STREAMFLOW AND STREAM QUALITY IN THE COAL-MINING REGION,

PATOKA RIVER BASIN, SOUTHWESTERN INDIANA, 1983-85

By Danny E. Renn

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 88-4150

Prepared in cooperation with the

INDIANA DEPARTMENT OF NATURAL RESOURCES

Indianapolis, Indiana

1989

DEPARTMENT OF THE INTERIOR

MANUEL L. LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
5957 Lakeside Boulevard
Indianapolis, IN 46278-1996

Copies of this report
can be purchased from:

U.S. Geological Survey
Books and Open-File Reports
Box 25425
Federal Center, Bldg. 810
Denver, CO 80225-0425

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Inch-pound units in this report may be converted to metric units (International System) by using the following conversion factors:

Multiply inch-pound unit	By	To obtain metric units
acre	0.4047	hectare
acre-foot (acre-ft)	0.001233	cubic hectometer
British thermal unit per pound (Btu/lb)	2.324	joule per gram
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pound per day (lb/d)	0.4536	kilogram per day
square mile (mi^2)	2.59	square kilometer
ton, short	0.9072	megagram

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5\ (°C + 32)$$

ABBREVIATIONS AND SYMBOLS

µg/L	microgram per liter
µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligram per liter

STREAMFLOW AND STREAM QUALITY IN THE COAL-MINING REGION, PATOKA RIVER BASIN, SOUTHWESTERN INDIANA, 1983-85

By Danny E. Renn

ABSTRACT

Streamflow and stream-quality data were collected for surface water in the coal-mining region of the Patoka River basin. Data were collected primarily in Pike County.

Data were collected 4 times at 29 surface-water sites during different seasons and conditions of streamflow. Data were collected August 1983, July 1984, December 1984, and February through March 1985. Six sites were on the Patoka River. Although the percentage of drainage from coal-mined lands increases from the upstream to the downstream sites, the major land use for all sites on the Patoka River is agriculture. Ten sites were on 8 tributaries to the Patoka River (excluding the South Fork Patoka River), 3 sites were on the South Fork Patoka River (the largest tributary to the Patoka River), and 10 sites were on 10 tributaries to the South Fork Patoka River. The major land use for these sites is coal mining.

Data obtained at the sites included instantaneous streamflow, pH, specific conductance, dissolved-oxygen concentration, water temperature and concentrations of alkalinity and hot acidity. Water samples were collected and analyzed to determine the concentrations of dissolved sulfate; dissolved, suspended, and total recoverable iron and manganese; dissolved solids; suspended sediment; and suspended sediment finer than 0.0625-millimeter diameter.

Streamflow in the Patoka River has been regulated since 1978 by Patoka Lake. Flow-duration analyses indicate that flow regulation by Patoka Lake generally has increased low streamflows and decreased high streamflows in the Patoka River.

When compared to sites on the tributaries, sites on the Patoka River generally had smaller values for specific conductance and concentrations of chemical constituents. Sites on the tributaries to the Patoka River (including the South Fork Patoka and its tributaries) had larger values due to the physical and chemical weathering of coal-mined material in their basins. Generally, for sites on the Patoka River, values of specific conductance and concentrations of dissolved sulfate and dissolved, suspended, and total recoverable manganese increased from the upstream to the downstream sites.

For the tributary sites, pH was near neutral at 11 sites (median pH value of 7.3 for all samplings), pH was low at 8 sites (median pH value of 3.7 for all samplings), and pH was variable at 3 sites depending on streamflow. At sites where pH was near neutral, when compared with sites where pH was low,

specific conductance and concentrations of alkalinity, dissolved sulfate, suspended iron, suspended manganese, dissolved solids, and suspended sediment generally were larger, and concentrations of acidity, dissolved iron, total recoverable iron, dissolved manganese, and total manganese generally were smaller. At those sites where pH varied with streamflow, concentrations of chemical constituents also varied.

For sites on the Patoka River, loads of dissolved sulfate, total recoverable manganese, and dissolved solids generally increased from the upstream to the downstream sites; loads of total recoverable iron were variable. Generally, there was an inverse relation of streamflow to concentrations of chemical constituents--the greater the streamflow, the smaller the concentrations. For sites on the tributaries, there was an inverse relation of streamflow to specific conductance and to concentrations of alkalinity, acidity, dissolved sulfate, and dissolved solids and a direct relation of streamflow to concentrations of dissolved, suspended, and total iron.

Data collected from 1965 through 1968 and during May and October 1979 were compared with data collected during the time of the study (1983-85). Few historical data were available, and those that were available were only for selected sites. Data for pH, alkalinity, acidity, and dissolved sulfate indicate minimal or no change in these constituents.

INTRODUCTION

Surface-water quality in the Patoka River basin is affected by drainage from coal-mined areas. Physical and chemical weathering of material in coal refuse piles, slurry ponds, cast overburden, and underground mines produce mineralized, and sometimes acidic, drainages. In comparison to water draining unmined areas, water draining coal-mined areas generally has larger concentrations of most chemical constituents. These changes in water quality affect the domestic, manufacturing, or agricultural uses of water draining mined areas.

This study was completed in cooperation with the Indiana Department of Natural Resources.

Purpose and Scope

This report describes the results of a study by the U.S. Geological Survey to determine the streamflow and stream quality in the Patoka River and its tributaries, including the South Fork Patoka River and its tributaries. The South Fork Patoka River is the largest tributary to the Patoka River.

Data were collected 4 times at 29 surface-water sites during different seasons and conditions of flow. Data were collected August 1983, July 1984, December 1984, and February through March 1985. Six sites were on the Patoka River, 10 sites were on 8 tributaries to the Patoka River (excluding the South Fork Patoka River), 3 sites were on the South Fork Patoka River, and 10 sites were on 10 tributaries to the South Fork Patoka River. Because the flow in the Patoka River is regulated by Patoka Lake, data collection was designed to represent four different flow conditions in the Patoka River: (1) Dry-weather steady-state low flows with large releases of water from Patoka Lake; (2) dry-weather steady-state low flows with small releases of water from Patoka Lake; (3) wet-weather nonsteady-state high flows with small releases of water from Patoka Lake; and (4) wet-weather nonsteady-state high flows with large releases of water from Patoka Lake. The tributaries were sampled four times at two different flow conditions--twice during dry-weather steady-state low flows and twice during wet-weather nonsteady-state high flows.

Physical Setting

The Patoka River basin is located in Pike, Dubois, Orange, and Crawford Counties; small contributing drainage areas of the basin are in Warrick, Gibson, Spencer, and Martin Counties (fig. 1). The primary area of study was located in Pike County; the two most upstream sampling sites are located in Dubois County.

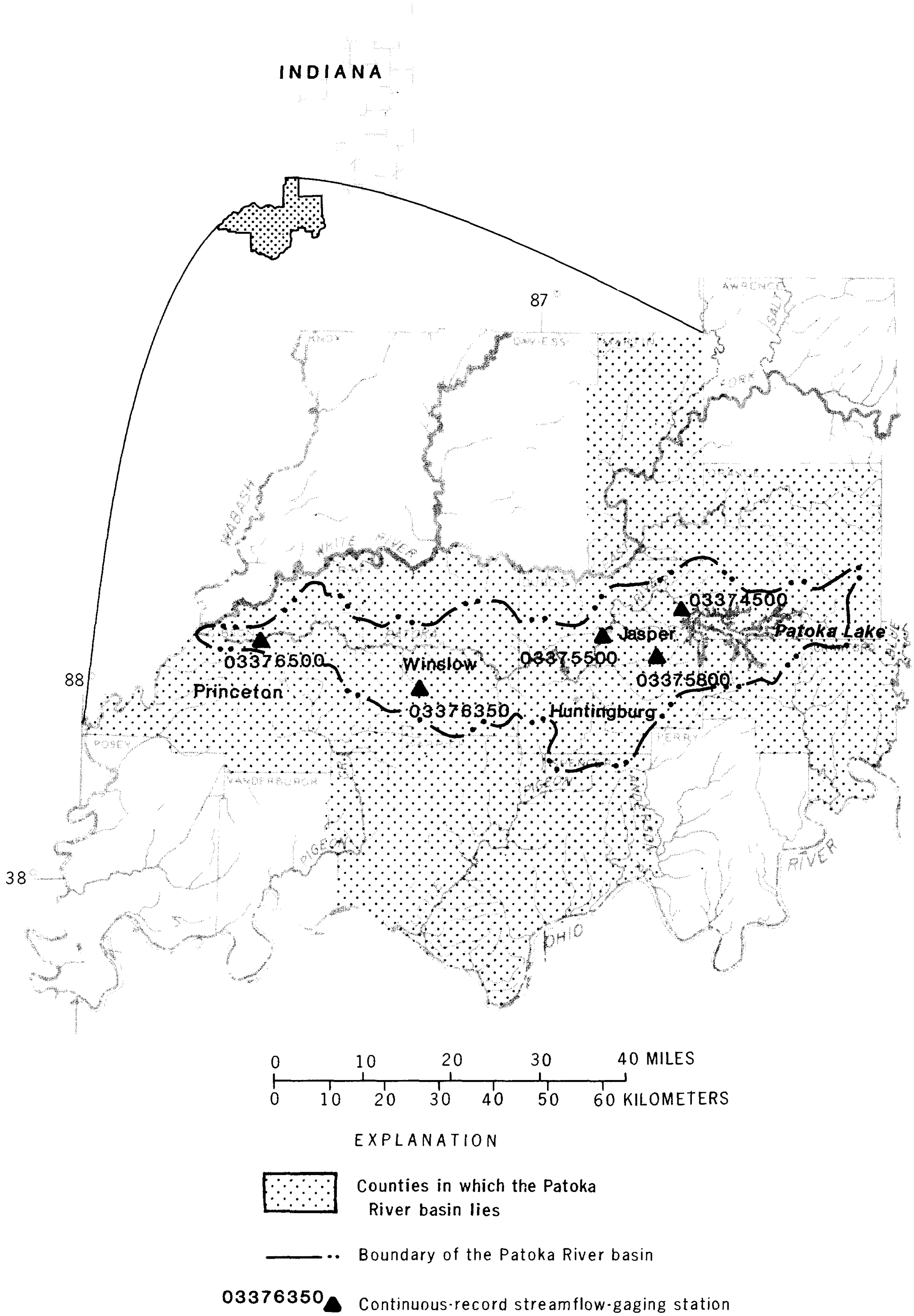


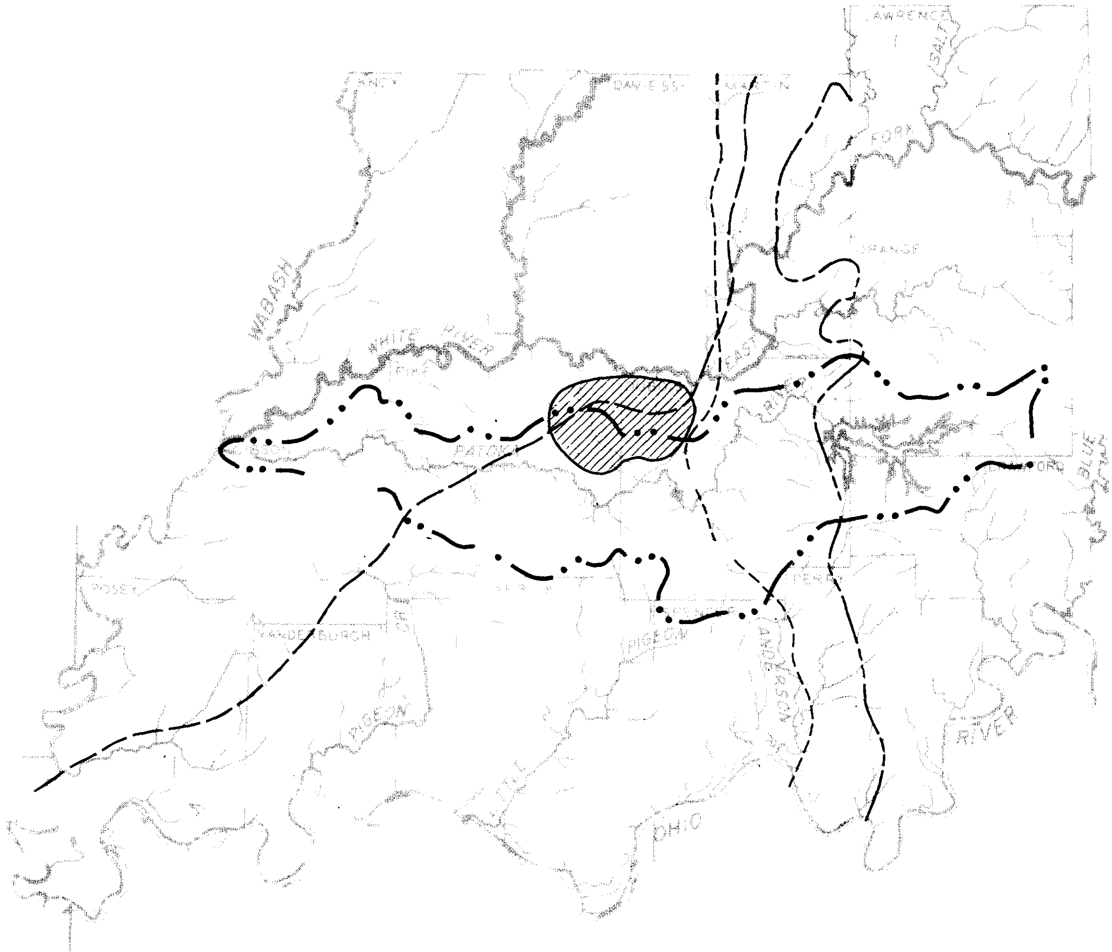
Figure 1.-- Locations of Patoka River basin, Patoka Lake, and continuous-record streamflow-gaging stations.

Geology

Sedimentary rocks of Mississippian and Pennsylvanian age underlie the study area (fig. 2). The rocks form almost flat-lying units of variable thickness and continuity and dip toward the southwest at 20 to 30 feet per mile. As a result, the older rocks crop out farther to the east than the younger rocks. Structure of the study area has been disturbed only slightly during the last one-half billion years.

Rocks of Mississippian age underlie the extreme eastern part of Dubois County and eastern Orange and Crawford Counties. These rocks unconformably underlie rocks of Pennsylvanian age (fig. 3). The middle part of the rocks of Mississippian age, the Blue River Group, are composed primarily of marine limestones of various textures (Gray, 1979, p. K3). The upper part of the rocks of Mississippian age, the West Baden, Stephensport, and Buffalo Wallow Groups are composed of cyclic sequences of limestone, sandstone, and shale (Gray, 1979, p. K3, and Shaver and others, 1986, p. 24). These rocks vary stratigraphically and areally in their physical and chemical composition.

Rocks of Pennsylvanian age underlie Pike County; Dubois County (except for the extreme eastern part); the small contributing drainage areas of Warrick, Gibson, Spencer, and Martin Counties; and the extreme western part of Orange County. These rocks (fig. 3) are composed of cyclic sequences of primarily clastic shale, siltstone, and sandstone intermixed with thin, widespread beds of coal, clay, limestone, and black shale (Gray, 1979, p. K1). All rocks vary stratigraphically and areally in their physical and chemical composition. The shale, which comprises the greatest volume of rocks of Pennsylvanian age in the study area, and the siltstone generally are calcareous and can contain limestone nodules, iron-rich concretions, and pyrite (Shaver and others, 1970). The sandstone is cemented by calcium carbonate or iron oxide, and the coal can contain pyrite or shale-pyrite partings (Shaver and others, 1970).



0 10 20 30 40 MILES

0 10 20 30 40 50 60 KILOMETERS

EXPLANATION

Lacustrine deposits

Boundary of the Patoka River basin

Maximum southern extent of Illinoian glaciation

Contact between Mississippian and Pennsylvanian bedrock

Boundary between Wabash Lowland and Crawford Upland

Figure 2.-- Locations of Patoka River basin, contact between Mississippian and Pennsylvanian rocks, physiographic units, lacustrine deposits, and glacial boundary.

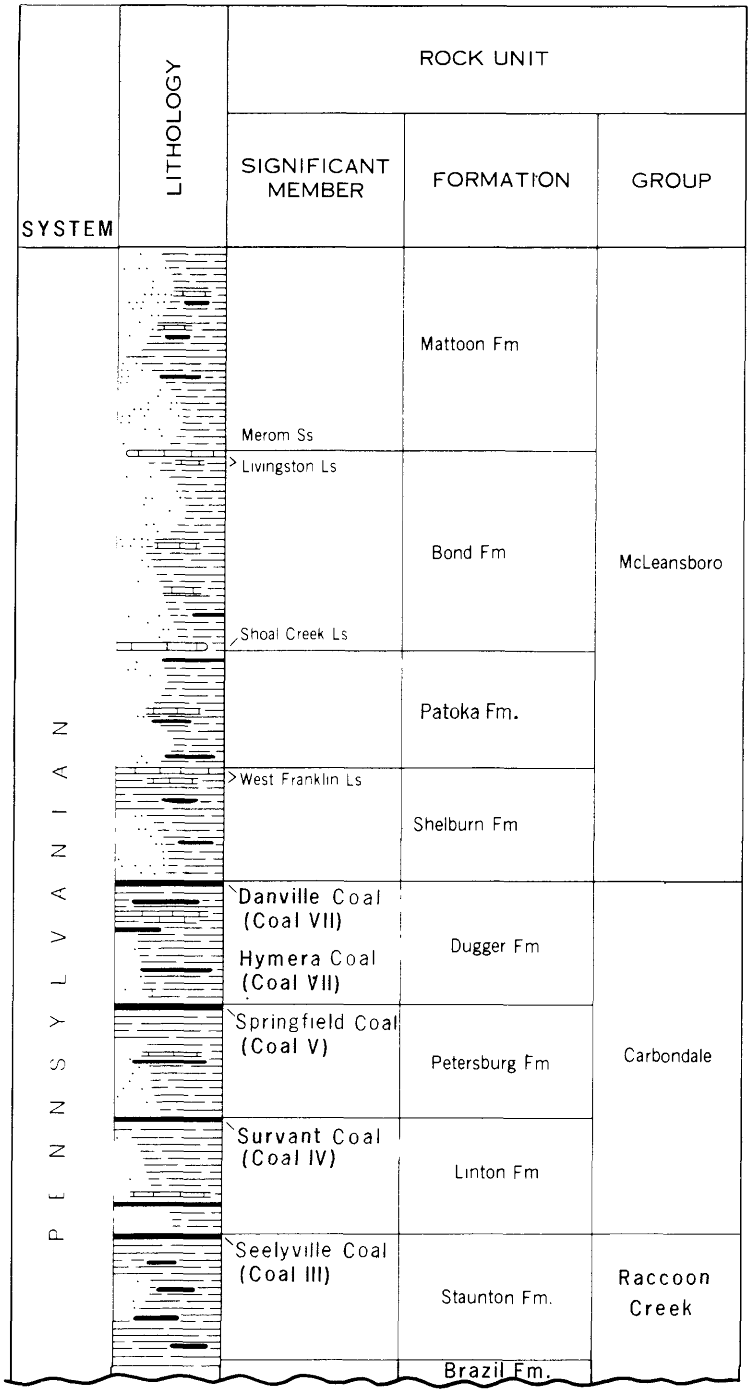


Figure 3 -- Generalized geologic column showing names and positions of groups, formations, and significant members of the Mississippian and Pennsylvanian Systems in the Patoka River basin.

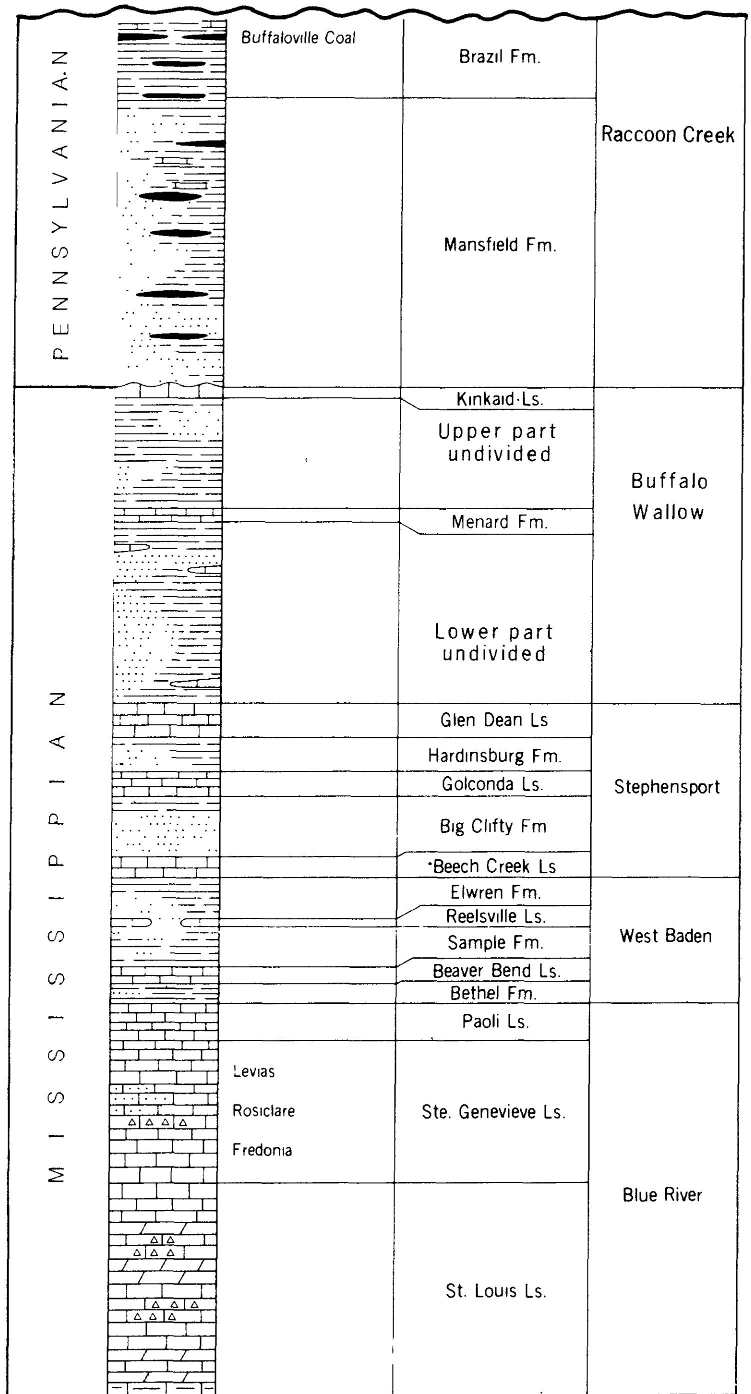


Figure 3 -- continued Geology modified from Gray and others, 1970 and Shaver and others, 1986. The stratigraphic nomenclature follows the usage of the Indiana Geologic Survey and may not necessarily follow the usage of the U.S. Geological Survey.

Physiography

The Patoka River basin includes part of an area of extensive lacustrine deposits and minimal glacial deposits (fig. 2). The basin also includes parts of the Crawford Upland and the Wabash Lowland physiographic units (fig. 2) (Schneider, 1966, p. 4). Each physiographic unit includes unique geologic features, such as structure, stratigraphy, lithology, and topography.

The Crawford Upland is in the eastern part of the Patoka River basin and is a deeply dissected area consisting of well-developed and well-entrenched dendritic drainage systems. The narrow tops of the drainage divides extend as much as 350 ft above the valley floors. Slopes are steep and flood plains usually are narrow to moderately wide in the large valleys (Schneider, 1966, p. 48). The Crawford Upland is underlain by the Blue River, West Baden, Stephensport, and Buffalo Wallow Groups of the rocks of Mississippian age and by the rocks of the Mansfield Formation of Pennsylvanian age.

The Wabash Lowland is in the western part of the Patoka River basin and is a broad, lowland tract consisting of extensive aggraded valleys and, in places, of thick lacustrine, outwash, and alluvial sediments. These deposits are of Holocene age. The upstream areas consist of rolling to undulating plains. Some of these plains contain well-developed and well-entrenched dendritic drainage systems that have drainage divides that extend as much as 150 ft above the valley floors (Schneider, 1966, p. 48-49). The Wabash Lowland is underlain by rocks of Pennsylvanian age.

Patoka River and Tributaries

The drainage area of the Patoka River basin is 862 mi^2 (square miles). Upstream from Winslow (fig. 4), the Patoka River has a natural meandering channel, but downstream from Winslow, the river has been channelized for about 16 miles. Downstream from the channelization, the river returns to a natural meandering channel. The river was channelized during 1921-22 (Corbett, 1969, p. 24). The channelization primarily occurs in the Dugger Formation of Pennsylvanian age.

Major tributaries to the Patoka River in the study area and their drainage areas, in square miles, are: South Fork Patoka River, 76.3; and Flat Creek, 58.9. Major tributaries to the South Fork Patoka River and their drainage areas, in square miles, are: Rough Creek, 10.2; Honey Creek, 9.17; Houchin ditch, 6.94; and Durham ditch, 6.26 (Hoggatt, 1975, p. 86 and p. 170).

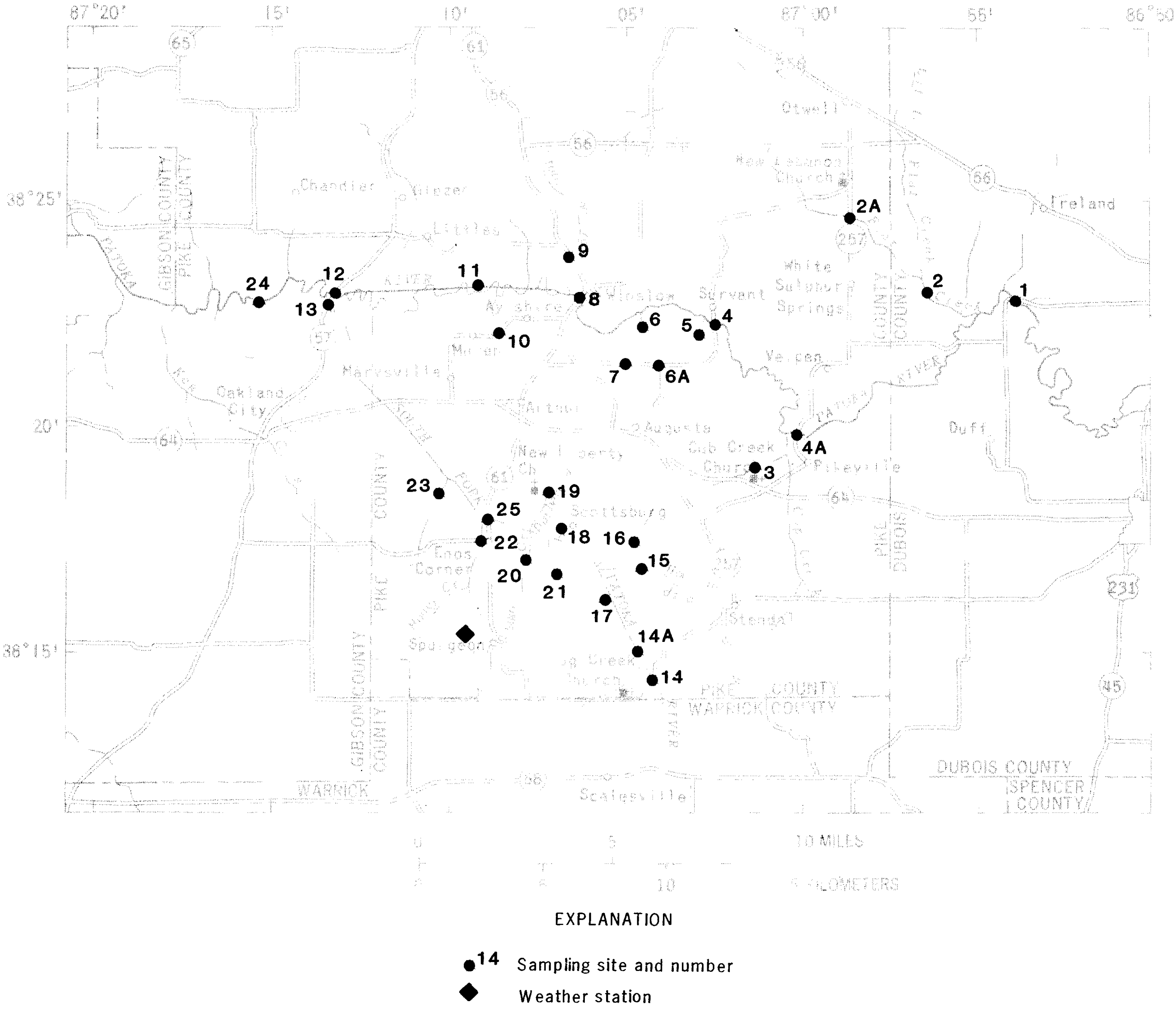


Figure 4.-- Locations of sampling sites.

Patoka Lake

Flow of the Patoka River has been regulated since February 1978 by Patoka Lake (fig. 1). The lake is used for flood control, water supply, and recreation. At normal pool level, it has an elevation of 536 feet, and is the third largest body of water in Indiana with a capacity of 178,730 acre-feet. At the dam, the drainage area of the Patoka River is 168 mi^2.

Two U.S. Geological Survey continuous-record streamflow-gaging stations located on the Patoka River (fig. 1) were used to determine flow-duration curves and largest daily mean flow for the period before and after construction of Patoka Lake. Patoka River near Cuzco (03374500) is located 2.1 river miles downstream from Patoka Lake and has a drainage area of 171 mi^2. At this station, a flow duration curve for water years (October-September) 1962-77 indicate that at the 95-, 50-, 25-, and 5-percent values the river flows were 0.85, 50.1, 196, and 1,130 ft^3/s (cubic feet per second). The largest daily mean flow was 13,500 ft^3/s. For the water years 1979-84 at the 95-, 50-, 25-, and 5-percent values, flows were 30.5, 134, 320, and 868 ft^3/s. The largest daily mean flow was 2,810 ft^3/s.

Patoka River near Princeton (03376500) (fig. 1) is located 96.7 river miles downstream from Patoka Lake and has a drainage area of 822 mi^2. At this station, a flow duration curve for the water years 1962-77 indicate that at the 95-, 50-, 25-, and 5-percent values, flows were 17.0, 336, 1,380, and 3,320 ft^3/s. The largest daily mean flow was 15,100 ft^3/s. For the water years 1979-84 at the 95-, 50-, 25-, and 5-percent values, flows were 79.4, 819, 2,040, and 4,070 ft^3/s. The largest daily mean flow was 12,000 ft^3/s.

The flow duration values of the Patoka River changed substantially after construction of Patoka Lake in 1978. To determine if this change is due to the lake or to changes in rainfall, six U.S. Geological Survey continuous-record streamflow-gaging stations (White River near Newberry, 03360500; East Fork White River near Bedford, 03371500; White River at Petersburg, 03374000; Patoka River at Hardinsburg, 03374455; Hall Creek near Saint Anthony, 03375800; and South Fork Patoka River near Spurgeon, 03376350) were used to determine the differences in the 50 and 25 percent flow duration values between the periods 1962-77 and 1979-84. These stations are located in southwestern Indiana, are unregulated, and range in drainage area from 12.8 to 11,125 mi^2. For the six stations, the average 50 percent flow duration value for 1979-84 was 1.36 times greater than the flow duration value for 1962-77 and the values ranged from 1.09 to 1.60 times greater. The average 25 percent flow duration value for 1979-84 was 1.21 times greater than the flow duration value for 1962-77 and the values ranged from 0.98 to 1.34 times greater. For Patoka River near Cuzco, the 50 and 25 percent flow duration values for 1979-84, respectively, were 2.68 and 1.63 times greater than the flow duration values for 1962-77. For Patoka River near Princeton, the 50 and 25 percent flow duration values for 1979-84, respectively, were 2.44 and 1.48 times greater than the flow duration values for 1962-77. Thus, the increase in the flow duration values cannot be accounted for by just an increase in rainfall. The increase in the flow duration values indicate that Patoka Lake has a significant effect on the flow of the Patoka River.

In general, flow regulation by Patoka Lake has increased low flows and decreased high flows in the Patoka River. These effects are greatest in the reaches immediately downstream from Patoka Lake and decrease as drainage area increases.

Water Use

There are four large municipalities in the Patoka River basin--Jasper, Winslow, Huntingburg, and Princeton (fig. 1). Jasper and Winslow use the Patoka River as their source of municipal water supplies. In 1984, municipal water withdrawals for Jasper were about 2.0 Mgal/d (million gallons per day) (Allen Mickunas, Jasper Department of Public Works, oral commun., 1985), and municipal water withdrawals for Winslow were about 110,000 gal/d (gallons per day) (Jerry Tislow, Winslow Water Department, oral commun., 1985). The withdrawals by Jasper and Winslow are the only major withdrawals of water from the Patoka River for domestic, manufacturing, or agricultural uses.

Huntingburg obtains its municipal water supplies from Huntingburg Reservoir. Huntingburg Reservoir is located on an unnamed tributary to Eel Creek, a tributary to the Patoka River. In 1984, municipal water withdrawals for Huntingburg were about 500,000 gal/d from the reservoir (Bud Suhrheinich, Huntingburg Municipal Utilities, oral commun., 1985). Prior to 1941, Princeton obtained its water supplies from the Patoka River; but, since 1941, the city has obtained its water supplies from wells located in unconsolidated deposits along the Patoka, White, and Wabash Rivers. In 1984, municipal water withdrawals for Princeton were about 1.5 Mgal/d (Denny Gray, Princeton Water Department, oral commun., 1985).

Water from the bedrock is a minor source of drinking water and usually has high concentrations of iron, manganese, and sulfate. Yields generally are less than 10 gallons per minute (Clark and Larrison, 1980, p. 28).

Coal Production and its Relation to Stream Quality

Coal deposits comprise only 3 percent of the rocks of Pennsylvanian age in Indiana; yet, they represent most of Indiana's mineral wealth (Wier, 1973, p. 4). From the 1800's to the early 1900's, almost all coal produced in Indiana was from underground mines. Coal production from surface mines steadily increased from the 1900's to the 1940's and rapidly increased from the 1940's until the present (1986). Currently (1986), all coal is produced from surface mines (Powell, 1972, p. 10). All coal in Indiana is high-volatile bituminous coal that has 11,000 to 14,000 British thermal unit per pound (Neavel, 1961, p. 16). Heat content and percentage of sulfur and ash from coal from the major beds vary considerably (Weir, 1973, p. 12-14).

In the Patoka River basin, almost all coal mining is in Pike County. Pike County is, and has been, a major producer of coal in Indiana (table 1, in the "Supplemental Data" section at the back of the report). Because it contains sizeable, recoverable coal reserves, Pike County also may be a major producer of coal in the future (table 2, in the "Supplemental Data" section at the back of the report). Production of coal in Pike County is from all the significant coal members in Indiana (fig. 3): Seelyville Coal (Coal III), Survant Coal (Coal IV), Springfield Coal (Coal V), Hymera Coal (Coal VI), and Danville Coal (Coal VII) (Illinois Basin Coal Planning Assistance Project, 1983, p. 179).

From 1941-80, 34,245 of Pike County's 214,400 acres (16 percent) were disturbed by surface mining (Indiana Department of Natural Resources, 1983, fig. 2). Of the 34,245 acres mined, 21,096 acres (62 percent) were mined before the State of Indiana's comprehensive reclamation law of 1968. In Pike County, underground and surface mining have resulted in 186 acres of refuse piles; 129 acres of slurry ponds; 3,113 acres of land with less than 75 percent vegetation cover; and 375 acres of surface-water impoundments affected by drainage from coal-mined areas (Allen and others, 1978, p. 9).

Before the current reclamation laws, coal mining, whether underground or surface, produced coal refuse piles and slurry ponds. Refuse, or gob, piles contain waste material, such as pyrite, shale, and clay, which were separated from the usable coal during cleaning operations. Slurry ponds contain very fine refuse material; the material is produced when the coal is cleaned further by washing. Surface mining also produced cast overburden ridges, which can contain pyrite, and in open last cuts, which usually are filled with water. An important property of the cast overburden is that it becomes, in effect, an unconsolidated aquifer in which the original transmissivity, hydraulic conductivity, and storage coefficients of the material are increased. These increases affect streamflows, in that the average unit-area streamflow for mined areas may be as much as five times greater than streamflows from unmined areas (Wilber and others, 1985, p. 15). Also, if underground mines are not sealed properly or, if subsequent surface mining intersects them, water and air can reach and interact with pyrite.

Pyrite is the most common sulfide mineral, and its oxidation is one of the most acidic of all weathering reactions. The oxidation of pyrite is the major source of acidity, iron, and sulfate in receiving water of coal-mined areas (Stumm and Morgan, 1981, p. 469). Framboidal pyrite (framboidal comes from the French word meaning strawberries and describes the basic morphologic shape of the pyrite) primarily is responsible for the acid mine drainage associated with coal-mined areas (Caruccio and others, 1977, p. 46). Framboidal pyrite was formed during the early phase of the formation of coal and may have had a microbial origin. Its morphology, which has a large surface area, and its small size (1 to 2 micrometers in diameter) results in rapid oxidation.

The oxidation of pyrite can be represented by the following chemical equations (Stumm and Morgan, 1981, p. 470):

$$FeS_2 \text{ (solid)} + 7/2\ O_2 + H_2O = Fe^{++} + 2\ SO_4^{--} + 2H^{+}; \qquad (1)$$
(pyrite)

$$Fe^{++} + 1/4\ O_2 + H^{+} = Fe^{+++} + 1/2\ H_2O; \qquad (2)$$

$$Fe^{+++} + 3H_2O = Fe(OH)_3 \text{ (solid)} + 3H^{+}; \text{ and} \qquad (3)$$

$$FeS_2 \text{ (solid)} + 14\ Fe^{+++} + 8\ H_2O = 15\ Fe^{++} + 2\ SO_4^{--} + 16\ H^{+}. \qquad (4)$$

When pyrite oxidizes (eq. 1), it releases dissolved ferrous iron, sulfate, and acidity (H+) into the receiving water. The ferrous iron then is oxidized to ferric iron (eq. 2). The ferric iron then is hydrolyzed (eq. 3), forming insoluble ferric hydroxide and releasing more acid into the receiving water. The chemical reaction associated with equation 3 imparts the red and yellow-orange color to the receiving water. The precipitated iron hydroxide is commonly called yellow boy. Pyrite can reduce ferric iron directly (eq. 4), in which the sulfide in the pyrite is oxidized, releasing ferrous iron (which may re-enter the reaction cycle at equation 2), sulfate, and acidity into the receiving water.

As long as pyrite, oxygen, and water (eqs. 1-3), or pyrite, ferric iron, and water (eq. 4) are available, the oxidation process can continue indefinitely. Therefore, acidity and its associated products, iron and sulfate, increase with time (Geidel and Caruccio, 1977, p. 44). The rate of the chemical reaction is increased greatly by iron bacteria, which are catalysts in the oxidation of ferrous to ferric iron (Stumm and Morgan, 1981, p. 471).

The acidic water associated with the oxidation of pyrite also accelerates the breakdown of carbonate and clay minerals. Thus, streams, which drain coal-mined areas, generally have increased concentrations of aluminum, manganese, iron, magnesium, sulfate, calcium, and silica (Grubb and Ryder, 1972, p. 34).

Alkalinity is produced when water comes in contact with calcium carbonate, such as calcite (Stumm and Morgan, 1981, p. 530):

$$CaCO_3 \text{ (solid)} + H_2O = Ca^{++} + HCO_3^{-} + OH^{-} \qquad (5)$$
(calcite)

This alkaline water can neutralize the acidic water associated with the oxidation of pyrite. Unlike acidity, most of the alkalinity is produced during the initial chemical reaction, and the rate of reactivity declines with time (Geidel and Caruccio, 1977, p. 44). This decline is because water coming in contact with calcium carbonate quickly becomes saturated as determined by the carbonate-bicarbonate equilibria.

The property pH is a measure of the acid-base equilibrium. The pH of pure water at 25 °C (degrees Celsius) is 7.0, and the typical pH range of natural water, not affected by pollution, is 6.0 to 8.5 (Hem, 1985, p. 64).

Methods of Study

Data were collected at 29 surface-water sites. Six sites were on the Patoka River and 23 sites were on tributaries to the Patoka River, including the South Fork Patoka River and its tributaries. Data were collected during different seasons and conditions of streamflow. Data were collected August 1983, July 1984, December 1984, and February through March 1985.

Selection of Sampling Sites

Twenty-nine sampling sites were selected for collection of streamflow and stream-quality data (fig. 3). Six sites were on the Patoka River: 1, 4, 4A, 8, 12, and 24. These sites were selected to determine the effects of coal mining on the Patoka River. Site 1 was upstream from the coal-mining region of the Patoka River basin, and baseline water-quality data were collected at this site. After the August 1983 sampling, the bridge at site 4 was found to be inadequate for sampling. A new site, 4A, was chosen. Although the percentage of drainage from coal-mined lands increases downstream, the major land use for all sites on the Patoka River is agriculture. Descriptions of these sites and their drainage areas are listed in table 3 (in the "Supplemental Data" section at the back of the report).

The remaining 23 sites were on streams where the major land use is coal mining. Most of these lands include unreclaimed surface coal-mined lands, but they also can include active and reclaimed surface coal-mined lands, unreclaimed refuse material from underground mines, or a combination of all four. Ten sites were on eight tributaries (excluding the South Fork Patoka River) to the Patoka River: 2, 2A, 3, 5, 6, 6A, 7, 9, 10, and 11. Sites 2A and 6A, respectively, are upstream of sites 2 and 6. Because of backwater during the February through March 1985 sampling, data were collected at sites 2A and 6A instead of at sites 2 and 6. Three sites were on the South Fork Patoka River: 13, 14A, and 25. Ten sites were on ten tributaries to the South Fork Patoka River: 14, 15, 16, 17, 18, 19, 20, 21, 22, and 23. Site 14A is directly downstream from sampling site 14.

Selection of Sampling Periods

Data collection was planned to sample four different flow conditions for sites on the Patoka River: (1) Dry-weather steady-state low flows (steady-state flows are flows that did not change prior to, or during, the sampling period) with large releases of water from Patoka Lake, which occurred during the August 1983 sampling; (2) dry-weather steady-state low flows with small releases of water from Patoka Lake, which occurred during the July 1984 sampling; (3) wet-weather nonsteady-state high flows (nonsteady-state flows are flows that changed prior to, or during, the sampling period) with small releases of water from Patoka Lake, which occurred during the December 1984 sampling; and (4) wet-weather nonsteady-state high flows with large releases of water from Patoka Lake, which occurred during the February through March 1985 sampling. The nonsteady-state high flows were the result of rain.

The unregulated tributaries were sampled at only two flow conditions: (1) dry-weather steady-state low flows, which correspond with sampling periods 1 and 2 for the Patoka River; and (2) wet-weather nonsteady-state high flows, which correspond with sampling periods 3 and 4 for the Patoka River.

Data Collection

Onsite data consisted of the physical properties instantaneous streamflow, pH, specific conductance, dissolved-oxygen concentration, water temperature and concentrations of alkalinity and hot acidity. Water samples were collected and analyzed to determine the concentrations of dissolved sulfate; dissolved, suspended, and total recoverable (hereafter referred to as total) iron and manganese; dissolved solids; suspended sediment; and suspended sediment finer than 0.0625-mm (millimeter) diameter (the sand-silt split). Methods developed by Skougstad and others (1979) were used for collecting and analyzing the water samples, and all samples were analyzed by the U.S. Geological Survey. Additional onsite data collected in June 1984 during steady-state low flows consisted of pH, specific conductance, dissolved-oxygen concentration, and water temperature. For some sites, data were not collected for all sampling periods because the sites were dry, flooded, or otherwise affected by weather. Physical properties and chemical constituents for each site are listed in table 4 (in the "Supplemental Data" section at the back of the report.

STREAMFLOW

Three U.S. Geological Survey continuous-record streamflow-gaging stations; Patoka River at Jasper (03375500), Patoka River near Princeton (03376500), and South Fork Patoka River near Spurgeon (03376350), were used to determine the general flow regimes in the study area prior to and during the four sampling periods. Flows for the three streamflow-gaging stations prior to and during the August 1983 sampling period are shown in figure 5. Flow in the Patoka River was controlled primarily by large releases from Patoka Lake of approximately 393 ft^3/s. Flow during this sampling period was low and steady state as indicated by instantaneous streamflow measurements done at the farthest upstream sampling site (site 1) and at the farthest downstream sampling site (site 24). On August 23, 1983, instantaneous streamflow was 377 ft^3/s at site 1; and, on August 25, 1983, it was 415 ft^3/s at site 24 (table 4, in the "Supplemental Data" section at the back of the report).

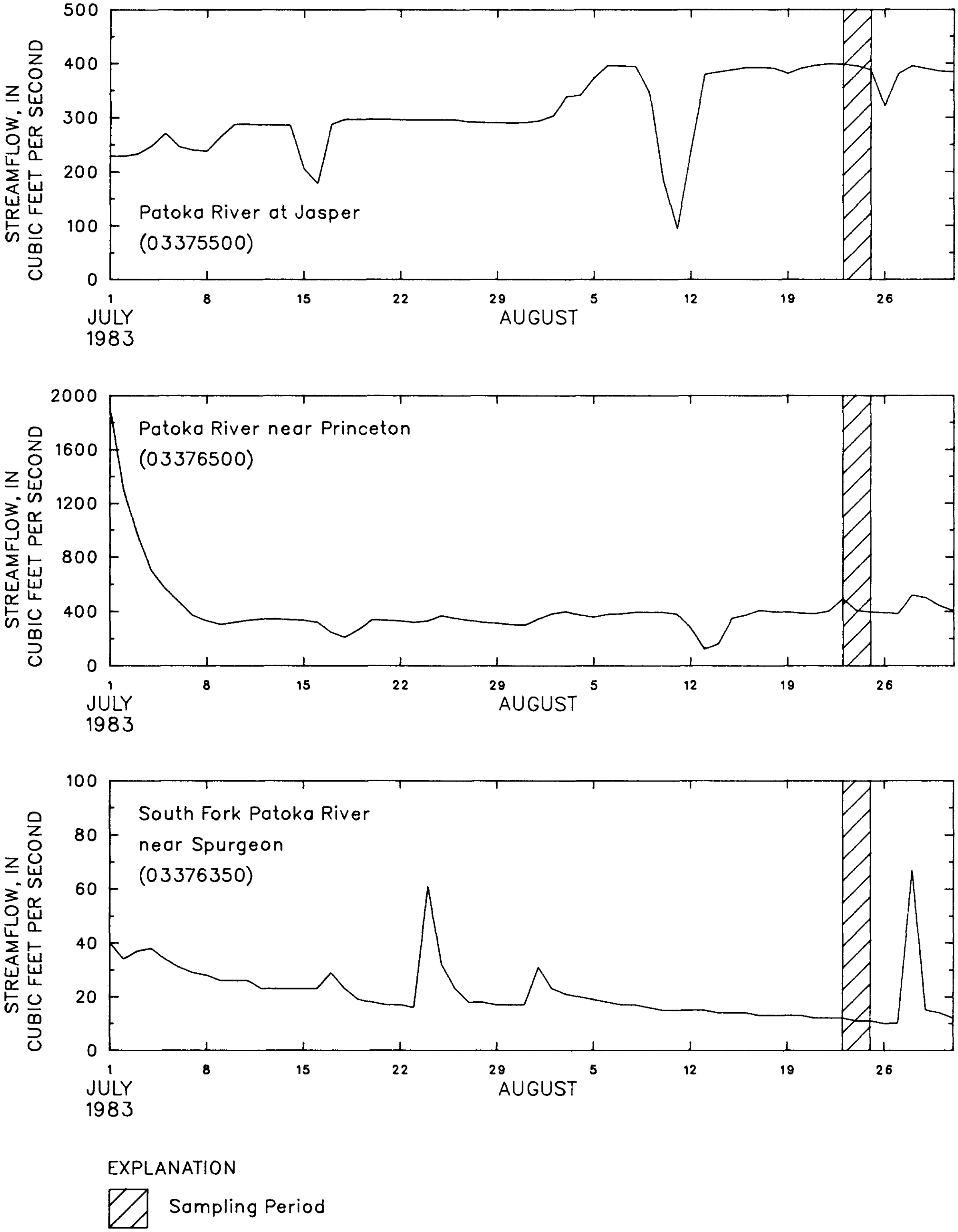


Figure 5.—— Streamflow for selected streamflow—gaging stations in the Patoka River Basin, July and August 1983.

Flows for the three streamflow-gaging stations prior to and during the July 1984 sampling period are shown in figure 6. Flow in the Patoka River again was controlled primarily by releases from Patoka Lake of approximately 49 ft^3/s. Flow during this sampling period was low (the lowest of the four sampling periods) and at steady state as indicated by the instantaneous streamflow at sites 1 and 24. On July 17, 1984, instantaneous streamflow was 61 ft^3/s at site 1; and, on July 18, 1984, it was 95 ft^3/s at site 24 (table 4).

Flows for the three streamflow-gaging stations prior to and during the December 1984 sampling period are shown in figure 7. Flow in the Patoka River and its tributaries primarily resulted from rainfall runoff, although releases from Patoka Lake were approximately 33 ft^3/s. At the Spurgeon weather station (fig. 3), 2.09 in. of rain was recorded for November 28, 1984 (National Oceanic and Atmospheric Administration, 1984a, p. 9); 0.35 in. on December 3, 1984; and 0.32 in. on December 6, 1984 (National Oceanic and Atmospheric Administration, 1984b, p. 8). Flow for the December 1984 sampling period was high and at nonsteady state as indicated by instantaneous streamflow at sites 1 and 24. On December 4, 1984, instantaneous streamflow was 348 ft^3/s at site 1; and, on December 5, 1984, it was 1,050 ft^3/s at site 24 (table 4). The large increase in flow (527 ft^3/s) that occurred between sites 12 and 24 resulted from nonsteady-state flow (table 4).

Flows for the three streamflow-gaging stations prior to and during the March through February 1985 sampling period are shown in figure 8. During this sampling period, the Patoka River in the study area was at overbank flood stage, and releases from Patoka Lake one week prior to and during the sampling period ranged from 97 to 608 ft^3/s. At the Spurgeon weather station, 0.18 in. of rain was recorded for February 22, 1985; 0.84 in. on February 23, 1985; and 0.32 in. on February 24, 1985 (National Oceanic and Atmospheric Administration, 1985, p. 9). Flow during the February through March 1985 sampling period was high (the highest of the four sampling periods) and at nonsteady state as indicated by instantaneous streamflow at sites 1, 8, and 12 (site 24 was inaccessible because of high water). On February 28, 1985, instantaneous streamflow was 1,350 ft^3/s at site 1; on February 26, 1985, instantaneous streamflow was 3,840 ft^3/s at site 8 (the highest flow measured for the four sampling periods); and, on February 27, 1985, it was 3,520 ft^3/s at site 12 (table 4). During this high-flow period, water from the channelized section of the Patoka River flowed into the old channel meanders. A part of the instantaneous streamflow measured at site 13, on the South Fork Patoka River (fig. 3), probably resulted from water flowing from the Patoka River into the South Fork Patoka River because the two streams are very close in distance and have similar elevations at this site.

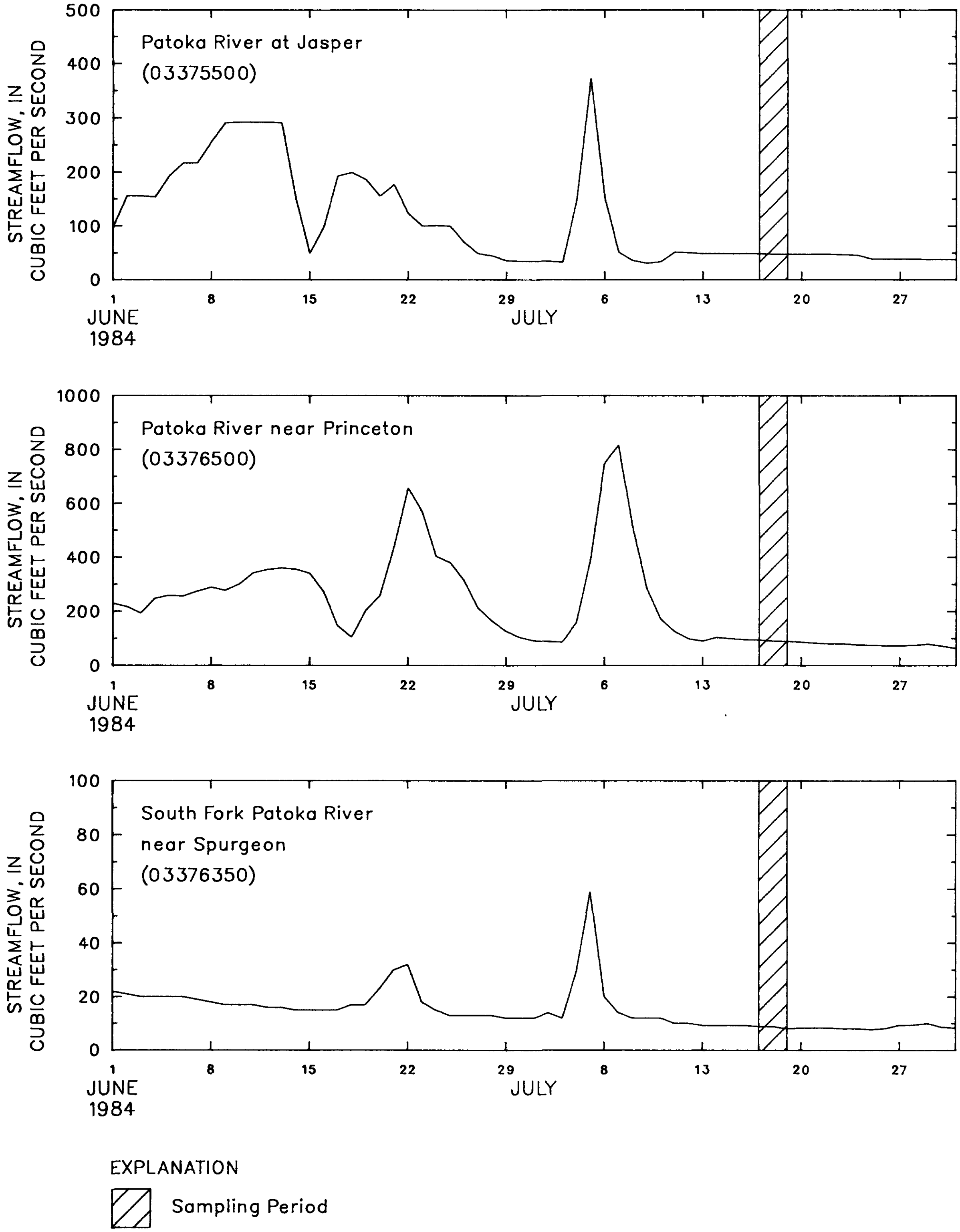


Figure 6.-- Streamflow for selected streamflow-gaging stations in the Patoka River Basin, June and July 1984.

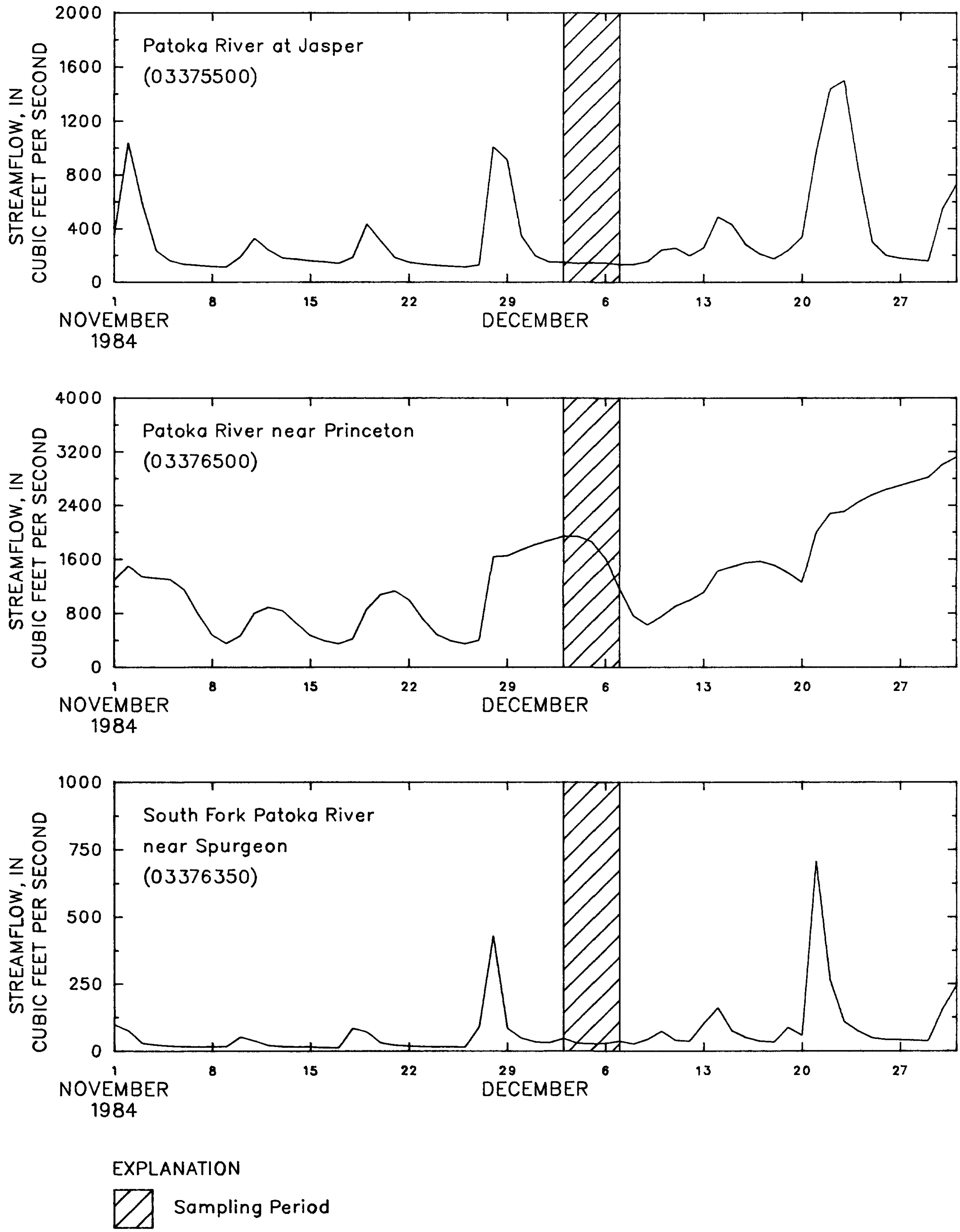
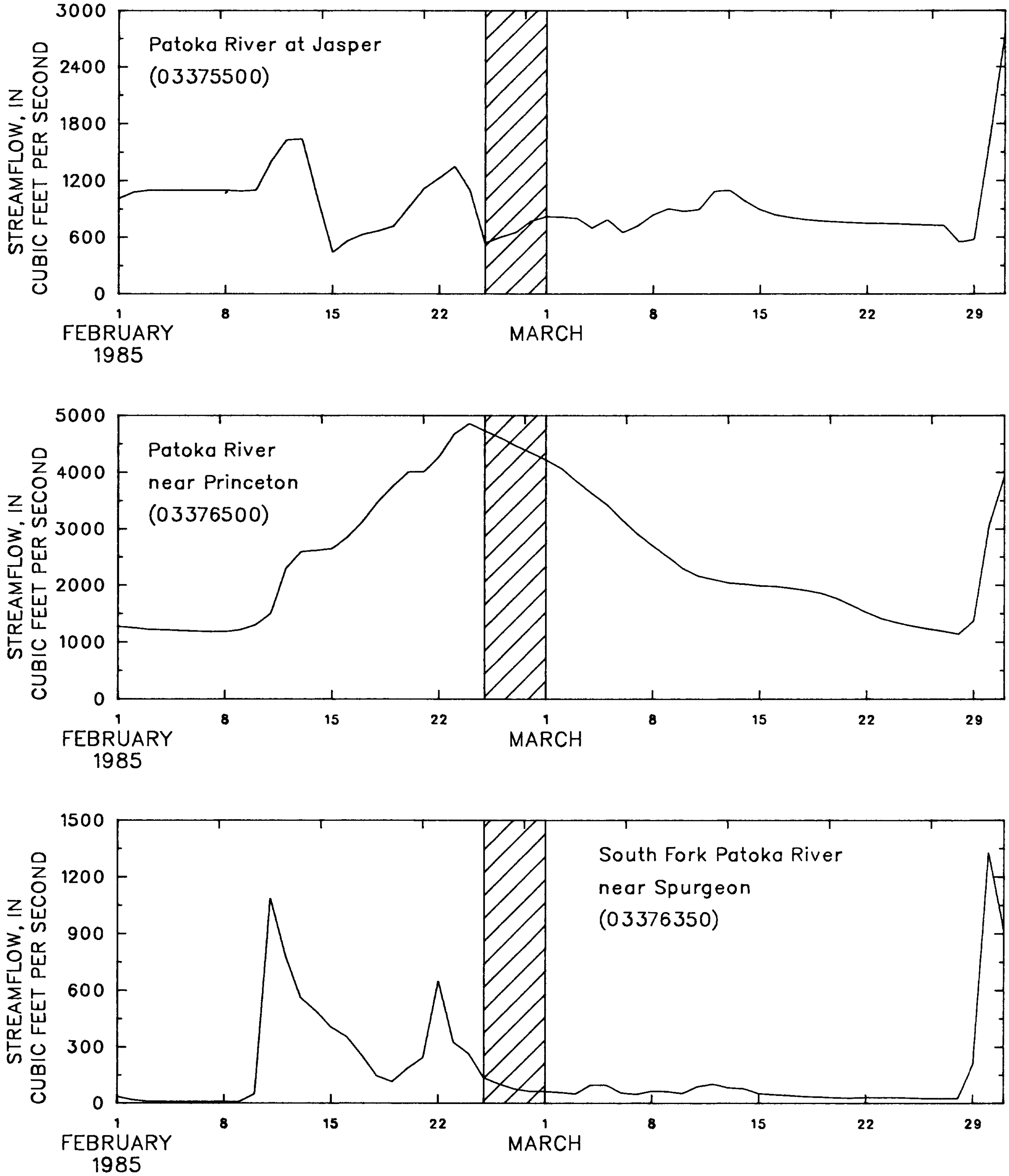


Figure 7.-- Streamflow for selected streamflow-gaging stations in the Patoka River Basin, November and December 1984.



EXPLANATION

Sampling Period

Figure 8.— — Streamflow for selected streamflow—gaging stations in the Patoka River Basin, February and March 1985.

In the study area, low flows in the Patoka River primarily resulted from small water releases from Patoka Lake, and high flows resulted from a combination of runoff from rain and releases from the lake. During the study, the greatest source of tributary flow to the Patoka River was the South Fork Patoka River (fig. 4). Maximum input to the Patoka River, measured at site 13 on the South Fork Patoka River during the July 1984 sampling, was 18 percent of the instantaneous streamflow measured at site 24 on the Patoka River. For the other tributaries to the Patoka River, the highest steady-state flow was at site 9 on Stone Coe Creek, and the highest nonsteady-state flow was at site 2 on Flat Creek. During low flow, the major sources of tributary flow to the South Fork Patoka River were sites 18 on Durham Ditch, 20 on Rough Creek, and 22 on Honey Creek. During high flows, these sites, and site 15 on Houchin Ditch, were the greatest sources of flow to the South Fork Patoka River. Flow in the remainder of the tributaries was minimal. Site 15 was dry during the August 1983 sampling, and sites 16, 17, 19, and 23 were dry during the August 1983 and July 1984 samplings, and site 5 was dry during all four sampling periods.

STREAM QUALITY

Water-quality data (table 4) collected during the study, 1983-85, were statistically analyzed to determine the mean, median, standard deviation, maximum, and minimum values. Changes in water quality between the upstream and the downstream sites on the Patoka River and changes in water quality for different flows for the Patoka River and the tributaries were determined. Chemical loads for the Patoka River and the tributaries and their rankings were determined. Water-quality data, collected from 1965-68 and 1979, were compared to data collected during the study to determine changes in water quality over time.

Analysis of Water-Quality Data

When compared to sites on the tributaries, sites on the Patoka River generally had smaller values for specific conductance and concentrations of chemical constituents. Sites on the tributaries to the Patoka River (including the South Fork Patoka River and its tributaries) had larger values due to the physical and chemical weathering of coal-mined material in their basins.

On the basis of pH, the tributary sites could be divided into sites where pH was near neutral (median pH value of 7.3 for all samplings), sites where pH was low (median pH value of 3.7 for all samplings), and sites where pH was variable, depending on streamflow. At sites where pH was near neutral, when compared with sites where pH was low, specific conductance and concentrations of alkalinity, dissolved sulfate, suspended iron, suspended manganese, dissolved solids, and suspended sediment generally were larger, and concentrations of acidity, dissolved iron, total iron, dissolved manganese, and total manganese generally were smaller.

A statistical analysis of the physical properties and the chemical constituents for all sites, sites on the Patoka River, sites where pH was near neutral, sites where pH was low, and sites where pH varied is given in table 5 (in the "Supplemental Data" section at the back of the report). Data collected in June 1984 (pH, specific conductance, water temperature, and dissolved-oxygen concentrations) is included only in the statistical summary for all sites. Except for the June 1984 sampling, site 5 was dry during all four sampling periods, thus it is included only in the statistical summary for all sites. The data are not distributed normally; therefore, the median, which is a better indicator of central tendency than the mean for data that are not distributed normally, is used for all comparisons.

Median values (table 5) for physical properties and chemical constituents for sites on the Patoka River (sites 1, 4, 4A, 8, 12, and 24) were: pH, 7.1; specific conductance, 302 μS/cm (microsiemens per centimeter at 25 degrees Celsius); alkalinity, 59.5 mg/L (milligram per liter); acidity, 14.5 mg/L as $CaCO_3$; dissolved sulfate, 55 mg/L; dissolved iron, 45 μg/L (microgram per liter); suspended iron, 2,090 μg/L; total iron, 2,200 μg/L; dissolved manganese, 260 μg/L; suspended manganese, 175 μg/L; total manganese, 480 μg/L; dissolved solids, 180 mg/L; suspended sediment, 81 mg/L; and percent suspended sediment finer than 0.0625 mm, 97 percent.

For all the sampling periods, all Patoka River sites, even the most upstream site from the area of coal mining, exceeded the recommended levels for concentrations of total iron (300 μg/L) and total manganese (50 μg/L) for domestic or public water supplies set by the U.S. Environmental Protection Agency (1976) and the Indiana State Board of Health (1977); whereas, only sites 12 and 24 exceeded the recommended level for concentrations of dissolved sulfate (250 mg/L) and only during the July 1984 sampling period (dry-weather steady-state flows with small releases of water from Patoka Lake).

For all the sampling periods on the Patoka River, the specific conductance and concentrations of dissolved sulfate and dissolved, suspended, and total manganese generally increased from the upstream to the downstream sites. For the four sampling periods, specific conductance and the concentrations of dissolved sulfate generally decreased with increased releases of water from Patoka Lake, especially during the August 1983 and December 1984 sampling periods. Other physical properties and chemical constituents did not substantially change from the upstream to the downstream sites for the four sampling periods.

Median values (table 5) for selected physical properties and chemical constituents for the tributary sites where pH was near neutral (2, 2A, 3, 7, 9, 10, 11, 13, 20, 22, and 25) were: pH, 7.3; specific conductance, 2,550 μS/cm; alkalinity, 132 mg/L; acidity, 30 mg/L as $CaCO_3$; dissolved sulfate, 1,550 mg/L; dissolved iron, 70 μg/L; suspended iron, 620 μg/L; total iron, 975 μg/L; dissolved manganese, 3,550 μg/L; suspended manganese, 75 μg/L; total manganese, 3,600 μg/L; dissolved solids, 2,390 mg/L; suspended sediment, 52 mg/L; and percent suspended sediment finer than 0.0625 mm, 97 percent.

Although sites where pH was near neutral had smaller median values for suspended and total iron than did sites on the Patoka River, the near neutral pH sites had greater variability. For sites where pH was near neutral, concentrations of suspended iron ranged from 30 to 9,500 μg/L, and concentrations of total iron ranged from 80 to 15,000 µg/L; whereas, for sites on the Patoka River, concentrations of suspended iron ranged from 1,170 to 5,000 µg/L, and concentrations of total iron ranged from 1,200 to 5,300 µg/L (tables 4 and 5).

Comparison between the August 1983 and July 1984 samplings (dry-weather steady-state flows) and the December 1984 and the February through March 1985 samplings (wet-weather nonsteady-state flows) indicate that for the wet-weather nonsteady-state flow sampling periods, most near neutral pH sites generally decreased in values of specific conductance and in concentrations of alkalinity, acidity, and dissolved sulfate, and increased in concentrations of dissolved, suspended, and total iron. Other physical properties and chemical constituents did not change substantially.

Median values (table 5) for selected physical properties and chemical constituents for the tributary sites where pH was low (6, 6A, 15, 16, 17, 18, 19, and 21) were: pH, 3.7; specific conductance, 2,210 µS/cm; alkalinity, 0 mg/L; acidity, 179 mg/L as $CaCO_3$; dissolved sulfate, 1,400 mg/L; dissolved iron, 3,900 µg/L; suspended iron, 400 µg/L; total iron, 4,300 µg/L; dissolved manganese, 17,000 µg/L; suspended manganese, 0 µg/L; total manganese, 16,000 µg/L; dissolved solids, 2,440 mg/L; suspended sediment, 20 mg/L; and percent suspended sediment finer than 0.0625 mm, 97.5 percent.

Comparison between the August 1983 and July 1984 samplings (dry-weather steady-state flows) and the December 1984 and the February through March 1985 samplings (wet-weather nonsteady-state flows) indicate that, for the wet-weather nonsteady-state flow sampling periods, most low pH sites generally increased in values of pH and decreased in values of specific conductance and in concentrations of acidity and dissolved sulfate. Other physical properties and chemical constituents did not change substantially.

Depending on particular flow regimens, sites 14, 14A, and 23 varied in values of pH and concentrations of chemical constituents. These variations were caused by runoff from rainfall, which resulted in: (1) flush-out and (2) dilution. Geidel and Caruccio (1977, p. 49) have reported that frequent flushings by rain of acid-producing materials prevents the accumulation of acid and its associated oxidation products. During this condition, the alkalinity produced is able to neutralize the acid that is produced. However, when flushings by rain are infrequent, acid and its associated oxidation products accumulate. For this condition, the alkalinity produced cannot neutralize the acid that is produced; this condition, which produces acidic drainage, is termed a "flush-out". Dilution occurs when a stream has a lower pH during dry-weather steady-state flows than during wet-weather nonsteady-state flows. This increase in pH is the result of the pH being raised because of dilution by rainfall.

A flush-out occurred at sites 14 and 14A during the December 1984 and February through March 1985 sampling periods. For these samplings, sites 14 and 14A had lower values of pH than during the August 1983 and July 1984 sampling periods (table 4). Also, as a result of flush out, concentrations of alkalinity and dissolved sulfate decreased, and concentrations of acidity and dissolved, suspended, and total iron increased. Although Geidel and Caruccio reported that concentrations of sulfate should increase during a flushout, for these samplings, the sulfate decreased. The reason for the decrease, instead of an increase, could not be determined due to the small number of samples. Other physical properties and chemical constituents did not change substantially.

Dilution occurred at site 23 during the February through March 1985 sampling period. For this sampling, site 23 had a higher value of pH than for the December 1984 sampling period (table 4) (site 23 was dry for the August 1983 and July 1984 sampling periods). Also, as a result of dilution, concentrations of alkalinity increased, and concentrations of acidity and total iron and manganese decreased. Other physical properties and chemical constituents did not change substantially.

Chemical Loads

Loads were computed using the following equation:

$$Qs = Qw \times Cs \times k, \qquad (6)$$

where Qs = pounds per day;

Qw = instantaneous streamflow, in cubic feet per second;

Cs = concentration, in milligrams per liter; and

k = conversion factor of 5.3939.

The greatest factor in determining loads was streamflow. Generally, at each site, a large streamflow also had a large load. Chemical loads for each site are listed in table 6 (in the "Supplemental Data" section at the back of the report).

Sites on the Patoka River were ranked by loads for dissolved sulfate (table 7, in the "Supplemental Data" section at the back of the report), total iron (table 8, in the "Supplemental Data" section at the back of the report), total manganese (table 9, in the "Supplemental Data" section at the back of the report), and dissolved solids (table 10, in the "Supplemental Data" section at the back of the report) for each sampling period. For sites on the Patoka River, loads of dissolved sulfate, total manganese, and dissolved solids generally increased from the upstream to the downstream sites; loads of total iron were variable.

Generally, there was an inverse relation of streamflow to concentrations of chemical constituents--the greater the streamflow the smaller the concentrations. Maximum loads for dissolved sulfate was 1,080,000 lb/d (pounds per day) for site 24; for total iron, 110,000 lb/d for site 8; for total manganese, 148,000 lb/d for site 12; and for dissolved solids, 3,460,000 lb/d for site 12 (table 6). These maximum loads occurred during the February through March 1985 sampling period, except for site 24, when the maximum load occurred during the December 1984 sampling period.

Sites other than those on the Patoka River (tributaries to the Patoka River, including the South Fork Patoka River and its tributaries) were ranked by loads for dissolved sulfate (table 11, in the "Supplemental Data" section at the back of the report), total iron (table 12, in the "Supplemental Data" section at the back of the report), total manganese (table 13, in the "Supplemental Data" section at the back of the report), and dissolved solids (table 14, in the "Supplemental Data" section at the back of the report) for each sampling period. In general, sites on the South Fork Patoka River and tributaries to the South Fork Patoka River had the largest loads. These large loads are a result of the large drainage areas and extensive coal mining in the drainage basins.

For sites on the South Fork Patoka River, loads for dissolved sulfate, total manganese, and dissolved solids always increased from the upstream to the downstream sites, and loads for total iron generally increased. For sites on tributaries to the Patoka River and on the South Fork Patoka River, substantial total iron loads (in order of load size) occurred at sites 18, 9, 6, 20, and, during high flows, at site 15. Substantial total manganese loads occurred at sites 18, 6, 9, 10, and 20; and substantial dissolved-solids loads occurred at sites 20, 9, 18, and 22.

For the tributary sites, there was an inverse relation of streamflow to values of specific conductance and concentrations of alkalinity, acidity, dissolved sulfate, and dissolved solids--the greater the streamflow the smaller the values and concentrations. There was a direct relation of streamflow to concentrations of dissolved, suspended, and total iron--the greater the streamflow the greater the concentrations. Maximum load for dissolved sulfate was 784,000 lb/d; for total iron, 8,360 lb/d; for total manganese, 4,880 lb/d; and for dissolved solids, 1,420,000 lb/d. All occurred at site 13 on the South Fork Patoka River during the February through March 1985 sampling period.

Historical Water-Quality Data

Data collected from 1965 through 1968 (Corbett, 1969), and during May and October 1979 (Renn and others, 1980; Renn, 1983), were compared with data collected during the study (1983-85). Few historical data were available. Data for pH, alkalinity, acidity, and dissolved sulfate were compared on a site-by-site basis. Only data collected during steady-state flows were compared.

Data collected from 1965 through 1968 at sites 4A, 8, 12, and 24, which are on the Patoka River, and sites 3, 7, 9, 13, 14, 14A, and 25, which are on the tributaries and where pH was near neutral, were used. These data indicated a general increase in pH, but minimal or no change in concentrations of alkalinity, acidity, or dissolved sulfate. Sites 24 and 25 also had an increase in concentrations of alkalinity and a decrease in concentrations of acidity and dissolved sulfate. Data collected for the same periods at sites 6A, 17, 18, and 21, also are on the tributaries and where pH was low, indicated minimal or no change in pH and in concentrations of alkalinity, acidity, or dissolved sulfate.

Data collected during May and October 1979 at sites 9, 18, 20, and 23 also were used. These data indicated minimal or no change in pH and in concentrations of alkalinity, acidity, or dissolved sulfate.

SUMMARY AND CONCLUSIONS

Streamflow in the Patoka River has been regulated since 1978 by Patoka Lake. Flow-duration analyses indicate that flow regulation by Patoka Lake generally has increased low streamflows and decreased high streamflows in the Patoka River. These effects are greatest in the reaches immediately downstream from Patoka Lake and decrease as drainage area increases. During the study, instantaneous streamflows in the Patoka River in the study area ranged from 61 to 3,840 ft^3/s. The largest source of tributary streamflow to the Patoka River was the South Fork Patoka River.

Values for specific conductance and concentrations of chemical constituents were generally larger for sites on the tributaries to the Patoka River (including the South Fork Patoka River and its tributaries) than for sites on the Patoka River. This is because the sites on the tributaries had a larger percentage of mined areas in their drainage basins compared to sites on the Patoka River.

For all sampling periods, the recommended levels for concentrations of total recoverable iron (300 μg/L) and total recoverable manganese (50 μg/L) were exceeded at all Patoka River sites; whereas, the recommended levels for concentrations of dissolved sulfate (250 mg/L) were exceeded at only the two most downstream sites (only during the lowest flow sampling period). In general, specific conductance and concentrations of dissolved sulfate and dissolved, suspended, and total manganese increased from the upstream to the downstream sites.

The values of pH on the tributaries were near neutral at 11 sites (median pH value of 7.3 for all samplings), low at 8 sites (median pH values of 3.7 for all samplings), and variable at 3 sites, depending on streamflow. The sites where pH was near neutral, compared to sites where pH was low, specific conductance and concentrations of alkalinity, dissolved sulfate, suspended iron, suspended manganese, dissolved solids, and suspended sediment generally were larger, and concentrations of acidity, dissolved and total iron, and dissolved and total manganese generally were smaller.

At sites on the Patoka River, loads of dissolved sulfate, total manganese, and dissolved solids generally increased from the upstream to the downstream sites; loads of total iron were variable. Generally, there was an inverse relation of streamflow to concentrations of chemical constituents--the greater the streamflow, the smaller the concentrations. At sites on the tributaries, there was an inverse relation of streamflow to specific conductance and concentrations of alkalinity, acidity, dissolved sulfate, and dissolved solids, and a direct relation of streamflow to concentrations of dissolved, suspended, and total iron.

Data collected from 1965 through 1968 and during May and October 1979 were compared with data collected during the study (1983-85). Few historical data were available, and those that were available were only for selected sites. Data for pH, alkalinity, acidity, and dissolved sulfate indicate minimal or no change in these constituents.

REFERENCES CITED

Allen, J.H., Thomas, T.C., and Kelly, R.R., 1978, A survey to determine the extent and environmental effect of derelict lands resulting from the surface extraction of coal, P.L. 62, Acts of 1976: Indianapolis, Indiana Department of Natural Resources, 46 p.

Caruccio, F.T., Ferm, J.C., Horne, J.C., Geidel, G., Baganaz, B., 1977, Paleoenvironment of coal and its relation to drainage quality: U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Office of Research and Development, no. EPA-600/7-77-067, 108 p. [Available from National Technical Information Services, U.S. Department of Commerce, Springfield, VA 22161.]

Clark, G.D., and Larrison, Dorothy, 1980, The Indiana water resource--Availability, uses, and needs: Indianapolis, Governor's Water Resources Study Commission, 508 p.

Corbett, D.M., 1969, Acid mine-drainage problem of the Patoka River watershed, southwestern Indiana: Bloomington, Indiana University Water Resources Research Center Report of Investigations no. 4, 173 p.

Geidel, G. and Caruccio, F.T., 1977, Time as a factor in acid mine drainage pollution: Symposium on Coal Mine Drainage Research, 7th, [Bituminous Coal Research] Louisville, Ky., 1977 Proceedings, p. 41-60.

Gray, H.H., 1979, Indiana, in The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States: U.S. Geological Survey Professional Paper 1110-A through L, p. K1-K20.

Gray, H.H., Wayne, W.J., and Wier, C.E., 1970, Regional geologic map no. 3, Vincennes sheet: Bloomington, Indiana Geological Survey, 1 sheet, scale 1:250,000.

Grubb, H.F., and Ryder, P.D., 1972, Effects of coal mining of the water resources of the Tradewater River basin, Kentucky: U.S. Geological Survey Water-Supply Paper 1940, 83 p.

Hem, J.D., 1970, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 363 p.

Hoggatt, R.E., 1975, Drainage areas of Indiana streams: Indianapolis, Indiana Department of Natural Resources, 231 p.

Illinois Basin Coal Planning Assistance Project, 1983, Coal resources fact book: Bloomington, Indiana University, The Environmental Systems Application Center, v. 1, 323 p.

Indiana Coal Association, 1980, Indiana coal facts: Terre Haute, Ind., 1 v.

_____ 1982, Indiana coal facts: Terre Haute, Ind., 1 v.

_____ 1983, Indiana coal facts: Terre Haute, Ind., 1 v.

Indiana Department of Natural Resources, 1983, Surface coal mining and reclamation in Indiana: Indianapolis, Division of Reclamation, pamphlet, 1 p.

Indiana State Board of Health, 1977, Guidelines for waste load allocations and total maximum daily loads: Indianapolis, Water Pollution Control Division, 24 p.

National Oceanic and Atmospheric Administration, 1984a, Climatological data for Indiana: Asheville, N.C., Environmental Data Service, v. 89, no. 11, 15 p.

_____ 1984b, Climatological data for Indiana: Asheville, N.C., Environmental Data Service, v. 89, no. 12, 15 p.

_____ 1985, Climatological data for Indiana: Asheville, N.C., Environmental Data Service, v. 90, no. 2, 24 p.

Neavel, R.C., 1961, Petrographic and chemical composition of Indiana coals: Bloomington, Indiana Geological Survey Bulletin 22, 81 p.

Powell, R.L., 1972, Coal strip-mined land in Indiana: Bloomington, Indiana Geological Survey Special Report 6, 18 p.

Renn, D.E., Ragone, S.E., and Wilber, W.G., 1980, Quality of surface water in the coal-mining region, southwestern Indiana, March and May 1979: U.S. Geological Survey Open-File Report 80-970, 65 p.

Renn, D.E., 1983, Quality of surface water in the coal-mining region, southwestern Indiana, October 1979 to September 1980: U.S. Geological Survey Open-File Report 83-680, 95 p.

Schneider, A.F., 1966, Physiography, in Lindsay, A.A., ed., Natural features of Indiana--Symposium, 1966 [Indiana sesquicentennial volume, 1816-1966]: Indianapolis, Indiana Academy of Science, p. 40-56.

Shaver, R.H., and others, 1970, Compendium of rock-unit stratigraphy in Indiana: Bloomington, Indiana Geological Survey Bulletin 43, 229 p.

_____ 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana--A revision: Bloomington, Indiana Geological Survey Bulletin 59, 203 p.

Skougstad, M.W., Fishman, M.J., Friedman, L.C., Erdmann, D.E., and Duncan, S.S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 5, chap. A1, 626 p.

Stumm, Werner, and Morgan, J.J., 1981, Aquatic chemistry; an introduction emphasizing chemical equilibria in natural waters (2nd ed.): New York, John Wiley, 780 p.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: Washington, D.C., 256 p.

Wier, C.E., 1973, Coal resources of Indiana: Bloomington, Indiana Geological Survey Bulletin 42-I, 40 p.

Wilber, W.G., Renn, D.E., and Crawford, C.G., 1985, Effects of land use and surficial geology on flow and water quality of streams in the coal mining region of southwestern Indiana, October 1979 through September 1980: U.S. Geological Survey Water-Resources Investigations Report 85-4234, 49 p.

(p. 33 follows)

SUPPLEMENTAL DATA

(Tables 1 - 14)

Table 1.--Combined underground and surface coal production, Pike County, Indiana, 1812-1982

[Data from Illinois Basin coal planning assistance project, 1983, table 7-4, p. 175; and Indiana Coal Association, 1980, 1982, and 1983; one ton is 2,000 pounds]

Period of record	Production (thousands of tons)	Percent[1]
1812-50	6	3.5
1851-1900	3,180	3.9
1901-49	97,100	10.8
1950-79	105,000	18.2
1980-82	17,700	19.6
Total (1812-1982)	223,000[2]	13.5

[1]Percentage of total production of coal mined in Indiana.
[2]Rounded to nearest 1,000 tons.

Table 2.--Recoverable reserves of underground and surface coal, Pike County, Indiana

[Data from Illinois Basin Coal Planning Assistance Project, 1983, fig. 7-18, p. 173]

Underground[1]		Surface[2]		Total	
Quantity[3] (thousands of tons)	Percentage of Indiana underground reserves	Quantity (thousands of tons)	Percentage of Indiana surface reserves	Quantity (thousands of tons)	Percentage of Indiana total reserves
370,000	2.4	180,000	9.3	549,000	3.2

[1]Underground reserves are coal seams greater than or equal to 28 inches in thickness and within 150 to 1,000 feet of the land surface.
[2]Surface reserves are coal seams greater than or equal to 28 inches in thickness and within 150 feet of the land surface.
[3]One ton = 2,000 pounds.

Table 3.--Description of sampling sites and drainage areas

SITE 1

382247087010001--Patoka River near Ireland

LOCATION--Lat 38°22'47"N., long 87°01'00"W., SW¼SW¼ sec. 31, T. 1 S., R. 5 W., Dubois County, Hydrologic Unit 05120209, at County Road 600 West, 1.6 miles south-southwest of Ireland, and 6.6 miles southeast of Otwell.

[1]DRAINAGE AREA--466 square miles

SITE 2

382308087032901--Flat Creek near White Sulphur Springs

LOCATION--Lat 38°23'08"N., long 87°03'29"W., NE¼SE¼ sec. 34, T. 1 S., R. 6 W., Dubois County, Hydrologic Unit 05120209, at County Road 50 North, 1.8 miles east of White Sulphur Springs, 5.0 miles south-southeast of Otwell, and 3.7 miles southwest of Ireland.

[2]DRAINAGE AREA--51.5 square miles

SITE 2A

382433087053101--Flat Creek near New Lebanon Church

LOCATION--Lat 38°24'33"N., long 87°05'31"W., SW¼SW¼ sec. 21, T. 1 S., R. 6 W., Pike County, Hydrologic Unit 05120209, at State Road 257, 0.85 mile south of New Lebanon Church, 3.1 miles south of Otwell, and 4.8 miles west of Ireland.

[2]DRAINAGE AREA--36.7 square miles

SITE 3

381901087075501--Beadens Creek near Cup Creek Church

LOCATION--Lat 38°19'01"N., long 87°07'55"W., NW¼NE¼ sec. 25, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 0.4 mile north of Cup Creek Church, 3.4 miles east-southeast of Augusta, and 3.5 miles north-northeast of Stendal.

[2]DRAINAGE AREA--2.61 square miles

Table 3.--Description of sampling sites and drainage areas--Continued

SITE 4

382221087091701--Patoka River at Survant

LOCATION--Lat 38°22'21"N., long 87°09'17"W., SW¼NE¼ sec. 2, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at State Road 364, at Survant.

[1]DRAINAGE AREA--585 square miles

SITE 4A

381941087065901--Patoka River near Velpen

LOCATION--Lat 38°19'41"N., long 87°06'59"W., SW¼NE¼ sec. 19, T. 2 S., R. 6 W., Pike County, Hydrologic Unit 05120209, at State Road 257, 2.0 miles south-southwest of Velpen, 0.6 mile north of Pikeville, and 5.0 miles west of Duff.

[1]DRAINAGE AREA--554 square miles

SITE 5

382201087093901--Hog Branch near Survant

LOCATION--Lat 38°22'01"N., long 87°09'39"W., NW¼SW¼ sec. 2, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 0.5 mile southwest of Survant, and 2.9 miles northeast of Augusta.

[2]DRAINAGE AREA.--0.98 square mile

SITE 6

382209087111401--Mill Creek near Augusta

LOCATION--Lat 38°22'09"N., long 87°11'14"W., NE¼SE¼ sec. 4, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 1.8 miles west-southwest of Survant, 2.5 miles north of Augusta, and 2.9 miles east of Ayrshire.

[2]DRAINAGE AREA.--2.82 square miles

Table 3.--Description of sampling sites and drainage areas--Continued

SITE 6A

382120087105601--Mill Creek at Augusta

LOCATION--Lat 38°21'20"N., long 87°10'56"W., SW¼NW¼ sec. 10, T. 2 S., 1.9 miles southwest of Survant, 1.7 miles north-northeast of Augusta, and 3.5 miles southeast of Ayrshire.

[2]DRAINAGE AREA.--2.01 square miles

SITE 7

382120087113501--Unnamed Tributary to Patoka River near Augusta

LOCATION--Lat 38°21'20"N., long 87°11'35"W., SE¼NW¼ sec. 9, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at State Road 364, 2.4 miles southwest of Survant, 1.6 miles north of Augusta, and 3.3 miles southeast of Ayrshire.

[2]DRAINAGE AREA--0.92 square mile

SITE 8

382248087130101--Patoka River at Winslow

LOCATION--Lat 38°22'48"N., long 87°13'01"W., SW¼SW¼ sec. 32, T. 1 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at State Road 61, at Winslow.

[1]DRAINAGE AREA.--603 square miles

SITE 9

382340087131101--Stone Coe Creek near Winslow

LOCATION--Lat 38°23'40"N., long 87°13'11"W., SW¼SW¼ sec. 29, T. 1 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at State Road 61, 0.8 mile northwest of Winslow, and 1.6 miles northeast of Ayrshire.

[2]DRAINAGE AREA--4.05 square miles

SITE 10

382200087152101--Barren ditch near Muren

LOCATION--Lat 38°22'00"N., long 87°15'21"W., SW¼SW¼ sec. 1, T. 2 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 0.7 mile east of Muren, and 1.6 miles northeast of Marysville.

[2]DRAINAGE AREA.--5.80 square miles

Table 3.--Description of sampling sites and drainage areas--Continued

SITE 11

382303087164101--Sugar Creek near Glezen

LOCATION--Lat 38°23'03"N., long 87°16'41"W., NW¼SW¼ sec. 35, T. 1 S., R. 8 W., 1.4 miles southeast of Littles, and 2.5 miles southeast of Glezen.

[2]DRAINAGE AREA.--3.74 square miles

SITE 12

382257087195901--Patoka River near Glezen

LOCATION--Lat 38°22'57"N., long 87°19'59"W., NW¼SW¼ sec. 32, T. 1 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at State Road 57 2.9 miles southwest of Glezen, and 2.8 miles southeast of Chandler.

[1]DRAINAGE AREA--650 square miles

SITE 13

382240087201201--South Fork Patoka River near Glezen

LOCATION--Lat 38°22'40"N., long 87°20'12"W., SE¼SE¼ sec. 31, T. 1 S., R. 8 W., Gibson County, Hydrologic Unit 05120209, at State Road 57, 3.3 miles southwest of Glezen, and 3.1 miles south-southeast of Chandler.

[1]DRAINAGE AREA.--76.1 square miles

SITE 14

381417087105301--Unnamed Tributary to South Fork Patoka River near Scalesville

LOCATION--Lat 38°14'17"N., long 87°10'53"W., SE¼NE¼ sec. 21, T. 3 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 2.8 miles north-northeast of Scalesville, and 1.0 mile northeast of Log Creek Church.

[2]DRAINAGE AREA--3.99 square miles

Table 3.--Descriptions of sampling sites and drainage areas--Continued

SITE 14A

381445087112101--South Fork Patoka River near Log Creek Church

LOCATION--Lat 38°14'45"N., long 87°11'21"W., SW¼SE¼ sec. 16, T. 3 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 1.1 miles northeast of Log Creek Church, and 3.1 miles northeast of Scalesville.

[2]DRAINAGE AREA--8.12 square miles

SITE 15

381642087120001--Houchin ditch near Scottsburg

LOCATION--Lat 38°16'42"N., long 87°12'00"W., NW¼SW¼ sec. 4, T. 3 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 1.3 miles southeast of Scottsburg, 3.1 miles west-northwest of Stendal, and 3.7 miles south of Augusta.

[2]DRAINAGE AREA--6.84 square miles

SITE 16

381722087120401--Unnamed Tributary to South Fork Patoka River near Scottsburg

LOCATION--Lat 38°17'22"N., long 87°12'04"W., SE¼SE¼ sec. 32, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at unnamed County Road, 1.0 mile east of Scottsburg, 3.4 miles northwest of Stendal, and 3.0 miles south of Augusta.

[2]DRAINAGE AREA--0.34 square mile

SITE 17

381621087122501--Unnamed Tributary to South Fork Patoka River near Stendal

LOCATION--Lat 38°16'21"N., long 87°12'25"W., NW¼NE¼ sec. 8, T. 3 S., R. 7 W., Pike County, Hydrologic Unit 05120209, 3.4 miles west of of Stendal, 1.3 miles southeast of Scottsburg, and 4.2 miles south-southwest of Augusta.

[2]DRAINAGE AREA--0.78 square mile

Table 3.--Description of sampling sites and drainage areas--Continued

SITE 18

381734087132501--Durham ditch near Scottsburg

LOCATION--Lat 38°17'34"N., long 87°13'25"W., SE¼SE¼ sec. 31, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, 0.4 mile northwest of Scottsburg, 4.6 miles northwest of Stendal, and 3.2 miles southwest of Augusta.

[2]DRAINAGE AREA--6.20 square miles

SITE 19

381814087141701--Unnamed Tributary to South Fork Patoka River near New Liberty Church

LOCATION--Lat 38°18'14"N., long 87°14'17"W., SW¼SW¼ sec. 30, T. 2 S., R. 7 W., Pike County, Hydrologic Unit 05120209, at Liberty Road, 0.4 mile east of New Liberty Church, 2.3 miles south of Arthur, and 3.2 miles southwest of Augusta.

[2]DRAINAGE AREA.--0.88 square mile

SITE 20

381708087143201--Rough Creek near Scottsburg

LOCATION--Lat 38°17'08"N., long 87°14'32"W., NE¼NE¼ sec. 1, T. 3 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at Scottsburg Road, 1.3 miles west of Scottsburg, 3.5 miles south of Arthur, and 4.3 miles southwest of Augusta.

[2]DRAINAGE AREA--9.99 square mile

SITE 21

381654087134101--Enos ditch near Scottsburg

LOCATION--Lat 38°16'54"N., long 87°13'41"W., NW¼SE¼ sec. 6, T. 3 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at Scottsburg Road, 0.7 mile southwest of Scottsburg, 3.8 miles south of Arthur, and 4.0 miles southwest of Augusta.

[2]DRAINAGE AREA--0.59 square mile

Table 3.--Description of sampling sites and drainage area--Continued

SITE 22

381722087155501--Honey Creek near Enos Corner

LOCATION--Lat 38°17'22"N., long 87°15'55"W., NE¼NE¼ sec. 2, T. 3 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at Blackfoot Road, 0.3 mile west of Enos Corner, 2.6 miles north of Spurgeon, and 5.5 miles southeast of Oakland City.

[2]DRAINAGE AREA--8.98 square miles

SITE 23

381828087165401--Wheeler Creek near Enos Corner

LOCATION--Lat 38°18'28"N., long 87°16'54"W., SE¼SE¼ sec. 27, T. 2 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at Kays Road, 1.7 miles northwest of Enos Corner, 3.1 miles south of Maryville, and 4.0 miles southeast of Oakland City.

[2]DRAINAGE AREA.--2.99 square miles

SITE 24

382238087221401--Patoka River near Oakland City

LOCATION--Lat 38°22'38"N., long 87°22'14"W., NW¼NW¼ sec. 1, T. 2 S., R. 9 W., Pike County, Hydrologic Unit 05120209, at Miller Road, 3.2 miles north-northwest of Oakland City, and 4.6 miles southwest of Glezen.

[1]DRAINAGE AREA.--730 square miles

SITE 25

03376350--South Fork Patoka River near Spurgeon

LOCATION--Lat 38°17'50"N., long 87°15'39"W., SE¼SE¼ sec. 35, T. 2 S., R. 8 W., Pike County, Hydrologic Unit 05120209, at State Road 61, 0.5 mile north of Enos Corner, and 3.1 miles north of Spurgeon.

[1]DRAINAGE AREA.--42.8 square miles

---

[1]From Hoggatt (1975).
[2]Computed from U.S. Geological Survey topographic maps.

Table 4.--Physical properties and chemical constituents for each site

[Measurements by U.S. Geological Survey; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; °C, degree Celsius; $CaCO_3$, calcium carbonate; H, hydrogen; SO_4, sulfate; µg/L, microgram per liter; mm, millimeter; time, 1430 hours is equivalent to 2:30 p.m., for example; dashes (--) indicate no data collected]

Site number (fig. 3)	Date of sampling	Time	Stream-flow, instan-taneous (ft^3/s)	pH	Specific conduct-ance (µS/cm)	Oxygen, dissolved (mg/L)	Water temper-ature (°C)	Alka-linity, onsite (mg/L as $CaCO_3$)	Acidity, onsite (mg/L as H)	Acidity, onsite (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
1	08-23-83	1200	377	6.7	183	5.7	27.0	67	0.2	11	20
	06-06-84	1230	--	6.6	198	6.7	24.5	--	--	--	--
	07-17-84	1000	61	6.9	302	7.0	25.0	78	.6	30	41
	12-04-84	0900	348	7.5	266	9.2	5.5	53	.6	30	45
	02-28-85	1030	1,350	7.4	216	10.3	5.0	45	.1	5.0	36
2	08-23-83	1452	.52	8.0	911	12.9	30.5	130	.2	12	320
	06-06-84	1255	--	7.1	1,520	8.5	25.5	--	--	--	--
	07-17-84	1430	.88	6.9	302	7.0	25.0	148	.6	30	790
	12-04-84	1500	33	7.4	726	11.4	3.5	103	.6	30	250
2A	03-01-85	1130	28	7.3	916	11.7	5.0	95	--	--	370
3	08-23-83	0900	.19	6.9	2,250	6.5	24.5	50	.1	6.5	1,400
	06-06-84	1330	--	7.5	2,020	9.4	25.5	--	--	--	--
	07-17-84	0830	.35	6.9	2,320	8.4	20.0	89	.0	.0	1,300
	12-07-84	1000	1.1	7.4	1,380	13.2	.0	61	.4	20	810
	02-28-85	1430	4.5	7.1	1,180	11.4	9.0	50	.1	5.0	570
4	08-24-83	1155	391	6.8	185	5.8	27.0	61	.4	22	21
	06-07-84	1410	--	6.8	282	6.1	24.5	--	--	--	--
4A	06-06-84	1315	--	6.7	247	5.4	24.5	--	--	--	--
	07-19-84	1000	50	7.0	318	7.7	24.5	75	.3	15	54
	02-26-85	1430	3,200	7.2	173	8.0	8.5	33	.1	5.0	38
5	06-06-84	1420	--	5.9	1,020	8.5	20.5	--	--	--	--
6	08-24-83	1500	.92	2.5	3,240	7.9	26.0	0	4.7	233	2,300
	06-06-84	1455	--	2.9	2,610	8.3	25.0	--	--	--	--
	07-19-84	0900	.64	2.9	3,160	8.8	19.5	0	--	--	1,700
	12-06-84	1245	3.3	3.3	2,210	13.3	1.0	0	2.4	119	1,400

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Time	Streamflow, instantaneous (ft^3/s)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Water temperature (°C)	Alkalinity, onsite (mg/L as $CaCO_3$)	Acidity, onsite (mg/L as H)	Acidity, onsite (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
6A	02-25-85	1530	6.1	3.9	680	12.4	4.0	0	0.8	40	330
7	08-23-83	1652	.36	7.1	2,710	8.4	25.0	130	.6	31	1,900
	06-06-84	1500	--	6.6	1,990	8.2	23.0	--	--	--	--
	07-19-84	1030	.24	7.1	2,570	9.1	20.0	153	1.8	89	1,600
	12-06-84	1400	.98	6.4	1,580	13.1	1.5	89	.4	20	910
	02-25-85	1745	2.8	6.8	1,000	11.4	7.0	67	.5	25	460
8	08-24-83	1804	386	7.0	197	6.3	28.0	59	.3	14	88
	06-06-84	1820	--	7.3	344	7.1	25.0	--	--	--	--
	07-19-84	1230	63	7.1	434	8.2	24.0	75	.4	20	100
	12-06-84	1130	454	7.0	342	10.7	2.0	42	.2	9.9	96
	02-26-85	0930	3,840	7.1	181	9.1	7.0	33	.1	5.0	46
9	08-25-83	1130	3.3	7.3	4,420	7.5	24.5	250	1.8	89	2,100
	06-06-84	1815	--	7.2	4,090	7.6	26.5	--	--	--	--
	07-19-84	1200	2.7	7.4	4,460	8.7	21.0	245	7.9	392	5,100
	12-07-84	1130	6.0	7.3	3,260	13.3	.5	190	1.2	60	2,400
	02-28-85	1215	10	6.9	2,930	12.9	2.5	134	.7	35	2,000
10	08-25-83	1345	0.82	5.8	2,530	7.2	26.5	1	0.4	18	1,600
	06-06-84	1805	--	6.8	2,070	8.5	25.0	--	--	--	--
	07-19-84	1330	.94	6.8	2,170	9.1	22.5	16	1.4	70	1,500
	02-28-85	1415	9.1	6.6	1,300	11.3	7.5	28	.3	15	660
11	08-25-83	1100	.01	7.4	2,060	--	26.5	180	.4	21	1,100
	06-06-84	1745	--	7.0	1,800	7.1	28.0	--	--	--	--
	07-18-84	1730	.08	7.4	1,770	7.2	26.5	111	.6	30	1,100
12	08-25-83	1350	394	6.9	260	5.7	28.0	60	.2	9.4	37
	06-06-84	1700	--	7.1	576	7.4	25.0	--	--	--	--
	07-18-84	1300	70	7.3	769	8.4	26.0	95	.4	20	290
	12-05-84	1430	--	7.4	373	9.0	3.5	--	--	--	--
	12-06-84	1600	523	7.2	434	10.7	2.0	33	.2	9.9	150
	02-27-85	1000	3,520	7.1	227	8.3	7.5	37	.1	5.0	56

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Time	Streamflow, instantaneous (ft^3/s)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Water temperature (°C)	Alkalinity, onsite (mg/L as $CaCO_3$)	Acidity, onsite (mg/L as H)	Acidity, onsite (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
13	08-25-83	1700	17	7.3	4,550	8.2	28.5	220	0.3	15	2,800
	06-06-84	1655	--	7.1	3,640	8.0	24.0	--	--	--	--
	07-18-84	1600	17	7.3	3,870	9.8	24.0	184	.9	45	2,800
	12-07-84	1100	44	7.0	2,390	13.2	.0	93	.3	15	1,400
	02-27-85	1430	323	7.1	934	9.4	7.0	31	.1	5.0	450
14	08-24-83	0825	.49	7.6	4,560	8.8	19.0	270	1.0	48	3,500
	06-07-84	1315	--	7.8	4,260	9.0	20.0	--	--	--	--
	07-17-84	1245	.54	7.9	4,660	8.9	18.5	307	.0	.0	2,600
	12-03-84	1600	3.4	3.7	1,220	11.8	5.0	0	1.3	65	1,000
	12-05-84	1600	--	4.3	1,130	13.4	.5	--	--	--	--
	02-26-85	0915	8.1	5.7	1,250	11.8	5.5	2	.8	40	820
14A	08-24-83	1015	.74	7.2	4,780	7.8	23.0	170	.9	45	3,800
	06-07-84	1300	--	7.1	3,930	10.1	21.5	--	--	--	--
	07-17-84	1130	.61	7.0	4,330	9.3	21.0	184	.0	.0	2,700
	12-05-84	1500	3.7	5.1	1,670	13.0	1.0	6	1.0	50	1,100
	02-26-85	1045	12	5.3	1,410	11.2	5.5	4	1.0	50	800
15	06-07-84	1150	--	7.4	1,480	8.2	24.5	--	--	--	--
	07-18-84	1215	.02	4.7	1,810	8.5	29.5	0	4.7	233	1,100
	12-05-84	1330	3.2	3.7	1,470	13.4	1.0	0	3.6	179	520
	02-26-85	1200	17	3.8	878	11.6	6.5	0	2.0	99	410
16	12-05-84	1230	.11	3.5	1,630	11.7	2.0	0	3.5	174	860
	02-26-85	1315	.43	3.6	1,340	10.4	9.0	0	3.6	179	670
17	12-04-84	1530	.34	4.6	928	8.0	3.0	0	2.3	114	1,100
	02-28-85	1045	.71	6.0	1,480	12.7	26.0	--	--	--	770
18	08-23-83	1420	3.0	3.1	4,250	7.2	27.0	0	7.8	387	3,200
	06-07-84	1100	--	3.2	3,960	7.9	22.0	--	--	--	--
	07-18-84	1015	2.1	3.1	4,440	9.0	19.5	0	--	--	3,100
	12-05-84	1100	4.2	3.5	3,150	11.7	.0	0	6.4	318	1,800
	02-26-85	1430	17	3.8	2,600	10.2	11.5	0	5.4	268	1,900

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Time	Streamflow, instantaneous (ft^3/s)	pH	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	Water temperature (°C)	Alkalinity, onsite (mg/L as $CaCO_3$)	Acidity, onsite (mg/L as H)	Acidity, onsite (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
19	12-05-84	0930	0.13	4.0	985	11.5	2.0	0	1.6	79	360
	02-26-85	1545	.48	4.8	800	9.9	10.0	0	1.1	55	390
20	08-24-83	1250	7.7	7.4	4,780	9.8	26.5	370	1.1	55	3,400
	06-07-84	1135	--	7.4	4,340	9.0	23.0	--	--	--	--
	07-17-84	1400	6.5	7.7	4,690	9.0	24.5	385	.0	.0	2,400
	12-04-84	1300	11	7.6	3,950	--	4.5	306	.7	35	2,400
	02-27-85	1500	21	7.3	3,950	10.8	9.0	291	.2	9.9	2,300
21	08-25-83	0900	.02	3.1	3,820	6.6	24.0	0	6.4	318	2,100
	06-07-84	1130	--	3.3	3,540	7.7	21.5	--	--	--	--
	07-17-84	1500	.10	4.9	4,060	7.1	23.5	8	11	546	2,500
	12-04-84	1415	.16	3.7	3,850	11.7	3.5	0	--	--	1,800
	02-27-85	1545	.75	3.5	2,660	11.1	7.5	0	4.2	209	1,500
22	08-24-83	1450	2.8	7.6	6,140	7.8	27.0	400	1.0	48	3,600
	06-07-84	0945	--	7.6	4,440	6.8	23.0	--	--	--	--
	07-18-84	0845	2.2	7.8	5,790	6.7	21.5	357	4.8	238	2,600
	12-04-84	1115	9.5	8.1	3,750	12.5	3.0	404	.0	.0	1,900
	02-27-85	1400	7.0	7.8	2,680	12.6	7.0	282	.0	.0	1,300
23	06-07-84	0930	--	7.3	3,850	8.2	23.0	--	--	--	--
	12-04-84	0930	.32	3.3	2,260	14.1	.0	0	2.7	134	1,500
	02-27-85	1315	3.7	6.5	2,320	12.3	5.5	86	1.4	70	1,500
24	08-25-83	1705	415	6.9	490	6.0	28.0	68	.3	15	170
	06-07-84	1715	--	7.0	1,130	7.6	25.0	--	--	--	--
	07-18-84	0830	95	7.0	1,440	7.2	24.5	103	.7	35	730
	12-05-84	1000	1,050	7.2	525	8.5	4.0	50	.3	15	190
25	06-07-84	1030	--	6.6	3,890	8.3	23.0	--	--	--	--
	07-18-84	1400	8.0	6.8	4,560	8.2	26.5	181	11	546	2,700
	12-06-84	1100	24	6.8	2,810	13.5	.0	72	1.1	55	1,900
	02-28-85	0945	64	7.7	2,400	13.3	2.0	54	1.1	55	1,500

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Iron, dissolved (µg/L as Fe)	Iron, suspended (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Manganese, suspended (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	Solids, residue at 180 °C, dissolved (mg/L)	Sediment, suspended (mg/L)	Sediment, suspended, sieve diameter percent finer than 0.062 mm
1	08-23-83	30	1,200	1,200	40	180	220	106	88	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-17-84	10	4,000	4,000	450	110	560	194	190	98
	12-04-84	180	1,200	1,400	310	10	320	--	33	99
	02-28-85	100	1,500	1,600	190	0	180	178	69	90
2	08-23-83	30	630	660	610	40	650	651	31	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-17-84	30	500	530	330	50	380	1,500	71	98
	12-04-84	60	1,200	1,300	570	0	570	--	29	100
2A	03-01-85	10	690	700	1,000	0	1,000	--	214	92
3	08-23-83	50	30	80	160	40	200	2,210	2	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-17-84	<10	240	240	1,200	100	1,300	2,330	65	98
	12-07-84	470	480	950	3,800	100	3,900	--	15	97
	02-28-85	210	890	1,100	2,800	400	3,200	983	35	87
4	08-24-83	20	2,300	2,300	60	170	230	98	123	--
	06-07-84	--	--	--	--	--	--	--	--	--
4A	06-06-84	--	--	--	--	--	--	--	--	--
	07-19-84	50	2,100	2,100	220	180	400	219	80	99
	02-26-85	160	1,600	1,800	70	60	130	140	53	97
5	06-06-84	--	--	--	--	--	--	--	--	--
6	08-24-83	3,900	0	3,900	31,000	0	30,000	3,390	6	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-19-84	3,800	400	4,200	21,000	7,000	28,000	3,030	76	99
	12-06-84	9,800	0	9,800	18,000	0	16,000	--	8	97

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Iron, dissolved (µg/L as Fe)	Iron, suspended (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Manganese, suspended (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	Solids, residue at 180 °C, dissolved (mg/L)	Sediment, suspended (mg/L)	Sediment, suspended, sieve diameter percent finer than 0.062 mm
6A	02-25-85	3,500	0	3,500	5,000	0	4,900	460	11	92
7	08-23-83	60	230	290	8,600	0	8,200	2,910	3	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-19-84	30	970	1,000	4,900	0	4,700	2,720	79	99
	12-06-84	540	460	1,000	5,400	100	5,500	--	10	91
	02-25-85	1,900	400	2,300	3,600	200	3,800	773	16	94
8	08-24-83	40	2,000	2,000	110	260	370	121	122	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-19-84	10	2,100	2,100	350	160	510	286	77	97
	12-06-84	180	1,600	1,800	620	10	630	--	100	97
	02-26-85	300	5,000	5,300	160	310	470	123	81	93
9	08-25-83	60	2,000	2,100	4,200	400	4,600	2,450	20	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-19-84	50	5,000	5,000	2,700	400	3,100	5,080	170	99
	12-07-84	8,800	1,200	10,000	5,500	0	5,500	--	328	99
	02-28-85	10,000	5,000	15,000	4,800	600	5,400	2,880	237	99
10	08-25-83	110	80	190	12,000	0	11,000	2,490	3	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-19-84	50	240	290	8,800	0	8,000	2,130	80	98
	02-28-85	1,100	300	1,400	5,900	1,000	6,900	82	9	91
11	08-25-83	40	1,600	1,600	14,000	0	14,000	2,010	35	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-18-84	70	740	810	400	90	490	1,580	55	99
12	08-25-83	20	3,200	3,200	170	290	460	160	138	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-18-84	20	3,100	3,100	600	230	830	606	120	99
	12-05-84	--	--	--	--	--	--	--	46	97
	12-06-84	1,100	3,500	4,600	950	50	1,000	--	42	95
	02-27-85	210	2,100	2,300	170	7,600	7,800	182	69	92

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Iron, dissolved (µg/L as Fe)	Iron, suspended (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Manganese, suspended (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	Solids, residue at 180 °C, dissolved (mg/L)	Sediment, suspended (mg/L)	Sediment, suspended, sieve diameter percent finer than 0.062 mm
13	08-25-83	60	670	730	3,500	0	3,400	4,600	15	--
	06-06-84	--	--	--	--	--	--	--	--	--
	07-18-84	80	490	570	3,900	0	4,000	4,480	313	99
	12-07-84	1,700	4,200	5,900	5,900	400	6,300	--	60	65
	02-27-85	1,300	3,500	4,800	2,500	300	2,800	813	49	83
14	08-24-83	60	270	330	4,000	100	4,100	5,270	7	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-17-84	60	410	470	3,400	100	3,500	5,170	133	95
	12-03-84	1,100	1,600	2,700	4,900	0	4,900	--	36	99
	12-05-84	--	--	--	--	--	--	--	--	--
	02-26-85	1,000	1,300	2,300	3,300	100	3,400	1,220	32	94
14A	08-24-83	60	770	830	4,400	700	5,100	5,480	13	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-17-84	40	790	830	5,000	300	5,300	5,220	135	99
	12-05-84	1,700	1,900	3,600	5,700	0	5,600	--	21	100
	02-26-85	2,200	1,200	3,400	4,000	100	4,100	1,290	30	97
15	06-07-84	--	--	--	--	--	--	--	--	--
	07-18-84	250	430	680	5,600	0	5,400	1,580	53	98
	12-05-84	24,000	7,000	31,000	9,700	0	9,700	--	178	99
	02-26-85	15,000	6,000	21,000	4,600	0	4,500	614	133	99
16	12-05-84	2,400	100	2,500	17,000	0	15,000	--	120	100
	02-26-85	2,900	0	2,900	12,000	0	12,000	1,060	5	86
17	12-04-84	810	150	960	11,000	0	11,000	--	2	75
	02-28-85	420	160	580	7,100	5,900	13,000	1,180	20	91
18	08-23-83	5,700	19,000	25,000	24,000	0	24,000	2,440	67	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-18-84	14,000	25,000	39,000	26,000	0	22,000	5,360	247	99
	12-05-84	26,000	11,000	37,000	20,000	0	20,000	--	352	100
	02-26-85	21,000	5,000	26,000	17,000	0	16,000	2,580	360	96

Table 4.--Physical properties and chemical constituents for each site--Continued

Site number (fig. 3)	Date of sampling	Iron, dissolved (µg/L as Fe)	Iron, suspended (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Manganese, suspended (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	Solids, residue at 180 °C, dissolved (mg/L)	Sediment, suspended (mg/L)	Sediment, suspended, sieve diameter percent finer than 0.062 mm
19	12-05-84	2,000	1,000	3,000	8,600	1,400	10,000	--	9	100
	02-26-85	1,500	300	1,800	6,600	0	6,500	633	10	91
20	08-24-83	70	210	280	910	70	980	5,180	13	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-17-84	60	390	450	890	0	830	4,820	137	85
	12-04-84	100	1,600	1,700	2,300	200	2,500	--	62	80
	02-27-85	570	2,300	2,900	4,500	800	5,300	2,030	30	90
21	08-25-83	6,600	0	6,600	26,000	0	26,000	3,760	14	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-17-84	330	4,800	5,100	33,000	0	30,000	4,160	101	99
	12-04-84	4,200	700	4,900	21,000	0	21,000	--	10	91
	02-27-85	4,300	0	4,300	17,000	0	16,000	2,440	13	74
22	08-24-83	60	210	270	290	80	370	5,560	30	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-18-84	140	260	400	320	40	360	5,500	164	91
	12-04-84	50	610	660	800	50	850	--	109	77
	02-27-85	40	460	500	1,700	300	2,000	2,370	43	96
23	06-07-84	--	--	--	--	--	--	--	--	--
	12-04-84	22,000	0	22,000	11,000	0	11,000	--	37	97
	02-27-85	4,500	9,500	14,000	5,100	900	6,000	2,320	406	88
24	08-25-83	30	2,700	2,700	300	190	490	327	120	--
	06-07-84	--	--	--	--	--	--	--	--	--
	07-18-84	30	3,100	3,100	900	400	1,300	1,420	130	98
	12-05-84	240	1,500	1,700	850	70	920	--	66	98
25	06-07-84	--	--	--	--	--	--	--	--	--
	07-18-84	160	2,500	2,700	7,800	0	5,800	4,490	194	99
	12-06-84	5,600	5,400	11,000	7,700	300	8,000	--	218	100
	02-28-85	7,000	500	12,000	6,900	6,100	13,000	2,390	256	99

Table 5.--Statistical analysis of physical properties and chemical constituents

[N, number of observations; mean, sum of all observations divided by the number of observations; median, the value midway in a frequency distribution; standard deviation, s = n(Ex2)-(Ex)2 where n = number of observations, (Ex2) is the sum of squared observations, and (Ex)2 is the sum of observations squared; max, maximum value of all observations; min, minimum value of all observations; $CaCO_3$, calcium carbonate]

	All sites[1]	Patoka River sites[2]	Neutral pH sites[3]	Low pH sites[4]	Variable pH sites[5]
	Instantaneous streamflow (cubic feet per second)				
N	85	18	36	21	10
mean	204	921	18.6	2.89	3.36
median	4.2	392	5.25	.71	2.07
std dev	675	1,250	54	4.97	3.90
max	3,840	3,840	323	17	12
min	0.01	50	.01	.02	.32
	pH				
N	110	19	36	21	11
median	7.0	7.1	7.3	3.7	5.7
std dev	1.56	0.21	.46	.81	1.59
max	8.1	7.5	8.1	6.0	7.9
min	2.5	6.6	5.8	2.5	3.3
	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)				
N	110	19	36	21	11
mean	2,210	385	2,780	2,350	2,690
median	1,990	302	2,550	2,210	2,260
std dev	1,570	298	1,510	1,270	1,550
max	6,140	1,440	6,140	4,440	4,780
min	173	173	302	680	1,130
	Oxygen, dissolved (milligrams per liter)				
N	109	19	35	21	11
mean	9.42	7.99	9.9	10.2	11.1
median	8.95	8.2	9.8	10.4	11.8
std dev	2.25	1.63	2.87	2.12	2.11
max	14.1	10.7	13.5	13.4	14.1
min	5.4	5.4	6.5	6.6	7.8

Table 5.--Statistical analysis of physical properties and chemical constituents--Continued

	All sites[1]	Patoka River sites[2]	Neutral pH sites[3]	Low pH sites[4]	Variable pH sites[5]
			Water temperature (degrees Celsius)		
N	110	19	36	21	11
mean	16.0	16.2	15.0	12.2	9.55
median	21.2	24.1	20	9.2	5.6
std dev	10.4	11.1	10.9	10.4	8.94
max	30.5	28.0	30.5	29.5	23
min	0	2.0	0	.0	0
			Alkalinity, onsite (milligrams per liter as $CaCO_3$)		
N	84	18	36	20	10
mean	95.9	59.3	165	.4	103
median	60.5	59.5	132	0	46
std dev	110	20.8	119	1.79	121
max	404	103	404	8	307
min	0	33	1	0	0
			Acidity, onsite (milligrams per liter as hydrogen)		
N	80	18	35	17	10
mean	1.62	.31	1.22	4.20	1.01
median	.66	.30	.6	3.6	.98
std dev	2.37	.18	2.26	2.64	.76
max	11	.7	11	11	2.7
min	0	.1	0	.8	0
			Acidity, onsite (milligrams per liter as $CaCO_3$)		
N	80	18	35	17	10
mean	80.6	15.3	60.6	208	50.2
median	33	14.5	30	179	49
std dev	118	9.23	112	131	37.7
max	546	35	546	546	134
min	0	5.0	0	40	0

Table 5.--Statistical analysis of physical properties and chemical constituents--Continued

	All sites[1]	Patoka River sites[2]	Neutral pH sites[3]	Low pH sites[4]	Variable pH sites[5]
			Sulfate, dissolved (milligrams per liter)		
N	85	18	36	21	10
mean	1,330	123	1,710	1,420	1,930
median	1,100	55	1,550	1,400	1,500
std dev	1,100	167	1,060	886	1,130
max	5,100	730	5,100	3,200	3,800
min	20	20	250	330	800
			Iron, dissolved (micrograms per liter)		
N	85	18	36	21	10
mean	2,690	152	1,130	7,260	3,270
median	210	45	70	3,900	1,050
std dev	5,520	254	2,520	8,000	6,720
max	26,000	1,100	10,000	26,000	22,000
min	10	10	10	250	40
			Iron, suspended (micrograms per liter)		
N	85	18	36	21	10
mean	2,220	2,420	1,280	3,870	1,770
median	1,000	2,090	620	400	995
std dev	3,780	1,040	1,500	6,850	2,780
max	25,000	5,000	5,400	25,000	9,500
min	0	1,170	30	0	0
			Iron, total recoverable (micrograms per liter)		
N	85	18	36	21	10
mean	4,960	2,570	2,540	11,100	5,050
median	2,100	2,200	975	4,300	2,500
std dev	7,980	1,130	3,720	12,800	7,180
max	39,000	5,300	15,000	39,000	22,000
min	80	1,200	80	580	330

Table 5.--Statistical analysis of physical properties and chemical constituents--Continued

	All sites[1]	Patoka River sites[2]	Neutral pH sites[3]	Low pH sites[4]	Variables pH sites[5]
			Manganese, dissolved (micrograms per liter)		
N	85	18	36	21	10
mean	6,350	362	3,920	16,200	5,080
median	4,000	260	3,550	17,000	4,650
std dev	7,640	299	3,420	8,690	2,220
max	33,000	950	14,000	33,000	11,000
min	40	40	160	4,600	3,300
			Manganese, suspended (micrograms per liter)		
N	85	18	36	21	10
mean	459	573	338	681	230
median	60	175	75	0	100
std dev	1,420	1,760	1,020	1,950	316
max	7,600	7,600	6,100	7,000	900
min	0	0	0	0	0
			Manganese, total recoverable (micrograms per liter)		
N	85	18	36	21	10
mean	6,580	934	4,140	16,200	5,300
median	4,500	480	3,600	16,000	5,000
std dev	7,450	1 740	3,580	8,250	2,180
max	30,000	7,800	14,000	30,000	11,000
min	130	130	200	4,500	3,400
			Solids, residue at 180 degrees Celsius, dissolved[6] (milligrams per liter)		
N	62	14	27	14	7
mean	2,220	297	2,780	2,330	3,710
median	2,080	180	2,390	2,440	5,170
std dev	1,800	349	1,620	1,500	2,000
max	5,560	1,420	5,560	5,360	5,480
min	82	98	82	460	1,220

Table 5.--Statistical analysis of physical properties and chemical constituents--Continued

	All sites[1]	Patoka River sites[2]	Neutral pH sites[3]	Low pH sites[4]	Variable pH sites[5]
			Sediment, suspended (milligrams per liter)		
N	85	19	36	21	10
mean	88.3	91.9	88.9	85.5	85
median	61	81	52	20	34
std dev	91.8	39.8	92.2	112	122
max	406	190	328	360	406
min	2	33	2	2	7
			Sediment, suspended, sieve diameter percent finer than 0.062 millimeter[7]		
N	67	14	27	18	8
mean	94.2	96.4	92.8	93.7	96.1
median	97	97	97	97.5	97
std dev	7.17	2.82	8.58	8.10	3.87
max	100	99	100	100	100
min	65	90	65	74	88

[1]Includes data for all sites for all sampling periods, including the reconnaissance.
[2]Includes data for sites 1, 4, 4A, 8, 12, and 24 (excludes reconnaissance).
[3]Includes data for sites 2, 2A, 3, 7, 9, 10, 11, 13, 20, 22, and 25 (excludes reconnaissance).
[4]Includes data for sites 6, 6A, 15, 16, 17, 18, 19, and 21 (excludes reconnaissance.
[5]Includes data for sites 14, 14A, and 23 (excludes reconnaissance).
[6]Data not collected for December 1984 sampling.
[7]Data not collected for August 1983 sampling.

Table 6.--Chemical loads

[All data, except date and time, are in pounds per day; time 1430 hours is equivalent to 2:30 p.m., for example; dashes (--) indicate no data collected; $CaCO_3$, calcium carbonate; H, hydrogen; °C, degree Celsius]

Site (fig. 3)	Date	Time	Alkalinity (as $CaCO_3$, onsite)	Acidity (as H, onsite)	Sulfate (dissolved)	Iron (dissolved)	Iron (suspended)	Iron (total recoverable)
1	08-23-83	1200	136,000	407	40,700	61.0	2,440	2,440
	07-17-84	1000	25,700	197	13,500	3.29	1,320	1,320
	12-04-84	0900	99,500	1,130	84,500	338	2,250	2,630
	02-28-85	1030	328,000	728	262,000	728	10,900	11,600
2	08-23-83	1452	365	.561	898	.084	1.77	1.85
	07-17-84	1430	702	2.85	3,750	.142	2.37	2.52
	12-04-84	1500	18,300	107	44,500	10.7	214	231
2A	03-01-85	1130	14,300	--	55,900	1.51	104	106
3	08-23-83	0900	51.2	.133	1,430	.051	.031	.082
	07-17-84	0830	168	0	2,450	.019	.453	.453
	12-07-84	1000	362	2.37	4,810	2.79	2.85	5.64
	02-28-85	1430	1,210	2.43	13,800	5.10	21.6	26.7
4	08-24-83	1155	129,000	928	44,300	42.2	4,850	4,850
4A	07-19-84	1000	20,200	80.9	14,600	13.5	566	566
	02-26-85	1430	570,000	1,730	656,000	2,760	27,600	31,100
6	08-24-83	1500	0	23.3	11,400	19.4	0	19.4
	07-19-84	0900	0	--	5,870	13.1	1.38	14.5
	12-06-84	1245	0	42.7	24,900	174	0	174
6A	02-25-85	1530	0	26.3	10,900	115	0	115

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Alkalinity (as $CaCO_3$, onsite)	Acidity (as H, onsite)	Sulfate (dissolved)	Iron (dissolved)	Iron (suspended)	Iron (total recoverable)
7	08-23-83	1652	252	1.16	3,690	0.117	0.447	0.563
	07-19-84	1030	198	2.33	2,070	.039	1.26	1.30
	12-06-84	1400	470	2.11	4,810	2.85	2.43	5.29
	02-25-85	1745	1,010	7.55	6,950	28.7	6.04	34.7
8	08-24-83	1804	123,000	625	183,000	83.3	4,160	4,160
	07-19-84	1230	25,500	136	34,000	3.40	714	714
	12-06-84	1130	103,000	490	235,000	441	3,920	4,410
	02-26-85	0930	684,000	2,070	953,000	6,210	104,000	110,000
9	08-25-83	1130	4,450	32.0	37,400	1.07	35.6	37.4
	07-19-84	1200	3,570	115	74,300	.728	72.8	72.8
	12-07-84	1130	6,150	38.8	77,700	285	38.8	324
	02-28-85	1215	7,230	37.8	108,000	539	270	809
10	08-25-83	1345	4.42	1.77	7,080	.487	.354	.840
	07-19-84	1330	81.1	7.10	7,600	.254	1.22	1.47
	02-28-85	1415	1,370	14.7	32,400	54.0	14.7	68.7
11	08-25-83	1100	.970	.002	5.93	.001	.008	.008
	07-18-84	1730	47.9	.259	475	.030	.319	.350
12	08-25-83	1350	128,000	425	78,600	42.5	6,800	6,800
	07-18-84	1300	35,900	151	109,000	7.55	1,170	1,170
	12-06-84	1600	93,100	564	423,000	3,100	9,870	13,000
	02-27-85	1000	702,000	1,900	1,060,000	3,990	39,900	43,700
13	08-25-83	1700	20,200	27.5	257,000	5.50	61.4	66.9
	07-18-84	1600	16,900	82.5	257,000	7.34	44.9	52.3
	12-07-84	1100	22,100	71.2	332,000	403	997	1,400
	02-27-85	1430	54,000	174	784,000	2,260	6,100	8,360

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Alkalinity (as $CaCO_3$, onsite)	Acidity (as H, onsite)	Sulfate (dissolved)	Iron (dissolved)	Iron (suspended)	Iron (total recoverable)
14	08-24-83	0825	714	2.64	9,250	0.159	0.714	0.872
	07-17-84	1245	894	0	7,570	.175	1.19	1.37
	12-03-84	1600	0	23.8	18,300	20.2	29.3	49.5
	02-26-85	0915	87.4	35.0	35,800	43.7	56.8	100
14A	08-24-83	1015	679	3.59	15,200	.240	3.07	3.31
	07-17-84	1130	605	0	8,880	.132	2.60	2.73
	12-05-84	1500	120	20.0	22,000	33.9	37.9	71.8
	02-26-85	1045	259	64.7	51,800	142	77.7	220
15	07-18-84	1215	0	.507	119	.027	.046	.073
	12-05-84	1330	0	62.1	8,970	414	121	535
	02-26-85	1200	0	183	37,600	1,380	550	7,920
16	12-05-84	1230	0	2.08	510	1.42	.059	1.48
	02-26-85	1315	0	5.34	1,550	6.73	0	6.73
17	12-04-84	1530	0	4.22	2,020	1.48	.275	1.76
	02-28-85	1045	--	--	2,950	1.61	.613	2.22
18	08-23-83	1420	0	126	51,800	92.2	307	404
	07-18-84	1015	0	--	35,100	158	283	442
	12-05-84	1100	0	145	40,800	589	249	838
	02-26-85	1430	0	495	174,000	1,920	458	2,380

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Alkalinity (as $CaCO_3$, onsite)	Acidity (as H, onsite)	Sulfate (dissolved)	Iron (dissolved)	Iron (suspended)	Iron (total recoverable)
19	12-05-84	0930	0	1.12	252	1.40	0.701	2.10
	02-26-85	1545	0	2.85	1,010	3.88	.777	4.66
20	08-24-83	1250	15,400	45.7	141,000	2.91	8.72	11.6
	07-17-84	1400	13,500	0	84,100	2.10	13.7	15.8
	12-04-84	1300	18,200	41.5	142,000	5.93	94.9	101
	02-27-85	1500	33,000	22.6	260,000	64.6	260	328
21	08-25-83	0900	0	.690	226	.712	0	.712
	07-17-84	1500	4.32	5.93	1,350	.718	2.59	2.75
	12-04-84	1415	0	--	1,550	3.62	.604	4.23
	02-27-84	1545	0	17.0	6,070	17.4	0	17.4
22	08-24-83	1450	6,040	15.1	54,400	.906	3.17	4.08
	07-18-84	0845	4,240	57.0	30,800	1.66	3.08	4.75
	12-04-84	1115	20,700	0	97,400	2.56	31.2	33.8
	02-27-85	1400	10,600	0	49,100	1.51	17.4	18.9
23	12-04-84	0930	0	4.66	2,590	38.0	0	38.0
	02-27-85	1315	1,720	27.9	29,900	89.8	190	279
24	08-25-83	1705	152,000	672	380,000	67.2	6,040	6,040
	07-28-84	0830	52,800	359	374,000	15.4	1,590	1,590
	12-05-84	1000	283,000	1,700	1,080,000	1,360	8,500	9,630
25	07-18-84	1400	7,810	474	116,000	6.90	109	116
	12-06-84	1100	9,320	142	246,000	725	699	1,420
	02-28-85	0945	18,600	380	518,000	2,420	173	4,140

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Manganese (dissolved)	Manganese (suspended)	Manganese (total recoverable)	Solids, (residue at 180 °C, dissolved)	Sediment, suspended
1	08-23-83	1200	81.3	366	447	216,000	179,000
	07-17-84	1000	148	36.2	184	63,800	62,500
	12-04-84	0900	582	18.8	601	--	61,900
	02-28-85	1030	1,380	0	1,380	1,300,000	502,000
2	08-23-83	1452	1.71	.112	1.82	1,830	87.0
	07-17-84	1430	1.57	.237	1.80	7,120	33.7
	12-04-84	1500	102	0	102	--	33.7
2A	03-01-85	1130	151	0	151	--	32,300
3	08-23-83	0900	.164	.041	.205	2,260	2.05
	07-17-84	0830	2.26	.189	2.45	4,400	123
	12-07-84	1000	22.6	.593	23.1	--	89.0
	02-28-85	1430	68.0	9.71	77.7	23,900	850
4	08-24-83	1155	126	358	485	207,000	259,000
4A	07-19-84	1000	59.3	48.5	108	59,100	21,600
	02-26-85	1430	1,210	1,040	2,240	2,420,000	915,000
6	08-24-83	1500	149	0	149	16,800	29.8
	07-19-84	0900	72.5	24.2	96.6	10,500	262
	12-06-84	1245	320	0	285	--	142
6A	02-25-85	1530	164	0	164	15,100	362

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Manganese (dissolved)	Manganese (suspended)	Manganese (total recoverable)	Solids, (residue at 180 °C, dissolved)	Sediment, suspended
7	08-23-83	1652	16.7	0	15.9	5,650	5.82
	07-19-84	1030	6.34	0	6.08	3,530	102
	12-06-84	1400	28.5	.529	29.1	--	52.9
	02-25-85	1745	54.4	3.02	57.4	11,700	242
8	08-24-83	1804	229	541	770	252,000	254,000
	07-19-84	1230	119	54.4	173	97,200	26,200
	12-06-84	1130	1,520	24.5	1,540	--	245,000
	02-26-85	0930	3,310	6,420	9,730	2,550,000	1,680,000
9	08-25-83	1130	74.8	7.12	81.9	43,600	356
	07-19-84	1200	39.3	5.82	45.1	74,000	2,480
	12-07-84	1130	178	0	178	--	10,600
	02-28-85	1215	259	32.4	291	155,000	12,800
10	08-25-83	1345	53.1	0	48.6	11,000	13.3
	07-19-84	1330	44.6	0	40.6	10,800	406
	02-28-85	1415	290	49.1	339	4,020	442
11	08-25-83	1100	.076	0	.076	10.8	.18
	07-18-84	1730	.173	.039	.211	682	23.7
12	08-25-83	1350	361	616	978	340,000	293,000
	07-18-84	1300	226	86.8	313	229,000	45,300
	12-06-84	1600	2,680	141	2,820	--	118,000
	02-27-85	1000	3,230	144,000	148,000	3,460,000	1,310,000
13	08-25-83	1700	321	0	312	422,000	1,380
	07-18-84	1600	358	0	367	411,000	28,700
	12-07-84	1100	1,400	94.9	1,500	--	14,200
	02-27-85	1430	4,360	523	4,880	1,420,000	85,400

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Manganese (dissolved)	Manganese (suspended)	Manganese (total recoverable)	Solids, (residue at 180 °C, dissolved)	Sediment, suspended
14	08-24-83	0825	10.6	0.264	10.8	13,900	18.5
	07-17-84	1245	9.90	.291	10.2	15,000	387
	12-03-84	1600	89.9	0	89.9	--	660
	02-26-85	0915	.144	4.37	148	53,300	1,400
14A	08-24-83	1015	17.6	2.79	20.4	21,900	51.9
	07-17-84	1130	16.4	.987	17.4	17,200	444
	12-05-84	1500	114	0	114	--	419
	02-26-85	1045	259	6.47	265	83,500	1,940
15	07-18-84	1215	.604	0	.582	170	5.72
	12-05-84	1330	167	0	167	--	3,070
	02-26-85	1200	422	0	422	56,300	12,200
16	12-05-84	1230	8.90	0	8.90	--	71.2
	02-26-85	1315	27.8	0	27.8	2,460	11.6
17	12-04-84	1530	20.2	0	20.2	--	3.67
	02-28-85	1045	27.2	22.6	49.8	4,520	76.6
18	08-23-83	1420	388	0	388	39,500	1,080
	07-18-84	1015	294	0	249	60,700	2,800
	12-05-84	1100	453	0	453	--	7,970
	02-26-85	1430	1,470	0	1,470	236,000	33,000

Table 6.--Chemical loads--Continued

Site (fig. 3)	Date	Time	Manganese (dissolved)	Manganese (suspended)	Manganese (total recoverable)	Solids, (residue at 180 °C, dissolved)	Sediment, suspended
19	12-05-84	0930	6.03	0.982	7.01	--	6.31
	02-26-85	1545	16.8	0	16.8	1,640	25.9
20	08-24-83	1250	37.8	2.91	40.7	215,000	540
	07-17-84	1400	31.2	0	29.1	169,000	4,800
	12-04-84	1300	136	11.9	148	--	3,680
	02-27-85	1500	510	90.6	600	230,000	3,400
21	08-25-83	0900	2.80	0	2.80	406	1.51
	07-17-84	1500	17.8	0	16.2	2,240	54.5
	12-04-84	1415	18.1	0	18.1	--	8.63
	02-27-84	1545	64.7	0	64.7	9,870	52.6
22	08-24-83	1450	4.38	1.21	5.59	84,000	453
	07-18-84	0845	3.80	.475	4.27	65,300	1,950
	12-04-84	1115	41.0	2.56	43.6	--	5,580
	02-27-85	1400	54.2	11.3	75.5	89,500	1,620
23	12-04-84	0930	19.0	0	19.0	--	63.9
	02-27-85	1315	102	18.0	120	46,300	8,100
24	08-25-83	1705	672	425	1,100	732,000	269,000
	07-28-84	0830	461	205	666	728,000	66,600
	12-05-84	1000	4,810	396	5,210	--	374,000
25	07-18-84	1400	336	0	250	194,000	8,370
	12-06-84	1100	997	38.8	1,040	--	28,200
	02-28-85	0945	2,380	2,100	4,490	825,222	88,400

Table 7.--Ranking of sites on the Patoka River by dissolved-sulfate loads for each sampling period

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period	Third sampling period[3]	Fourth sampling period[4]
1	24	24	24	12
2	8	12	12	8
3	12	8	8	4A
4	4	4A	1	1
5	1	1	--	--

[1]Rankings are from maximum to minimum loads.
[2]Site 4 moved upstream to 4A.
[3]No data for site 4A.
[4]No data for site 24.

Table 8.--Ranking of sites on the Patoka River by total recoverable iron loads for each sampling period

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period	Third sampling period[3]	Fourth sampling period[4]
1	12	24	12	8
2	24	1	24	12
3	4	12	8	4A
4	8	8	1	1
5	1	4A	--	--

[1]Rankings are from maximum to minimum loads.
[2]Site 4 moved upstream to 4A.
[3]No data for site 4A.
[4]No data for site 24.

Table 9.--Ranking of sites on the Patoka River by total recoverable manganese loads for each sampling period

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period	Third sampling period[3]	Fourth sampling period[4]
1	24	24	24	12
2	12	12	12	8
3	8	1	8	4A
4	4A	8	1	1
5	1	4A	--	--

[1]Rankings are from maximum to minimum loads.
[2]Site 4 moved upstream to 4A.
[3]No data for site 4A.
[4]No data for site 24.

Table 10.--Ranking of sites on the Patoka River by dissolved-solids loads for each sampling period

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period	Third sampling period[3]	Fourth sampling period[4]
1	24	24	--	12
2	12	12	--	8
3	8	8	--	4A
4	1	1	--	1
5	4	4A	--	--

[1]Rankings are from maximum to minimum loads.
[2]Site 4 moved upstream to 4A.
[3]No data for third sampling period.
[4]No data for site 24.

Table 11.--Ranking of sulfate loads for each sampling period for sites on tributaries to the Patoka River, South Fork Patoka River, and tributaries to the South Fork Patoka River

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period[3]	Third sampling period[4]	Fourth sampling period[5]
1	13	13	13	13
2	20	25	25	25
3	22	20	20	20
4	18	9	22	18
5	9	18	9	9
6	14A	22	2	2A
7	6	14A	18	14A
8	14	10	6	22
9	10	14	14A	15
10	7	6	14	14
11	3	2	15	10
12	2	3	3	23
13	21	7	7	3
14	11	21	23	6A
15	--	11	17	7
16	--	15	21	21
17	--	--	16	17
18	--	--	19	16
19	--	--	--	19

[1]Rankings are from maximum to minimum loads.
[2]No data for sites 2A, 5, 6A, 15, 16, 17, 19, 23, and 25.
[3]No data for sites 2A, 5, 6A, 16, 17, 19, and 23.
[4]No data for sites 2A, 5, 6A, 10, and 11.
[5]No data for sites 2, 5, 6, and 11.

Table 12.--Ranking of total recoverable iron loads for each sampling period for sites on tributaries to the Patoka River, South Fork Patoka River, and tributaries to the South Fork Patoka River

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period[3]	Third sampling period[4]	Fourth sampling period[5]
1	18	18	25	13
2	13	25	13	15
3	9	9	18	25
4	6	13	15	18
5	20	20	9	9
6	22	6	2	20
7	14A	22	6	23
8	2	21	20	14A
9	14	14A	14A	6A
10	10	2	14	2A
11	21	10	23	14
12	7	14	22	10
13	3	7	3	7
14	11	3	7	3
15	--	11	21	22
16	--	15	19	21
17	--	--	17	16
18	--	--	16	19
19	--	--	--	17
20	--	--	--	--
21	--	--	--	--

[1]Rankings are from maximum to minimum loads.
[2]No data for sites 2A, 5, 6A, 15, 16, 17, 19, 23, and 25.
[3]No data for sites 2A, 5, 6A, 16, 17, 19, and 23.
[4]No data for sites 2A, 5, 6A, 10, and 11.
[5]No data for sites 2, 5, 6, and 11.

Table 13.--Ranking of total recoverable manganese loads for each sampling period for sites on tributaries to the Patoka River, South Fork Patoka River, and tributaries to the South Fork Patoka River

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period[3]	Third sampling period[4]	Fourth sampling period[5]
1	18	13	13	13
2	13	25	25	25
3	6	18	18	18
4	9	6	6	20
5	10	9	9	15
6	20	10	15	10
7	14A	20	20	9
8	7	14A	14A	14A
9	14	21	2	6A
10	22	14	14	2A
11	21	7	22	14
12	2	22	7	23
13	3	3	3	3
14	11	2	17	22
15	--	15	23	21
16	--	11	21	7
17	--	--	16	17
18	--	--	19	16
19	--	--	--	19

[1]Rankings are from maximum to minimum loads.
[2]No data for sites 2A, 5, 6A, 15, 16, 17, 19, 23, and 25.
[3]No data for sites 2A, 5, 6A, 16, 17, 19, and 23.
[4]No data for third sampling period.
[5]No data for sites 2, 5, 2A, 6, and 11.

Table 14.--Ranking of dissolved solids loads for each sampling period for sites on tributaries to the Patoka River, South Fork Patoka River, and tributaries to the South Fork Patoka River

[dashes (--) indicate no data collected]

Rank[1]	First sampling period[2]	Second sampling period[3]	Third sampling period[4]	Fourth sampling period[5]
1	13	13	--	13
2	20	25	--	25
3	22	20	--	18
4	9	9	--	20
5	18	22	--	9
6	14A	22	--	9
7	6	14A	--	14A
8	14	14	--	15
9	10	10	--	14
10	7	6	--	23
11	3	2	--	3
12	2	3	--	6A
13	21	7	--	7
14	11	21	--	21
15	--	11	--	17
16	--	15	--	10
17	--	--	--	16
18	--	--	--	19

[1]Rankings are from maximum to minimum loads.
[2]No data for sites 2A, 6A, 15, 16, 17, 19, 23, and 25.
[3]No data for sites 2A, 6A, 16, 17, 19, and 23.
[4]No data for third sampling period.
[5]No data for sites 2, 2A, 6, and 11.

☆U.S. GOVERNMENT PRINTING OFFICE: 1989-645-630/32009