Sampling depth and phytoplankton counts, South Lake, Sullivan County, Ind.--Continued

Date of sampling	Time of sampling[1]	Depth of sample (ft)	Dominant organism[2]			Percent of total cells	Total cell count (cells/mL)
			Common name	Phylum	Class		
9-15-76	1315	1.0	Green algae	Chlorophyta	Chlorophyceae	52	840
			Diatoms	Chrysophyta	Bacillariophyceae	24	
9-15-76	1320	9.1	Green algae	Chlorophyta	Chlorophyceae	50	3,700
			Euglenoids	Euglenophyta	Cryptophysceae	47	
11-10-76	1030	1.0	Euglenoids	Euglenophyta	Euglenophyceae	68	1,200
			Yellow-brown algae	Chrysophyta	Chrysophyceae	19	
1-20-77	1630	2.0	Yellow-brown algae	Chrysophyta	Chrysophyceae	64	900
			Euglenoids	Euglenophyta	Cryptophyceae	24	
1-20-77	1635	9.1	Yellow-brown algae	Chrysophyta	Chrysophyceae	50	93
			Euglenoids	Euglenophyta	Cryptophyceae	20	
			Green algae	Chlorophyta	Chlorophyceae	19	
5-26-77	1210	1.0	Green algae	Chlorophyta	Chlorophyceae	74	330
			Diatoms	Chrysophyta	Bacillariophyceae	18	
5-26-77	1220	6.0	Yellow-brown algae	Chrysophyta	Chrysophyceae	32	580
			Green algae	Chlorophyta	Chlorophyceae	25	
9-21-77	1430	9.1	Euglenoids	Euglenophyta	Cryptophyceae	40	1,500
			Green algae	Chlorophyta	Chlorophyceae	24	
			Diatoms	Chrysophyta	Bacillariophyceae	16	
			Blue-green algae	Cyanophyta	Cyanophyceae	15	
11-16-77	1330	9.1	Euglenoids	Euglenophyta	Cryptophyceae	82	120
			Diatoms	Chrysophyta	Bacillariophyceae	18	
8-14-78	1500	1.0	Green algae	Chlorophyta	Chlorophyceae	74	4,200
			Blue-green algae	Cyanophyta	Cyanophyceae	23	

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[1] Military time. For example, 1400 is 2:00 p.m.

[2] Organisms having percent of total cell count greater than or equal to 15 percent.

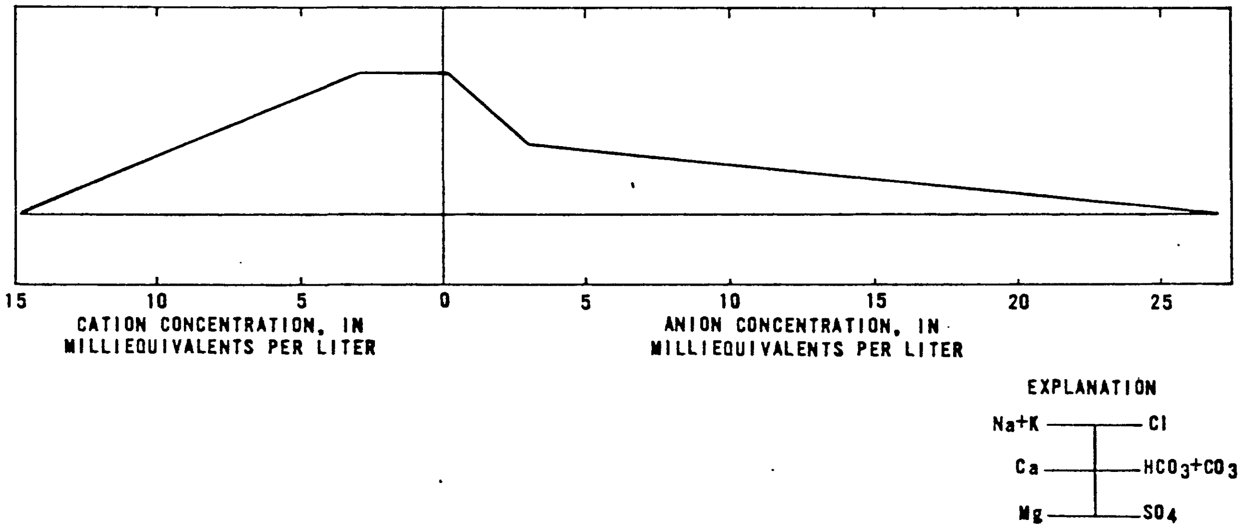

Figure 12. -- Pattern representing analysis of water sample collected at a depth of 1 foot on May 13, 1975, South Lake.

SUMMARY AND CONCLUSIONS

Production of coal, an increasingly important energy resource in the United States, is a major industry in Indiana. The impact of mining on the water quality of streams draining affected basins is unique to each area and has not been adequately studied in Indiana.

Water quality was surveyed on Spencer Creek tributary, a stream draining a small mined watershed, and on South Lake, an adjacent last-cut lake in southwestern Indiana. Water samples were analyzed for major cations and anions, as well as for dissolved and suspended metals. Water temperature, specific conductance, dissolved-oxygen concentration, and pH were measured at each site, and vertical-profile data for these field measurements were plotted. Phytoplankton samples were collected at South Lake for determining types of organisms and their densities.

In general, the data were not distributed normally, and nonparametric statistics were used to characterize the data.

Downstream from the mine, median concentrations of all major ions in the tributary exceeded median background concentrations. Among the cations, sodium demonstrated the greatest increase in median concentration, from 20 mg/L at the background sites to 360 mg/L at the mined site. The factor contributing most to the preferential release of sodium was probably the replacement of sodium by calcium and hydrogen ions on clay particles.

Sulfate concentrations of the tributary showed the greatest response to mining--median concentrations of 77 and 1,100 mg/L at the background and mined sites, respectively. The increase in concentration of sulfate downstream from the mine probably resulted from the increase in oxidation of pyritic material exposed during mining.

The increases in sulfate concentration were not accompanied by decreases in pH. Exchange of hydrogen ions for other cations and an increase in bicarbonate buffering probably caused higher pH at the mined site than at the background sites.

Compared with other metals at both the background and the mined sites, concentrations of aluminum, iron, and manganese dominated the dissolved and suspended phases. The median dissolved-manganese concentrations at both the background and the mined sites (40 and 285 mg/L, respectively) were greater than those for any other metals.

The maximum manganese concentrations at the background and the mined sites and the median concentration at the mined sites exceeded concentrations recommended for drinking water by the Environmental Protection Agency. The maximum iron concentration at the mined site also exceeded its recommended concentration.

Median concentrations of suspended aluminum and iron (160 and 370 mg/L at the background sites and 610 and 990 mg/L at the mined sites) exceeded median concentrations of other metals at both background and mined sites.

Metal concentrations of both the dissolved and the suspended phases generally increased downstream from mining. Additionally, though dissolved-solids concentrations were consistently higher than suspended-solids concentrations at background and mined sites, metals were usually transported more effectively in the suspended phase than in the dissolved phase. The concentrations of metals sorbed on the suspended sediment collected downstream from the mine were no greater than those of metals adsorbed on sediment collected at background sites.

In general, the distribution of metals from streambed materials was similar to that of suspended metals. Iron was the most abundant metal sorbed by streambed material; aluminum was second to iron in abundance. All metals detected in the water samples were also detected on streambed material.

Specific conductance of streams, as well as dissolved-solids and sulfate concentrations, is a good indicator of mining.

Concentrations of suspended metals in Spencer Creek tributary decreased after the construction of sediment ponds. Suspended-iron, aluminum, and manganese concentrations decreased by more than 50 percent.

During high flows at background and mined sites, major dissolved-ion concentrations decreased because of dilution. Concentrations of dissolved iron and dissolved manganese at the mined site were higher during high flows than during low flows, probably because of salt leaching.

Suspended-metal concentrations were lower at high flow than at low flow at the background site but were higher at high flow than at low flow at the mined site. Quantity of sediment carried to the stream by surface runoff was much greater from the mined area than from the forested and pastured lands upstream from the mine.

The periods of thermal stratification of South Lake in winter and summer were separated by vernal and autumnal mixing periods characteristic of temperate dimictic lakes. Chemical stratification was permanent near the lake bottom. Phytoplankton populations varied with season and generally followed patterns reported for other lakes in Indiana's latitude. Analyses of water samples from South Lake indicated that its water is a mixed cation and sulfate type.

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Tables 2, 3, 5, 6, and 7

Table 2.--Flow and water-quality data from sediment-pond outfalls to the Spencer Creek tributary at the 1250 pit, Hawthorn Mine, Sullivan County, Ind.

[From Indiana Stream Pollution Control Board monthly monitoring report for NPDES discharge permits, DMR-1 Form, Indiana State Board of Health]

Date of sampling	Flow (Mgal/d)	pH	Dissolved iron (mg/L)	Suspended solids (mg/L)	Acidity, as $CaCO_3$ (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)
Sediment pond 2						
8-5-77	0.0	---	----	--	----	---
8-12-77	.625	7.9	0.44	43	-488	544
8-15-77	.550	7.7	.08	25	-382	434
8-23-77	.625	7.8	.40	15	-388	480
8-30-77	.875	7.7	.13	10	-414	484
9-7-77	.750	7.7	.05	2	-464	520
9-13-77	.575	7.7	.37	12	-346	396
9-20-77	.475	7.8	.24	15	-366	440
9-27-77	.175	7.5	.18	45	-554	610
10-4-77	.200	7.2	.18	25	-148	210
10-11-77	.325	7.8	.13	7	-582	648
10-18-77	.400	7.7	.21	1	-514	580
10-28-77	.0	---	----	--	----	---
11-2-77	.275	7.5	.45	34	-610	664
11-8-77	.325	7.3	.77	11	-676	744
11-17-77	.475	7.5	.72	5	-584	620
11-21-77	.425	7.6	.23	15	----	---
11-30-77	.400	6.6	.48	19	----	---
12-7-77	.0	---	----	--	----	---
12-13-77	.225	8.1	3.42	44	-295	326
12-22-77	.0	---	----	--	----	---
12-28-77	.350	8.0	.35	21	-589	616
3-2-78	.0	---	----	--	----	---
3-8-78	.0	---	----	--	----	---
3-16-78	.0	---	----	--	----	---

Table 2.--Flow and water-quality data from sediment-pond outfalls to the Spencer Creek tributary at the 1250 pit, Hawthorn Mine, Sullivan County, Ind.--Continued

Date of sampling	Flow (Mgal/d)	pH	Dissolved iron (mg/L)	Suspended solids (mg/L)	Acidity, as $CaCO_3$ (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)
Sediment pond 2--Continued						
3-24-78	0.0	---	----	--	----	---
3-30-78	.450	7.0	0.47	9	-754	788
4-5-78	.700	7.8	2.04	133	-730	772
4-12-78	.752	8.0	.66	31	-752	800
4-21-78	.0	---	----	---	----	---
4-26-78	.0	---	----	---	----	---
5-3-78	.950	8.2	.13	4	-593	646
5-10-78	.575	7.8	.13	23	-466	494
5-17-78	.475	8.0	.42	11	-618	664
5-24-78	.750	7.1	.34	1	-514	552
6-2-78	.325	7.3	.10	4	-594	654
6-6-78	.525	7.2	.06	15	-610	692
6-14-78	.875	7.8	.26	10	-544	624
6-21-78	.580	7.6	.20	35	-556	620
6-28-78	.850	7.6	.40	33	-527	530
7-5-78	.800	7.9	.14	26	-509	543
7-11-78	.800	8.0	.20	15	-491	522
7-18-78	.950	7.3	.26	19	-324	384
7-28-78	.600	7.6	.23	33	-376	436
8-4-78	.550	7.4	.12	3	----	---
9-7-78	.950	7.1	.12	1	-244	304
9-13-78	.850	7.3	.31	5	-268	334
9-20-78	.975	6.9	.03	3	-400	450
9-26-78	.875	8.1	.14	20	-498	548
10-5-78	.475	6.9	.23	28	----	---
10-10-78	.975	7.2	.12	12	----	---

Table 2.--Flow and water-quality data from sediment-pond outfalls to the Spencer Creek tributary at the 1250 pit, Hawthorn Mine, Sullivan County, Ind.--Continued

Date of sampling	Flow (Mgal/d)	pH	Dissolved iron (mg/L)	Suspended solids (mg/L)	Acidity, as $CaCO_3$ (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)
			Sediment pond 15			
8-11-78	0.950	7.0	0.37	7	----	---
8-18-78	.875	6.8	.32	6	----	---
8-23-78	.900	6.4	.25	7	----	---
8-31-78	.950	6.5	1.17	20	----	---
10-19-78	.180	7.5	.23	6	----	---
11-7-78	.275	6.8	.13	5	-318	402
11-15-78	.325	6.8	.27	1	-288	348
11-20-78	.250	6.4	.16	4	-274	346
12-6-78	.250	6.7	.10	4	-220	320
12-12-78	.125	6.6	.13	13	-180	304
12-19-78	.125	6.6	.18	1	-156	260

Table 3.--Water-level and water-quality data for observation wells 3 and 5, Hawthorn Mine, Sullivan County, Ind.

[Aolad Hossain, Hydrologist, Indiana Division, Peabody Coal Co., written commun., 1980; sampling and analysis by Peabody Coal Company]

Water levels, constituents, and properties	Well 3		Well 5	
	Sampling date		Sampling date	
	6-26-79	9-11-79	6-26-79	9-12-79
Water-level elevation above NGVD of 1929	571.91	n/a[1]	564.84	n/a[1]
pH, field	7.6	7.2	7.0	6.6
Temperature (°C)	17	14	16	14
Specific conductance (μmho/cm at 25° C)	900	1,000	1,900	1,100
Acidity, as $CaCO_3$ (mg/L)	-530	-572	-258	-272
Alkalinity, as $CaCO_3$ (mg/L)	690	664	378	332
Total hardness, as $CaCO_3$ (mg/L)	223	257	1,518	1,336
Total dissolved solids, residue on evaporation at 180° C (mg/L)	571	482	2,421	2,108
Sulfate (mg/L)	34	30	1,079	807
Arsenic (mg/L)	0.001	.001	.001	.001
Barium (mg/L)	0.4	.3	.2	.2
Cadmium (mg/L)	0.002	.003	.002	.003
Calcium (mg/L)	40	42	322	264
Chromium (mg/L)	0.02	.03	.08	.02
Copper (mg/L)	0.02	.02	.02	.02
Iron (mg/L)	0.11	.09	.47	.27
Lead (mg/L)	0.02	.02	.02	.02
Magnesium (mg/L)	30	30	168	141
Manganese (mg/L)	0.09	.14	2.14	2.05
Mercury (μg/L)	0.02	.02	.02	.02
Potassium (mg/L)	3	3	3	2
Nickel (mg/L)	0.02	.02	.02	.02
Selenium (mg/L)	0.001	.001	.001	.001
Silver (mg/L)	0.002	.005	.008	.011
Sodium (mg/L)	175	149	124	139
Zinc (mg/L)	0.03	.02	.02	.02
Chloride (mg/L)	18	17	21	23
Fluoride (mg/L)	0.48	.32	.32	.33
Nitrate (mg/L)	1.20	1.39	1.04	1.93

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[1] Not available.

Table 5.--Water-column constituents and properties and streambed constituents at background sites, Spencer Creek tributary, Sullivan County, Ind.

[Time is expressed as a 1-24 hour day: for example, 1400 is the same as 2:00 p.m.
Total hardness and alkalinity are expressed as calcium carbonate]

DATE	TIME	ACIDITY (MG/L)	ALKA-LINITY (MG/L)	ALUMINUM, DISSOLVED (UG/L)	ALUMINUM, SUSPENDED (UG/L)	ALUMINUM, TOTAL (UG/L)	ALUMINUM, STREAMBED (UG/G)	BICAR-BONATE (MG/L)	CADMIUM, DISSOLVED (UG/L)	CADMIUM, SUSPENDED (UG/L)	CADMIUM, TOTAL (UG/L)	CADMIUM, STREAMBED (UG/G)
01-15-76	1215	10.0	48	10	240	250	2100	58.0	0	0	0	0
02-20-76	1130	10.0	57	20	160	180	2700	69.0	0	0	0	10
03-25-76	1730	55.0	72	10	40	50	1300	88.0	0	0	0	0
04-23-76	1255	0.0	94	20	130	150	4100	114.0	0	0	0	0
05-14-76	1100	10.0	91	10	80	90	4500	111.0	0	0	0	0
03-16-77	1440	0.0	71	20	170	190	3200	87.0	1	0	0	0
03-21-78	1400	0.0	10	40	960	1000	940	22.0	-	-	-	10
05-18-78	1330	0.0	51	20	0	0	4500	62.0	-	-	-	-
02-23-79	1300	-	10	200	4900	5100	-	12.2	-	-	-	-
04-17-79	1300	0.0	35	200	300	500	4400	42.7	-	-	-	-

DATE	TIME	CALCIUM (MG/L)	CARBON DIOXIDE (MG/L)	CAR-BONATE (MG/L)	CHLOR-IDE (MG/L)	CHROMIUM, DISSOLVED (UG/L)	CHROMIUM, SUSPENDED (UG/L)	CHROMIUM, TOTAL (UG/L)	CHROMIUM, STREAMBED (UG/G)	COBALT, DISSOLVED (UG/L)	COBALT, SUSPENDED (UG/L)	COBALT, TOTAL (UG/L)
01-15-76	1215	21.0	23.0	0.0	8.5	0	10	10	8	0	0	0
02-20-76	1130	25.0	0.9	0.0	7.4	10	0	10	3	0	0	0
03-25-76	1730	32.0	2.8	0.0	7.4	10	0	10	3	0	0	0
04-23-76	1255	36.0	1.2	0.0	7.3	10	0	10	9	0	0	0
05-14-76	1100	37.0	2.8	0.0	7.7	10	0	10	90	0	0	0
03-16-77	1440	39.0	14.0	0.0	14.0	10	0	10	6	0	2	2
03-21-78	1400	14.0	0.8	0.0	7.9	2	8	10	10	2	-	-
05-18-78	1330	27.0	244.0	0.0	8.9	0	10	10	10	-	-	-
02-23-79	1300	7.3	-	-	2.0	-	-	-	-	-	-	-
04-17-79	1300	20.0	-	-	5.4	-	-	-	-	-	-	-

DATE	TIME	COBALT, STREAMBED (UG/G)	COPPER, DISSOLVED (UG/L)	COPPER, SUSPENDED (UG/L)	COPPER, TOTAL (UG/L)	COPPER, STREAMBED (UG/G)	HARDNESS, NONCARBONATE (MG/L)	HARDNESS, TOTAL (MG/L)	IRON, DISSOLVED (UG/L)	IRON, SUSPENDED (UG/L)
01-15-76	1215	14	0	0	0	4	50	98	20	370
02-20-76	1130	330	0	0	0	5	55	110	30	260
03-25-76	1730	860	0	0	0	340	65	140	30	60
04-23-76	1255	15	0	0	0	7	75	170	20	360
05-14-76	1100	18	0	0	0	8	75	170	50	150
03-16-77	1440	20	0	20	20	6	100	170	30	470
03-21-78	1400	10	2	0	2	10	44	62	40	1760
05-18-78	1330	-	0	0	0	10	78	130	100	450
02-23-79	1300	-	-	-	-	-	21	31	80	9020
04-17-79	1300	-	-	-	-	-	64	99	30	400

DATE	TIME	IRON, TOTAL (UG/L)	IRON, STREAMBED (UG/G)	LEAD, DISSOLVED (UG/L)	LEAD, SUSPENDED (UG/L)	LEAD, TOTAL (UG/L)	LEAD, STREAMBED (UG/G)	MAGNE-SIUM (MG/L)	MANGANESE, DISSOLVED (UG/L)	MANGANESE, SUSPENDED (UG/L)	MANGANESE, TOTAL (UG/L)
01-15-76	1215	390	13000	0	1	1	17	11.0	10	0	10
02-20-76	1130	290	9100	0	2	2	400	12.0	10	0	10
03-25-76	1730	90	5000	1	0	0	1000	14.0	20	0	10
04-23-76	1255	380	22000	0	2	2	19	19.0	40	20	60
05-14-76	1100	200	18000	0	2	2	19	18.0	70	0	70
03-16-77	1440	500	12000	2	0	2	20	18.0	170	20	190
03-21-78	1400	1800	2300	1	0	1	10	6.5	30	40	70
05-18-78	1330	550	26000	-	-	0	-	15.0	250	20	270
02-23-79	1300	9100	-	-	-	-	-	3.1	80	300	380
04-17-79	1300	430	25000	-	-	-	-	12.0	80	10	90

DATE	TIME	MANGANESE, STREAMBED (UG/G)	NICKEL, DISSOLVED (UG/L)	NICKEL, SUSPENDED (UG/L)	NICKEL, TOTAL (UG/L)	NICKEL, STREAMBED (UG/G)	ORGANIC CAR-BON, DISSOLVED (MG/L)	ORGANIC CAR-BON, SUSPENDED (MG/L)	ORGANIC CARBON, TOTAL (MG/L)	PH
01-15-76	1215	620	1	3	4	12	-	-	2.4	6.6
02-20-76	1130	770	0	4	4	330	-	-	2.5	8.1
03-25-76	1730	600	2	2	4	670	-	-	5.2	7.7
04-23-76	1255	940	5	21	26	18	-	-	7.9	8.2
05-14-76	1100	1200	2	0	1	20	43.0	0.4	-	7.8
03-16-77	1440	750	10	11	21	20	7.3	0.5	-	7.0
03-21-78	1400	1300	2	2	4	10	-	-	-	7.6
05-18-78	1330	180	15	0	6	10	11.0	1.2	9.3	5.6
02-23-79	1300	-	-	-	-	-	-	-	-	6.8
04-17-79	1300	2200	-	-	-	-	-	-	-	7.0

DATE	TIME	ORTHOPHOSPHATE, DISSOLVED (MG/L)	ORTHOPHOSPHORUS, DISSOLVED (MG/L)	ORTHOPHOS-PHORUS, TOTAL (MG/L)	OXYGEN, DISSOLVED (MG/L)	PHOSPHATE, TOTAL (MG/L)	PHYTO-PLANKTON (CELL/ML)	POTAS-SIUM (MG/L)	SILICA (MG/L)	SODIUM (MG/L)
01-15-76	1215	-	-	-	10.6	-	-	2.6	-	11
02-20-76	1130	-	-	-	12.1	-	-	2.3	-	13
03-25-76	1730	-	-	-	10.7	-	-	2.2	-	16
04-23-76	1255	-	-	-	7.8	-	-	2.8	-	20
05-14-76	1100	-	-	-	8.7	-	-	3.1	-	19
03-16-77	1440	-	-	-	9.4	-	93	4.9	-	17
03-21-78	1400	0.00	0.000	0.020	5.5	0.15	-	4.0	10	5
05-18-78	1330	0.00	0.000	0.000	8.4	0.03	-	1.9	12	11
02-23-79	1300	-	-	-	14.2	-	-	2.5	6	2
04-17-79	1300	-	-	-	8.9	-	-	2.0	12	11

DATE	TIME	SOLIDS, DISSOLVED (MG/L)	SOLIDS, SUSPENDED (MG/L)	SOLIDS, TOTAL (MG/L)	SPECIFIC CONDUCTANCE (UMHO/CM)	STREAM-FLOW (FT3/S)	SULFATE (MG/L)	TEMP-ATURE (DEG C)	ZINC, DISSOLVED (UG/L)	ZINC, SUSPENDED (UG/L)	ZINC, TOTAL (UG/L)	ZINC, STREAMBED (UG/G)
01-15-76	1215	171	-	-	272	-	71	0.6	10	0	10	17
02-20-76	1130	199	-	-	198	-	75	4.4	10	0	10	17
03-25-76	1730	218	-	-	366	-	91	12.6	0	20	20	11
04-23-76	1255	259	-	-	480	-	100	19.9	0	0	0	26
05-14-76	1100	267	-	-	407	-	100	16.5	0	10	10	31
03-16-77	1440	278	-	-	425	-	120	14.2	0	40	40	24
03-21-78	1400	114	69	183	205	0.61	45	6.6	10	0	10	10
05-18-78	1330	200	19	219	311	-	77	19.9	10	0	10	30
02-23-79	1300	62	-	-	48	2.56	21	1.9	-	-	-	-
04-17-79	1300	172	-	-	240	-	79	18.2	-	-	-	-

Table 6.--Water-column constituents and properties and streambed constituents at mined site. Spencer Creek tributary, Sullivan County, Ind.

[Time is expressed as a 1-24 hour day; for example, 1400 is the same as 2:00 p.m.
Total hardness and alkalinity are expressed as calcium carbonate]

DATE	TIME	ACIDITY (MG/L)	ALKA-LINITY (MG/L)	ALUMINUM, DISSOLVED (UG/L)	ALUMINUM, SUSPENDED (UG/L)	ALUMINUM, TOTAL (UG/L)	ALUMINUM, STREAMBED (UG/G)	BICAR-BONATE (MG/L)	CADMIUM, DISSOLVED (UG/L)	CADMIUM, SUSPENDED (UG/L)	CADMIUM, TOTAL (UG/L)	CADMIUM, STREAMBED (UG/G)
04-18-75	0830	0.0	239	60	170	230	2500	291.0	2	0	0	1
05-14-75	0830	0.0	322	30	180	210	3200	392.0	0	0	0	0
06-18-75	1130	0.0	171	20	310	330	250	209.0	0	0	0	1
07-16-75	0915	0.0	226	20	30	50	4200	275.0	0	0	0	0
08-26-75	1415	0.0	228	20	800	820	3400	278.0	0	0	0	0
09-23-75	1300	0.0	93	40	610	650	3500	113.0	0	0	0	0
10-17-75	0935	0.0	209	200	240	440	1800	255.0	0	0	0	1
10-17-75	1400	0.0	315	120	660	780	2400	384.0	0	0	0	3
01-15-76	1245	0.0	57	20	1700	1700	3500	70.0	0	0	0	0
02-20-76	1100	15.0	230	20	880	900	3200	280.0	1	0	0	0
03-25-76	1630	40.0	77	10	3800	3800	2100	94.0	0	0	0	200
04-23-76	1330	0.0	449	20	13000	13000	4800	548.0	0	1	1	0
05-14-76	1130	15.0	270	20	3000	3000	3700	329.0	0	0	0	1
07-16-76	1300	15.0	49	30	12000	12000	3700	60.0	0	0	0	1
09-01-76	1400	70.0	477	310	1700	2000	4600	582.0	1	0	0	0
11-18-76	1330	30.0	501	20	30	50	5300	611.0	0	0	0	0
03-16-77	1715	0.0	200	20	420	440	3000	247.0	0	0	0	1
05-26-77	1400	0.0	290	30	150	180	10	350.0	0	0	0	10
07-07-77	1545	0.0	460	30	70	100	500	560.0	0	0	0	10
09-21-77	1600	0.0	440	40	280	320	520	540.0	0	0	0	10
11-16-77	1515	0.0	56	0	6000	6000	1000	80.0	1	0	0	10
03-21-78	1100	0.0	90	100	11000	11000	610	110.0	-	-	-	10
03-22-78	1630	0.0	210	30	1800	1800	620	260.0	-	-	-	10
05-18-78	1100	0.0	110	50	240	290	2300	140.0	-	-	-	-
07-12-78	1100	20.0	460	30	70	100	920	560.0	0	0	0	10
07-13-78	1200	10.0	430	60	28000	28000	1100	520.0	0	0	0	10
10-17-78	1230	0.0	200	100	-	-	1200	244.0	-	-	-	-
02-15-79	1200	0.0	320	-	-	1100	2400	390.4	-	-	1	10
02-23-79	1200	-	19	200	14800	15000	-	23.2	-	-	-	-
04-17-79	1200	0.0	400	100	200	300	5100	488.0	-	-	-	-
05-17-79	1200	0.0	160	-	-	130	3900	195.2	-	-	0	10

DATE	TIME	CALCIUM (MG/L)	CARBON DIOXIDE (MG/L)	CAR-BONATE (MG/L)	CHLOR-IDE (MG/L)	CHROMIUM, DISSOLVED (UG/L)	CHROMIUM, SUSPENDED (UG/L)	CHROMIUM, TOTAL (UG/L)	CHROMIUM, STREAMBED (UG/G)	COBALT, DISSOLVED (UG/L)	COBALT, SUSPENDED (UG/L)	COBALT, TOTAL (UG/L)
04-18-75	0830	140.0	64.0	0.0	13.0	0	10	10	10	1	0	1
05-14-75	0830	110.0	9.9	0.0	14.0	10	10	20	44	0	0	0
06-18-75	1130	110.0	17.0	0.0	13.0	20	0	20	20	0	1	1
07-16-75	0915	200.0	18.0	0.0	26.0	10	0	10	28	0	0	0
08-26-75	1415	120.0	7.1	0.0	12.0	10	0	10	12	0	1	1
09-23-75	1300	84.0	6.9	0.0	8.0	0	10	10	7	0	0	0
10-17-75	0935	160.0	12.0	0.0	29.0	20	0	20	5	0	0	0
10-17-75	1400	140.0	19.0	0.0	26.0	10	20	30	10	0	0	3
01-15-76	1245	26.0	14.0	0.0	8.3	0	340	340	12	0	1	1
02-20-76	1100	68.0	2.2	0.0	12.0	10	0	10	6	2	0	2
03-25-76	1630	46.0	1.9	0.0	8.7	10	0	10	4	1	1	2
04-23-76	1330	95.0	4.4	0.0	23.0	10	30	40	9	2	22	24
05-14-76	1130	110.0	5.3	0.0	21.0	10	0	10	140	2	3	5
07-16-76	1300	50.0	4.8	0.0	3.9	10	0	10	5	1	9	10
09-01-76	1400	250.0	4.7	-	16.0	10	0	10	10	6	0	6
11-18-76	1330	220.0	3.1	0.0	18.0	10	0	10	9	2	0	2
03-16-77	1715	76.0	5.0	0.0	18.0	10	0	10	4	1	1	2
05-26-77	1400	130.0	7.0	0.0	21.0	20	20	40	10	0	1	1
07-07-77	1545	68.0	5.7	0.0	22.0	3	7	10	10	0	0	0
09-21-77	1600	180.0	4.3	0.0	23.0	1	-	10	10	5	0	0
11-16-77	1515	32.0	0.5	0.0	11.0	-	-	20	10	0	0	0
03-21-78	1100	54.0	1.9	0.0	8.0	0	10	10	10	6	-	-
03-22-78	1630	81.0	2.1	0.0	9.0	3	7	10	10	9	-	-
05-18-78	1100	50.0	42.0	0.0	7.9	0	10	10	10	-	-	-
07-12-78	1100	160.0	7.5	0.0	21.0	0	20	20	10	11	2	13
07-13-78	1200	170.0	40.0	0.0	21.0	0	30	30	10	3	12	15
10-17-78	1230	130.0	-	-	12.0	-	-	-	-	-	-	-
02-15-79	1200	82.0	-	-	17.0	-	-	20	10	-	-	-
02-23-79	1200	12.0	-	-	3.1	-	-	-	-	-	-	-
04-17-79	1200	140.0	-	-	21.0	-	-	-	-	-	-	-
05-17-79	1200	60.0	-	-	8.7	-	-	20	20	-	-	-

DATE	TIME	COBALT, STREAMBED (UG/G)	COPPER, DISSOLVED (UG/L)	COPPER, SUSPENDED (UG/L)	COPPER, TOTAL (UG/L)	COPPER, STREAMBED (UG/G)	HARDNESS, NONCARBONATE (MG/L)	HARDNESS, TOTAL (MG/L)	IRON, DISSOLVED (UG/L)	IRON, SUSPENDED (UG/L)
04-18-75	0830	9	0	0	0	5	420	660	210	70
05-14-75	0830	20	0	0	0	7	290	610	40	400
06-18-75	1130	14	0	10	10	4	380	550	20	440
07-16-75	0915	12	10	10	20	8	770	990	40	210
08-26-75	1415	17	10	0	10	7	480	710	10	1290
09-23-75	1300	18	10	0	10	7	260	350	20	980
10-17-75	0935	14	0	20	20	4	540	750	40	720
10-17-75	1400	16	0	10	10	6	450	760	130	1270
01-15-76	1245	19	0	10	10	10	65	120	20	3280
02-20-76	1100	420	10	0	0	7	97	330	10	1690
03-25-76	1630	310	0	10	10	200	120	200	20	4680
04-23-76	1330	19	10	50	60	9	97	550	20	39980
05-14-76	1130	20	0	10	10	8	220	490	20	6380
07-16-76	1300	7	0	20	20	6	160	210	0	18000
09-01-76	1400	20	20	0	10	10	720	1200	330	4450
11-18-76	1330	16	10	10	20	9	620	1100	50	70
03-16-77	1715	10	0	10	10	6	130	330	20	790
05-26-77	1400	10	2	1	3	10	380	660	10	220
07-07-77	1545	10	0	7	7	10	60	520	10	990
09-21-77	1600	10	0	0	0	10	540	980	40	140
11-16-77	1515	10	6	3	9	10	76	140	110	8890
03-21-78	1100	10	2	12	14	10	150	240	150	19840
03-22-78	1630	10	0	3	3	10	160	370	30	3070
05-18-78	1100	-	1	0	0	10	120	240	120	460
07-12-78	1100	0	0	0	0	10	480	930	0	100
07-13-78	1200	0	2	17	19	10	490	920	10	32990
10-17-78	1230	-	-	-	-	-	400	600	10	-
02-15-79	1200	20	-	-	3	10	82	400	30	2970
02-23-79	1200	-	-	-	-	-	33	52	70	38930
04-17-79	1200	-	-	-	-	-	270	670	30	280
05-17-79	1200	20	-	-	2	10	120	280	20	290

Table 6.—Water-column constituents and properties and streambed constituents at mined site, Spencer Creek tributary, Sullivan County, Ind.—Continued

DATE	TIME	IRON, TOTAL (UG/L)	IRON, STREAMBED (UG/G)	LEAD, DISSOLVED (UG/L)	LEAD, SUSPENDED (UG/L)	LEAD, TOTAL (UG/L)	LEAD, STREAMBED (UG/G)	MAGNE-SIUM (MG/L)	MANGANESE, DISSOLVED (UG/L)	MANGANESE, SUSPENDED (UG/L)	MANGANESE, TOTAL (UG/L)
04-18-75	0830	280	12000	1	0	0	11	75.0	140	0	140
05-14-75	0830	440	18000	0	0	0	22	81.0	180	10	190
06-18-75	1130	460	11000	0	0	0	16	67.0	150	10	160
07-16-75	0915	250	13000	1	0	1	17	120.0	350	160	510
08-26-75	1415	1300	15000	0	3	3	15	100.0	60	50	110
09-23-75	1300	1000	15000	0	3	3	19	34.0	290	10	300
10-17-75	0935	760	8600	3	0	0	16	84.0	140	30	170
10-17-75	1400	1400	14000	2	0	2	12	100.0	640	70	710
01-15-76	1245	3300	23000	0	4	4	26	14.0	60	60	120
02-20-76	1100	1700	17000	0	2	2	470	38.0	300	40	340
03-25-76	1630	4700	5800	2	2	4	480	21.0	380	10	390
04-23-76	1330	40000	16000	1	22	23	19	75.0	250	1050	1300
05-14-76	1130	6400	27000	0	4	4	19	52.0	250	140	390
07-16-76	1300	18000	8900	0	13	13	11	21.0	1300	600	1900
09-01-76	1400	4800	17000	2	3	5	20	140.0	580	0	560
11-18-76	1330	130	19000	2	0	2	14	140.0	280	10	290
03-16-77	1715	810	8800	0	1	1	10	35.0	350	50	400
05-26-77	1400	230	4000	3	2	5	10	82.0	40	30	70
07-07-77	1545	1000	2700	12	0	5	10	85.0	40	10	50
09-21-77	1600	180	5400	0	0	0	10	130.0	400	0	400
11-16-77	1515	9000	1400	0	6	6	20	15.0	10	250	260
03-21-78	1100	20000	2100	0	-	-	10	26.0	360	310	670
03-22-78	1630	3100	2000	0	0	0	10	41.0	570	10	580
05-18-78	1100	580	2400	-	-	1	-	27.0	140	10	150
07-12-78	1100	100	7000	0	7	7	10	130.0	430	0	430
07-13-78	1200	33000	7000	0	30	30	10	120.0	470	440	910
10-17-78	1230	-	12000	-	-	-	-	67.0	1800	-	-
02-15-79	1200	3000	24000	-	-	14	20	48.0	510	30	540
02-23-79	1200	39000	-	-	-	-	-	5.4	120	980	1100
04-17-79	1200	330	39000	-	-	-	-	77.0	290	0	280
05-17-79	1200	310	34000	-	-	1	20	32.0	160	10	170

DATE	TIME	MANGANESE, STREAMBED (UG/G)	NICKEL, DISSOLVED (UG/L)	NICKEL, SUSPENDED (UG/L)	NICKEL, TOTAL (UG/L)	NICKEL, STREAMBED (UG/G)	ORGANIC CARBON, DISSOLVED (MG/L)	ORGANIC CARBON, SUSPENDED (MG/L)	ORGANIC CARBON, TOTAL (MG/L)	PH
04-18-75	0830	780	15	15	30	15	-	-	-	6.9
05-14-75	0830	1600	12	3	15	24	-	-	7.2	7.8
06-18-75	1130	1100	6	0	6	21	-	-	17.0	7.3
07-16-75	0915	940	4	3	7	13	-	-	2.8	7.4
08-26-75	1415	130	6	30	36	21	-	-	6.0	7.8
09-23-75	1300	1000	2	3	5	20	-	-	4.6	7.4
10-17-75	0935	800	2	2	4	17	-	-	5.4	7.5
10-17-75	1400	970	4	270	270	20	-	-	5.0	7.5
01-15-76	1245	940	5	0	2	22	-	-	3.3	6.9
02-20-76	1100	1600	8	6	14	440	-	-	3.3	8.3
03-25-76	1630	550	5	7	12	300	-	-	20.0	7.9
04-23-76	1330	14000	12	79	91	24	-	-	35.0	8.3
05-14-76	1130	1300	15	14	29	27	6.9	0.7	7.6	8.0
07-16-76	1300	380	4	24	28	9	9.3	-	-	7.3
09-01-76	1400	1000	24	10	34	20	-	-	-	8.3
11-18-76	1330	750	20	3	23	19	3.6	-	-	8.5
03-16-77	1715	540	20	0	17	20	6.1	0.6	6.7	7.9
05-26-77	1400	750	4	1	5	10	-	-	5.5	7.9
07-07-77	1545	440	20	2	22	10	-	-	-	8.2
09-21-77	1600	18	46	2	48	10	10.0	8.1	-	8.3
11-16-77	1515	430	3	12	15	100	-	-	-	8.4
03-21-78	1100	788	11	17	28	10	6.4	-	-	8.0
03-22-78	1630	840	20	6	26	10	-	-	-	8.3
05-18-78	1100	780	0	8	8	10	12.0	0.8	10.0	6.7
07-12-78	1100	1100	64	0	59	24	4.0	-	-	8.1
07-13-78	1200	780	29	23	52	23	6.4	-	7.9	7.3
10-17-78	1230	800	-	-	-	-	12.0	0.6	-	8.1
02-15-79	1200	1200	-	-	-	-	4.2	0.4	-	8.3
02-23-79	1200	-	-	-	-	-	-	-	-	7.3
04-17-79	1200	1500	-	-	-	-	-	-	-	8.4
05-17-79	1200	150	-	-	-	-	4.4	0.3	-	7.9

Table 6.—Water-column constituents and properties and streambed constituents at mined site, Spencer Creek tributary, Sullivan County, Ind.—Continued

DATE	TIME	ORTHOPHOSPHATE, DISSOLVED (MG/L)	ORTHOPHOSPHORUS, DISSOLVED (MG/L)	ORTHOPHOSPHORUS, TOTAL (MG/L)	OXYGEN, DISSOLVED (MG/L)	PHOSPHATE, TOTAL (MG/L)	PHYTOPLANKTON (CELL/ML)	POTASSIUM (MG/L)	SILICA (MG/L)	SODIUM (MG/L)
04-18-75	0830	-	-	-	10.4	-	-	3.8	-	230
05-14-75	0830	-	-	-	-	-	2600	4.7	-	410
06-18-75	1130	-	-	-	7.6	-	5500	5.1	-	330
07-16-75	0915	-	-	-	2.7	-	3600	7.3	-	560
08-26-75	1415	-	-	-	-	-	4400	7.3	-	340
09-23-75	1300	-	-	-	4.3	-	840	3.5	-	160
10-17-75	0935	-	-	-	3.5	-	-	7.0	-	620
10-17-75	1400	-	-	-	5.7	-	-	7.2	-	610
01-15-76	1245	-	-	-	11.4	-	-	2.6	-	30
02-20-76	1100	-	-	-	12.0	-	-	3.4	-	230
03-25-76	1630	-	-	-	9.1	-	-	2.4	-	76
04-23-76	1330	-	-	-	4.2	-	-	7.0	-	780
05-14-76	1130	-	-	-	6.4	-	-	5.4	-	580
07-16-76	1300	-	-	-	5.5	-	-	5.5	-	100
09-01-76	1400	-	-	-	9.0	-	-	9.7	-	540
11-18-76	1330	-	-	-	13.2	-	600	8.5	-	680
03-16-77	1715	-	-	-	9.5	-	200	5.2	-	280
05-26-77	1400	-	-	-	9.2	-	4000	6.8	-	500
07-07-77	1545	-	-	-	6.6	-	-	7.6	-	800
09-21-77	1600	-	-	-	9.4	-	-	9.0	-	760
11-16-77	1515	-	-	-	10.6	-	1800	8.4	-	54
03-21-78	1100	0.00	0.000	0.050	5.2	0.80	-	4.3	7	140
03-22-78	1630	0.00	0.000	0.010	5.5	0.12	-	4.4	7	200
05-18-78	1100	0.00	0.000	0.000	8.0	0.06	-	3.0	9	65
07-12-78	1100	-	-	-	9.0	0.00	-	9.5	8	800
07-13-78	1200	-	-	-	7.9	1.30	-	8.5	7	750
10-17-78	1230	-	-	-	10.6	-	-	5.3	5	410
02-15-79	1200	-	-	0.086	14.3	-	-	4.4	7	380
02-23-79	1200	-	-	-	14.5	-	-	2.6	5	11
04-17-79	1200	-	-	-	10.0	-	-	7.1	8	530
05-17-79	1200	-	-	-	8.5	-	-	5.0	7	210

DATE	TIME	SOLIDS, DISSOLVED (MG/L)	SOLIDS, SUSPENDED (MG/L)	SOLIDS, TOTAL (MG/L)	SPECIFIC CONDUCTANCE (UMHO/CM)	STREAMFLOW (FT3/S)	SULFATE (MG/L)	TEMPERATURE (DEG C)	ZINC, DISSOLVED (UG/L)	ZINC, SUSPENDED (UG/L)	ZINC, TOTAL (UG/L)	ZINC, STREAMBED (UG/G)
04-18-75	0830	1640	-	-	3900	0.42	940	14.7	10	0	0	19
05-14-75	0830	2040	-	-	2160	0.23	1200	14.0	0	10	10	28
06-18-75	1130	1750	-	-	1930	0.05	1100	23.5	10	10	20	19
07-16-75	0915	2070	-	-	3080	0.00	1900	18.3	0	20	20	29
08-26-75	1415	1970	-	-	2590	0.03	1100	23.6	10	0	10	23
09-23-75	1300	1000	-	-	1515	-	610	14.1	10	0	10	25
10-17-75	0935	2290	-	-	3523	-	1800	13.2	20	0	20	21
10-17-75	1400	2830	-	-	3430	-	1700	12.4	10	10	20	39
01-15-76	1245	260	-	-	426	-	130	0.3	10	10	20	29
02-20-76	1100	1140	-	-	1190	-	590	4.1	10	0	10	28
03-25-76	1630	510	-	-	764	-	280	13.1	0	20	20	17
04-23-76	1330	3140	-	-	4500	-	1800	21.9	20	100	120	25
05-14-76	1130	2320	-	-	2880	-	1300	18.7	0	20	20	32
07-16-76	1300	666	-	-	880	-	380	24.3	0	50	50	9
09-01-76	1400	3270	-	-	3470	-	1800	20.3	10	20	30	40
11-18-76	1330	3480	-	-	4560	-	1100	5.5	20	0	10	29
03-16-77	1715	1270	-	-	1730	-	720	13.4	0	20	20	18
05-26-77	1400	2460	-	-	2930	-	1400	27.1	50	0	30	10
07-07-77	1545	2910	-	-	3640	-	1600	32.9	10	0	10	10
09-21-77	1600	3560	-	-	3950	-	1900	23.0	10	0	10	10
11-16-77	1515	348	-	-	267	1.69	170	14.2	10	10	20	10
03-21-78	1100	721	154	875	699	12.09	380	6.7	10	40	-	10
03-22-78	1630	1080	140	1220	1588	6.22	580	9.4	0	20	20	10
05-18-78	1100	451	20	471	705	0.44	230	20.2	10	0	10	20
07-12-78	1100	3690	0	3680	4466	0.32	2100	23.3	0	0	0	20
07-13-78	1200	3420	90	3510	3755	0.94	2200	30.0	10	40	50	30
10-17-78	1230	2000	-	-	2592	0.14	1200	13.1	-	-	-	-
02-15-79	1200	1700	-	-	2127	-	800	0.2	-	-	20	40
02-23-79	1200	137	-	-	132	25.81	44	1.3	-	-	-	-
04-17-79	1200	2330	-	-	3040	1.32	1200	16.9	-	-	-	-
05-17-79	1200	961	-	-	1319	0.96	530	20.9	-	-	20	40

Table 7.—Water-column constituents and properties and lakebed constituents at South Lake, Sullivan County, Ind.

[Time is expressed as a 1-24 hour day; for example, 1400 is the same as 2:00 p.m.
Total hardness and alkalinity are expressed as calcium carbonate]

DATE	TIME	ACIDITY (MG/L)	ALKA-LINITY (MG/L)	ALUMINUM, DISSOLVED (UG/L)	ALUMINUM, SUSPENDED (UG/L)	ALUMINUM, TOTAL (UG/L)	ALUMINUM, STREAMBED (UG/G)	BICAR-BONATE (MG/L)	CADMIUM, DISSOLVED (UG/L)	CADMIUM, SUSPENDED (UG/L)	CADMIUM, TOTAL (UG/L)
05-13-75	1400	0.0	120	10	0	10	-	146.0	0	0	0
06-17-75	1330	0.0	153	20	0	0	-	186.0	0	0	0
07-16-75	1130	0.0	212	30	0	0	-	258.0	0	2	2
08-27-75	0930	0.0	200	0	20	20	-	244.0	0	0	0
09-24-75	1100	0.0	225	30	50	80	-	274.0	0	0	0
10-18-75	1030	0.0	133	60	30	90	-	162.0	0	0	0
02-20-76		-	-	-	-	-	-	-	-	-	-
03-25-76	1300	35.0	190	10	20	30	-	232.0	0	0	0
03-25-76	1315	-	-	-	-	-	-	-	-	-	-
06-16-76	1130	-	-	-	-	-	-	-	-	-	-
07-16-76	1600	-	-	-	-	-	-	-	-	-	-
07-16-76	1605	-	-	-	-	-	-	-	-	-	-
09-15-76	1315	-	-	-	-	-	-	-	-	-	-
09-15-76	1320	-	-	-	-	-	-	-	-	-	-
11-19-76	1030	-	-	-	-	-	-	-	-	-	-
01-20-77	1630	-	-	-	-	30	-	-	-	-	2
01-20-77	1635	-	-	-	-	-	-	-	-	-	-
01-20-77	1640	-	-	-	-	280	-	-	-	-	0
03-17-77	1130	-	-	-	-	40	-	-	-	-	1
03-17-77	1135	-	-	-	-	30	-	-	-	-	0
03-17-77	1140	-	-	-	-	30	-	-	-	-	0
05-26-77	1210	-	-	-	-	-	-	-	-	-	-
05-26-77	1220	-	-	-	-	-	-	-	-	-	-
07-07-77	1150	-	-	-	-	-	-	-	-	-	-
07-07-77	1155	-	-	-	-	-	-	-	-	-	-
07-07-77	1200	-	-	-	-	-	-	-	-	-	-
07-07-77	1205	-	-	-	-	-	-	-	-	-	-
07-07-77	1210	-	-	-	-	-	-	-	-	-	-
09-21-77	1430	-	-	-	-	60	-	-	-	-	0
09-21-77	1435	-	-	-	-	160	-	-	-	-	0
11-16-77	1330	0.0	260	0	130	130	-	320.0	0	1	1
08-14-78	1500	0.0	170	10	0	0	-	210.0	1	0	1

DATE	TIME	CALCIUM (MG/L)	CARBON DIOXIDE (MG/L)	CAR-BONATE (MG/L)	CHLOR-IDE (MG/L)	CHROMIUM, DISSOLVED (UG/L)	CHROMIUM, SUSPENDED (UG/L)	CHROMIUM, TOTAL (UG/L)	COBALT, DISSOLVED (UG/L)	COBALT, SUSPENDED (UG/L)	COBALT, TOTAL (UG/L)
05-13-75	1400	180.0	2.9	0.0	2.3	10	0	10	0	0	0
06-17-75	1330	230.0	7.5	0.0	3.0	20	10	30	0	0	0
07-16-75	1130	280.0	10.0	0.0	4.0	10	0	10	0	0	0
08-27-75	0930	240.0	3.5	0.0	2.9	10	0	10	0	0	0
09-24-75	1100	250.0	11.0	0.0	4.3	10	0	10	0	0	0
10-18-75	1030	260.0	6.5	0.0	4.3	20	10	30	0	1	1
02-20-76		-	-	-	-	-	-	-	-	-	-
03-25-76	1300	240.0	5.9	0.0	3.8	10	0	10	1	0	0
03-25-76	1315	-	-	-	-	-	-	-	-	-	-
06-16-76	1130	-	-	-	-	-	-	-	-	-	-
07-16-76	1600	-	-	-	-	-	-	-	-	-	-
07-16-76	1605	-	-	-	-	-	-	-	-	-	-
09-15-76	1315	-	-	-	-	-	-	-	-	-	-
09-15-76	1320	-	-	-	-	-	-	-	-	-	-
11-19-76	1030	-	-	-	-	-	-	-	-	-	-
01-20-77	1630	-	-	-	-	-	-	20	-	-	2
01-20-77	1635	-	-	-	-	-	-	-	-	-	-
01-20-77	1640	-	-	-	-	-	-	20	-	-	15
03-17-77	1130	-	-	-	-	-	-	20	-	-	1
03-17-77	1135	-	-	-	-	-	-	20	-	-	2
03-17-77	1140	-	-	-	-	-	-	20	-	-	4
05-26-77	1210	-	-	-	-	-	-	-	-	-	-
05-26-77	1220	-	-	-	-	-	-	-	-	-	-
07-07-77	1150	-	-	-	-	-	-	-	-	-	-
07-07-77	1155	-	-	-	-	-	-	-	-	-	-
07-07-77	1200	-	-	-	-	-	-	-	-	-	-
07-07-77	1205	-	-	-	-	-	-	-	-	-	-
07-07-77	1210	-	-	-	-	-	-	-	-	-	-
09-21-77	1430	-	-	-	-	-	-	10	-	-	0
09-21-77	1435	-	-	-	-	-	-	10	-	-	3
11-16-77	1330	300.0	27.0	0.0	5.9	-	-	10	0	0	0
08-14-78	1500	240.0	6.7	0.0	4.1	2	58	60	3	0	3

DATE	TIME	COPPER, DISSOLVED (UG/L)	COPPER, SUSPENDED (UG/L)	COPPER, TOTAL (UG/L)	HARDNESS, NONCARBONATE (MG/L)	HARDNESS, TOTAL (MG/L)	IRON, DISSOLVED (UG/L)	IRON, SUSPENDED (UG/L)
05-13-75	1400	10	0	0	1100	1200	20	70
06-17-75	1330	10	10	20	1200	1400	30	50
07-16-75	1130	10	10	20	1400	1600	50	40
08-27-75	0930	10	0	10	1400	1600	10	30
09-24-75	1100	10	0	10	1200	1400	40	20
10-18-75	1030	10	0	10	1300	1400	20	90
02-20-76		-	-	-	-	-	-	-
03-25-76	1300	10	0	10	1400	1500	50	190
03-25-76	1315	-	-	-	-	-	-	-
06-16-76	1130	-	-	-	-	-	-	-
07-16-76	1600	-	-	-	-	-	-	-
07-16-76	1605	-	-	-	-	-	-	-
09-15-76	1315	-	-	-	-	-	-	-
09-15-76	1320	-	-	-	-	-	-	-
11-19-76	1030	-	-	-	-	-	-	-
01-20-77	1630	-	-	20	-	-	-	-
01-20-77	1635	-	-	-	-	-	-	-
01-20-77	1640	-	-	20	-	-	-	-
03-17-77	1130	-	-	10	-	-	-	-
03-17-77	1135	-	-	10	-	-	-	-
03-17-77	1140	-	-	30	-	-	-	-
05-26-77	1210	-	-	-	-	-	-	-
05-26-77	1220	-	-	-	-	-	-	-
07-07-77	1150	-	-	-	-	-	-	-
07-07-77	1155	-	-	-	-	-	-	-
07-07-77	1200	-	-	-	-	-	-	-
07-07-77	1205	-	-	-	-	-	-	-
07-07-77	1210	-	-	-	-	-	-	-
09-21-77	1430	-	-	2	-	-	-	-
09-21-77	1435	-	-	0	-	-	-	-
11-16-77	1330	4	1	5	1500	1800	10	90
08-14-78	1500	0	1	1	1300	1400	20	20

Table 7.--Water-column constituents and properties and lakebed constituents at South Lake, Sullivan County, Ind.--Continued

DATE	TIME	IRON, TOTAL (UG/L)	LEAD, DISSOLVED (UG/L)	LEAD, SUSPENDED (UG/L)	LEAD, TOTAL (UG/L)	MAGNESIUM (MG/L)	MANGANESE, DISSOLVED (UG/L)	MANGANESE, SUSPENDED (UG/L)	MANGANESE, TOTAL (UG/L)
05-13-75	1400	90	0	0	0	180.0	220	50	270
06-17-75	1330	100	0	0	0	200.0	100	50	150
07-16-75	1130	90	0	0	0	220.0	380	100	480
08-27-75	0930	40	3	0	0	240.0	30	110	140
09-24-75	1100	60	0	2	2	190.0	200	190	390
10-18-75	1030	110	0	0	0	180.0	150	110	260
02-20-76		-	-	-	-	-	-	-	-
03-25-76	1300	250	1	0	1	230.0	210	40	250
03-25-76	1315	-	-	-	-	-	-	-	-
06-16-76	1130	-	-	-	-	-	-	-	-
07-16-76	1600	-	-	-	-	-	-	-	-
07-16-76	1605	-	-	-	-	-	-	-	-
09-15-76	1315	-	-	-	-	-	-	-	-
09-15-76	1320	-	-	-	-	-	-	-	-
11-19-76	1030	-	-	-	-	-	-	-	-
01-20-77	1630	90	-	-	3	-	-	-	320
01-20-77	1635	-	-	-	-	-	-	-	-
01-20-77	1640	1300	-	-	2	-	-	-	14000
03-17-77	1130	260	-	-	6	-	-	-	510
03-17-77	1135	130	-	-	2	-	-	-	690
03-17-77	1140	170	-	-	3	-	-	-	2300
05-26-77	1210	-	-	-	-	-	-	-	-
05-26-77	1220	-	-	-	-	-	-	-	-
07-07-77	1150	-	-	-	-	-	-	-	-
07-07-77	1155	-	-	-	-	-	-	-	-
07-07-77	1200	-	-	-	-	-	-	-	-
07-07-77	1205	-	-	-	-	-	-	-	-
07-07-77	1210	-	-	-	-	-	-	-	-
09-21-77	1430	80	-	-	3	-	-	-	470
09-21-77	1435	220	-	-	4	-	-	-	9500
11-16-77	1330	100	1	1	2	250.0	1200	200	1400
08-14-78	1500	40	2	0	2	200.0	110	30	140

DATE	TIME	NICKEL, DISSOLVED (UG/L)	NICKEL, SUSPENDED (UG/L)	NICKEL, TOTAL (UG/L)	NICKEL, STREAMBED (UG/G)	ORGANIC CARBON, DISSOLVED (MG/L)	ORGANIC CARBON, TOTAL (MG/L)	PH
05-13-75	1400	7	18	25	-	-	8.5	7.9
06-17-75	1330	4	0	0	-	-	13.0	7.6
07-16-75	1130	4	0	4	-	-	3.4	7.6
08-27-75	0930	4	27	31	-	-	5.6	6.0
09-24-75	1100	4	8	12	-	-	3.2	7.6
10-18-75	1030	2	0	2	-	-	6.8	7.5
02-20-76		-	-	-	-	-	-	8.0
03-25-76	1300	5	1	6	-	-	7.5	7.8
03-25-76	1315	-	-	-	-	-	-	7.4
06-16-76	1130	-	-	-	-	-	-	6.5
07-16-76	1600	-	-	-	-	-	-	-
07-16-76	1605	-	-	-	-	-	-	-
09-15-76	1315	-	-	-	-	-	-	7.7
09-15-76	1320	-	-	-	-	-	-	7.1
11-19-76	1030	-	-	-	-	-	-	7.6
01-20-77	1630	-	-	13	-	-	-	7.5
01-20-77	1635	-	-	-	-	-	-	7.6
01-20-77	1640	-	-	25	-	-	-	7.0
03-17-77	1130	-	-	12	-	-	3.3	7.5
03-17-77	1135	-	-	13	-	-	5.2	7.4
03-17-77	1140	-	-	13	-	-	-	7.3
05-26-77	1210	-	-	-	-	-	-	7.2
05-26-77	1220	-	-	-	-	-	-	7.2
07-07-77	1150	-	-	-	-	-	-	8.0
07-07-77	1155	-	-	-	-	-	-	9.0
07-07-77	1200	-	-	-	-	-	-	7.6
07-07-77	1205	-	-	-	-	-	-	7.5
07-07-77	1210	-	-	-	-	-	-	7.3
09-21-77	1430	-	-	10	-	-	6.1	7.5
09-21-77	1435	-	-	17	-	-	7.5	6.7
11-16-77	1330	7	7	14	-	3.4	-	7.3
08-14-78	1500	9	0	4	-	16.0	-	7.7

Table 7.—Water-column constituents and properties and lakebed constituents at South Lake, Sullivan County, Ind.—Continued

DATE	TIME	OXYGEN, DISSOLVED (MG/L)	PHOSPHATE, TOTAL (MG/L)	PHYTO-PLANKTON (CELL/ML)	POTAS-SIUM (MG/L)	SILICA (MG/L)	SODIUM (MG/L)	SOLIDS, DISSOLVED (MG/L)	SOLIDS, SUSPENDED (MG/L)
05-13-75	1400	-	-	170	2.9	-	68	2020	-
06-17-75	1330	8.0	-	5800	4.1	-	73	1230	-
07-16-75	1130	8.7	-	1600	4.9	-	81	1990	-
08-27-75	0930	-	-	1500	5.0	-	77	2620	-
09-24-75	1100	7.6	-	3700	4.5	-	83	1690	-
10-18-75	1030	7.7	-	2800	5.0	-	84	2790	-
02-20-76		11.6	-	950	-	-	-	-	-
03-25-76	1300	10.9	-	330	4.3	-	72	2370	-
03-25-76	1315	23.5	-	1900	-	-	-	-	-
06-16-76	1130	7.8	-	930	-	-	-	-	-
07-16-76	1600	-	-	45000	-	-	-	-	-
07-16-76	1605	-	-	21000	-	-	-	-	-
09-15-76	1315	9.2	-	840	-	-	-	-	-
09-15-76	1320	7.2	-	3700	-	-	-	-	-
11-19-76	1030	10.7	-	1200	-	-	-	-	-
01-20-77	1630	11.4	-	900	-	-	-	-	-
01-20-77	1635	11.4	-	93	-	-	-	-	-
01-20-77	1640	2.6	-	-	-	-	-	-	-
03-17-77	1130	10.6	-	1300	-	-	-	-	-
03-17-77	1135	11.7	-	230	-	-	-	-	-
03-17-77	1140	9.8	-	220	-	-	-	-	-
05-26-77	1210	8.2	-	330	-	-	-	-	-
05-26-77	1220	13.7	-	580	-	-	-	-	-
07-07-77	1150	9.3	-	-	-	-	-	-	-
07-07-77	1155	10.4	-	-	-	-	-	-	-
07-07-77	1200	11.9	-	-	-	-	-	-	-
07-07-77	1205	10.2	-	-	-	-	-	-	-
07-07-77	1210	8.6	-	-	-	-	-	-	-
09-21-77	1430	9.7	-	1500	-	-	-	-	-
09-21-77	1435	3.4	-	-	-	-	-	-	-
11-16-77	1330	8.8	-	120	5.2	-	84	2490	-
08-14-78	1500	8.7	0.03	4200	5.0	2	80	2140	40

DATE	TIME	SOLIDS, TOTAL (MG/L)	SPECIFIC CONDUCTANCE (UMHO/CM)	SULFATE (MG/L)	TEMP-ATURE (DEG C)	ZINC, DISSOLVED (UG/L)	ZINC, SUSPENDED (UG/L)	ZINC, TOTAL (UG/L)
05-13-75	1400	-	1920	1300	21.5	10	10	20
06-17-75	1330	-	1840	1400	26.0	10	10	20
07-16-75	1130	-	2430	1600	25.6	0	20	20
08-27-75	0930	-	2770	1600	27.9	10	0	10
09-24-75	1100	-	2824	1600	18.0	10	0	10
10-18-75	1030	-	2890	1800	15.3	10	10	20
02-20-76		-	2270	-	7.2	-	-	-
03-25-76	1300	-	2260	1400	12.1	10	0	10
03-25-76	1315	-	2600	-	10.8	-	-	-
06-16-76	1130	-	1570	-	25.9	-	-	-
07-16-76	1600	-	-	-	-	-	-	-
07-16-76	1605	-	-	-	-	-	-	-
09-15-76	1315	-	2810	-	23.6	-	-	-
09-15-76	1320	-	2760	-	22.0	-	-	-
11-19-76	1030	-	3260	-	6.4	-	-	-
01-20-77	1630	-	2680	-	2.3	-	-	30
01-20-77	1635	-	2810	-	2.7	-	-	-
01-20-77	1640	-	3530	-	6.8	-	-	70
03-17-77	1130	-	2400	-	11.1	-	-	20
03-17-77	1135	-	2840	-	5.6	-	-	30
03-17-77	1140	-	2920	-	5.6	-	-	30
05-26-77	1210	-	2400	-	25.8	-	-	-
05-26-77	1220	-	2600	-	24.1	-	-	-
07-07-77	1150	-	2300	-	29.3	-	-	-
07-07-77	1155	-	2275	-	28.7	-	-	-
07-07-77	1200	-	560	-	25.0	-	-	-
07-07-77	1205	-	2680	-	21.3	-	-	-
07-07-77	1210	-	800	-	18.9	-	-	-
09-21-77	1430	-	2680	-	22.4	-	-	10
09-21-77	1435	-	3050	-	18.8	-	-	10
11-16-77	1330	-	1872	770	12.2	20	0	20
08-14-78	1500	2180	2170	1300	27.2	10	0	10