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

By William G. Wilber, Danny E. Renn, and Charles G. Crawford

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TABLES

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

Multiply inch-pound unit	By	To obtain Metric unit
acre	0.0040	square kilometer (km^2)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.0733	cubic meter per second per square kilometer [$(m^3/s)/mi^2$]
square mile (mi^2)	2.590	square kilometer (km^2)
ton, short (2,000 lb)	0.9072	megagram (Mg)
mile (mi)	1.609	kilometer (km)

To convert degree Fahrenheit (°F) to degree Celsius (°C)

$$(0.556)\ (°F - 32°) = °C$$

ABBREVIATIONS AND SYMBOLS

Abbreviations and symbols	Description
°C	degree Celsius
$CaCO_3$	calcium carbonate
Eh	oxidation-reduction potential
Eijkm	random error component
°F	degree Fahrenheit
ft	foot
ft/mi	foot per mile
$(ft^3/s)mi^2$	cubic foot per second per square mile
Gj	effect of the jth glacial province
LC50	96-hour median lethal concentration
LGij	effect of the interaction of the ith land use with the jth glacial province
Li	effect of the ith land use
g/g	microgram per gram
g/L	microgram per liter
mg/L	milligram per liter
mi	mile
mi	square mile
N	number of observations
Nj	individual observation
P(ij)k	effect of the kth stream in the ith land use in the jth glacial province
pH	logarithm of the reciprocal of the hydrogen-ion activity, in moles per liter
rs	Pearson rank correlation coefficient
sm	effect of the mth season
TL50	96-hour median tolerance limit
Yijk	concentration of a water-quality constituent from the kth stream in the ith land use in the jth glacial province

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ABSTRACT

An assessment of streams in the coal-mining region of southwestern Indiana was done from October 1979 through September 1980 during stable stream flows to provide baseline hydrologic and water-quality information and to document the effect of several natural and human-induced factors on water quality in the region.

Streams in southwestern Indiana are generally well buffered against acidification from acid-mine drainage because they flow upon calcareous unconsolidated surficial deposits and bedrock. The pH of streams draining forested, agricultural, and reclaimed mined watersheds ranged from 6.3 to 8.8, which is generally within the range of natural waters. The pH of streams draining unreclaimed mined watersheds ranged from 3.8 to 7.9, which was much more variable than for streams draining lands used for other activities.

Concentrations of major dissolved constituents in streams affected by coal mining were significantly higher than in streams unaffected by mining. The principal cause of the elevated concentrations of dissolved constituents was the oxidation of pyrite and marcasite and subsequent dissolution of calcite and dolomite. The principal water type of streams draining forested and agricultural watersheds was calcium bicarbonate, whereas the principal water types of streams draining mined watersheds were magnesium sulfate and magnesium-calcium sulfate.

Concentrations of boron, iron, manganese, nickel, and zinc were generally higher in streams draining mined areas than in streams draining forested and agricultural watersheds. Median concentrations of iron and manganese were lower in streams draining reclaimed mined watersheds than in streams draining unreclaimed mined watersheds; this suggests that post-1967 surface-mine reclamation techniques have been effective at reducing concentrations of these metals in streams. Concentrations of aluminum, iron, manganese, nickel, and zinc increased significantly as pH decreased below 6.0 in streams draining unreclaimed mined watersheds. The elevated concentrations of metals in waters and the low pH result from the oxidation of the sulfide in pyrite to sulfate, which releases dissolved ferrous iron, other metals, and acidity into the water.

Median suspended-sediment concentrations of samples from streams draining agricultural and mined watersheds were 1.5 and 5.4 times those of streams draining forested watersheds. Suspended sediment in streams was composed primarily of silt and clay-sized particles.

The effect of surficial geology on stream quality was evident for several dissolved constituents in forested and agricultural watersheds. In general, pH and concentrations of alkalinity and calcium were significantly higher in streams draining the Wisconsin glacial province than in streams draining the Illinoian glacial province and unglaciated regions. The higher pH and concentrations of these constituents suggests that there is greater dissolution of carbonate minerals in the Wisconsin glacial province than the other regions. Median concentrations of arsenic, lead, and manganese for streams draining the Wisconsin glacial province were significantly lower than for those constituents in streams draining the Illinoian province and unglaciated region. The median cadmium concentration for streams draining the Wisconsin glacial province was lower than for streams draining the unglaciated region. These differences may have been due to lower solubilities of metal and trace elements at higher pH values in the Wisconsin glacial province than in the Illinoian glacial province and the unglaciated region.

INTRODUCTION

Background

Coal mining has affected surface water in much of the continental United States. Drainage from mined lands commonly is acidic because of the oxidation of sulfide in pyrite and marcasite exposed during mining. In addition to low pH and high acidity, acid mine drainage has elevated concentrations of most major dissolved and suspended constituents, including aluminum, iron, manganese, and some trace[1] elements. In Indiana, before 1967, pyrite and marcasite were often left exposed on the surface after the coal had been removed. In 1967, the Indiana Surface Mines Act (Indiana Code 13-4-6) was passed. This Act requires that spoil piles be graded to a maximum slope of 33 percent or less, depending on land-use capability, and that a cover crop be established. These reclamation techniques, and others, have helped reduce the amount of acid mine drainage to streams. However, acid-mine drainage from unreclaimed mined areas continues to be a water-quality problem.

[1]There is no precise definition of the term "trace" with reference to constituents in natural water. However, in this report, substances whose concentrations are typically less than 1.0 mg/L are grouped in this category.

Acid-mine drainage is not the only cause of water-quality degradation. Erosion from unreclaimed areas of old mines or unvegetated areas in new mines can substantially increase sediment loads in streams, (Dyer and Curtis, 1977). Hydrologic conditions also are altered by mining and reclamation. During mining, aquifers are disturbed or removed and the surface-drainage system may be altered. During subsequent reclamation, the cast overburden may become an unconsolidated aquifer in which the original transmissivity, hydraulic conductivity, and storage coefficients of the aquifer materials are changed. Final mine cuts are flooded to become lakes, and the hydrologic connection between surface water and ground water is changed.

Hydrologic and water-quality data for the coal-mining region are needed by operators and owners of mines and others who must make sound resource-management decisions. For example, section 507(b)(11) of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) requires that extensive information about the probable hydrologic consequences of mining be included in permit applications so that the regulatory authority can determine the probable cumulative impact of mining on the hydrology of the area. Hydrologic and water-quality information on the general area surrounding proposed mine sites is to be made available from an appropriate Federal or State agency before mining begins.

Purpose and Scope

The purpose of this study was to provide hydrologic and water-quality information related to streams in the coal-mining region. Because of the large size of the region, detailed water-quality assessments of all streams that might be affected by future mining were not possible. A different approach was needed.

The approach and objectives of this study were to (1) determine the significance of factors that affect water quality of streams and (2) use this information to provide general (non-site specific) water-quality characteristics for streams with similar hydrologic and watershed characteristics.

A summary of water-quality data and an analysis of factors affecting water quality of streams in the coal-mining region of southwestern Indiana are presented in this report.

DESCRIPTION OF STUDY AREA

Coal underlies 6,500 mi^2 of southwestern Indiana (about one-sixth the area of the entire State) in an area along the eastern side of the Illinois Basin (fig. 1). The Indiana part of the Illinois Basin is drained by the Wabash and Ohio Rivers and their tributaries.

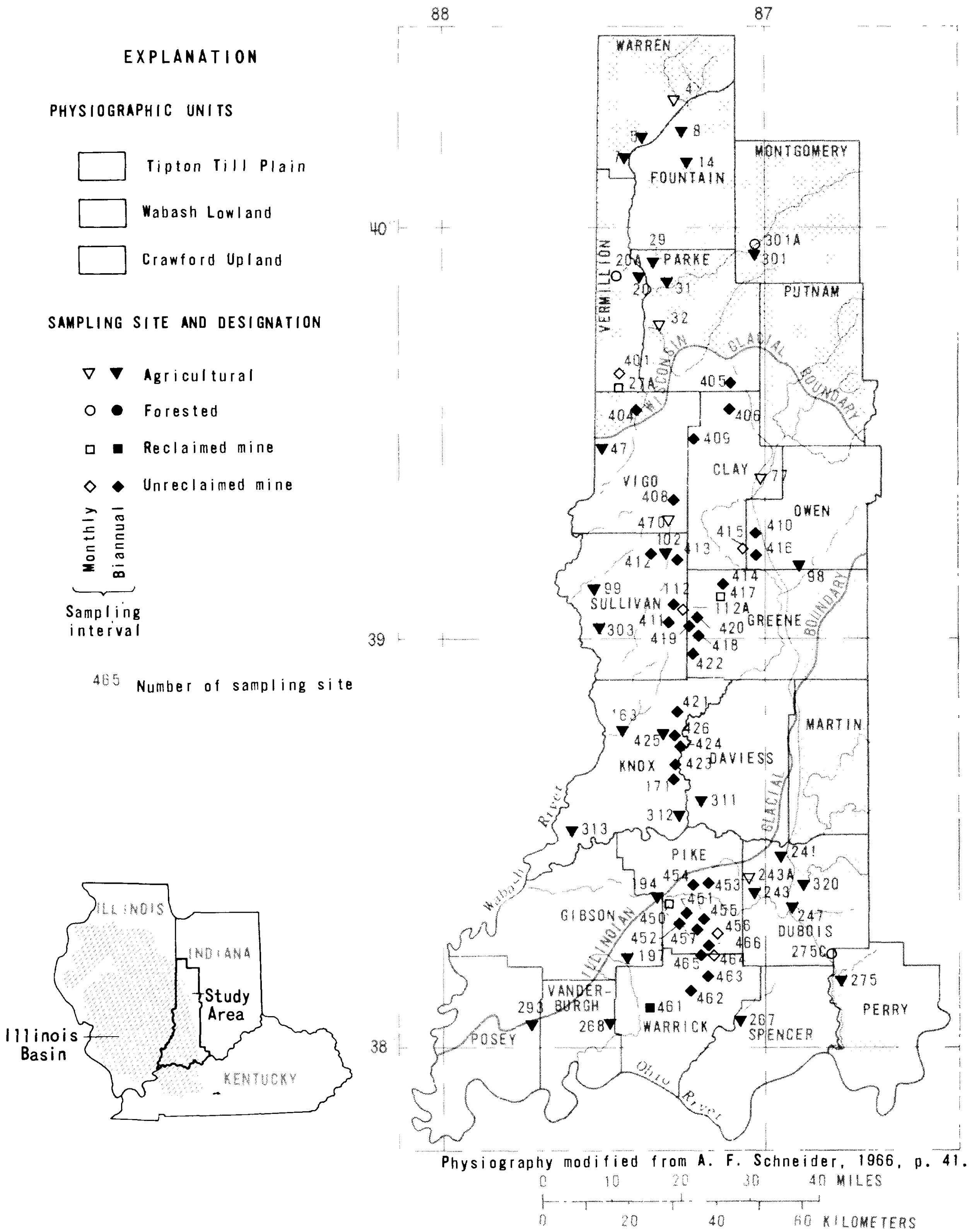


Figure 1.-- Locations of glacial provinces, physiographic units, and stream-sampling sites in the coal-mining region, southwestern Indiana.

The topography and the geology of southwestern Indiana were significantly affected by glaciation of the Pleistocene Epoch. Virtually all the landscape in the northern two-thirds of the study area has been affected by glaciation. Between the Wisconsin glacial boundary and the Illinoian glacial boundary that delineates the maximum extent of glaciation in southwestern Indiana, bedrock features are intimately mixed with those of glacial deposition. South of the Illinoian glacial boundary, valleys cut in bedrock have been partly filled with silt and clay from glacial lakes. Almost the entire unglaciated part of the State is covered by a veneer of loess (Wayne, 1966, p. 21).

Physiography and Geology

The coal-mining region of southwestern Indiana is distinguished by three physiographic units -- the Tipton Till Plain, Wabash Lowland, and Crawford Upland (Malott, 1922, p. 66) -- whose distinct topography and geology were determined by the extent of glaciation (fig. 1).

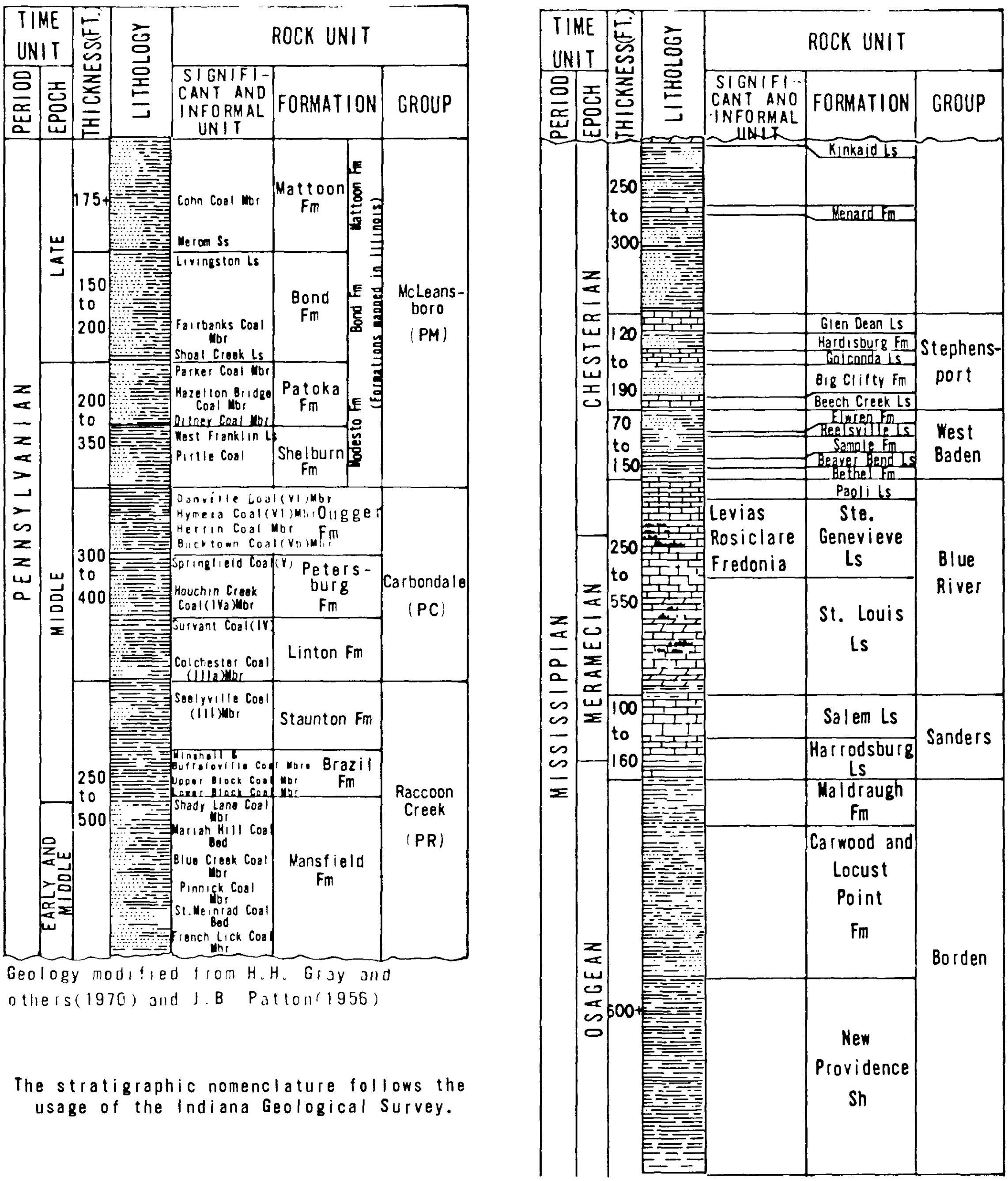
The Tipton Till Plain is a nearly flat to gently rolling glacial plain, whose major soils are derived from till and outwash of Wisconsin age. Soils in the region are underlain by loam and silty-clay loam of early and late Wisconsin age.

The Wabash Lowland is the largest physiographic unit in southern Indiana. This region is described by Schneider (1966, p. 48) as a broad, lowland area having an average elevation of about 500 feet above sea level. The predominent unconsolidated deposits are Illinoian till and, in places, thick lake beds, outwash, and alluvium.

The Crawford Upland unit is a deeply dissected upland area with local relief of 300 to 350 feet (Schneider, 1966, p. 48). Unconsolidated Quaternary deposits in the area include lacustrine deposits locally known as the Atherton Formation and alluvium locally known as the Martinsville Formation.

According to Schneider (1966, p. 47), the bedrock underlying the Tipton Till Plain and Wabash Lowlands consists of alternating cyclical layers of shale, sandstone, coal, and limestone of Pennsylvanian age. Bedrock underlying the Crawford Uplands consists of alternating layers of sandstone, shale, and limestone of the Mansfield formation (Pennsylvanian) and the Chesterian Series (Mississippian). A generalized geologic column for southwestern Indiana is shown in figure 2.

Commercial coal beds crop out in a zone that extends from north to south through the center of the study area. The most extensive coal beds are nearly flat, blanket-like deposits that dip generally southwest into the Illinois Basin at an average slope of about 25 ft/mi (Powell, 1972, p. 3).



Geology modified from H.H. Gray and others (1970) and J.B. Patton (1956)

The stratigraphic nomenclature follows the usage of the Indiana Geological Survey.

Figure 2.-- Generalized geologic column, coal-mining region, southwestern Indiana.

Land Use

Land use in the 21 counties that comprise the study area is 65.7 percent agricultural, 26.2 percent forested, 2.3 percent residential, 0.5 percent commercial and industrial, 1.1 percent recreational and open, 0.9 percent wetlands and water, 1.1 percent surface-mined and unreclaimed-mined lands, and 2.2 percent other uses (Kris Kothe, Indiana State Planning Services Agency, Department of Commerce, written commun., 1979; Mark Blade, west-central Indiana Economic Development District, Inc., written commun., 1979).

Most of the coal mining in Indiana is in six counties: Vigo, Sullivan, Warrick, Pike, Greene, and Clay, where the coal beds crop out or lie at shallow depths. Surface mining, currently the most efficient method of mining coal in Indiana, accounts for 90 percent of the State's annual coal production (Wier, 1973, p. 21).

In the last 50 years, almost 100,000 acres in southwestern Indiana has been disturbed directly by surface mining or indirectly by spoil deposition (Powell, 1972). By 1977, 500 million tons of coal had been surface mined in Indiana, and recoverable reserves were estimated to be 17,200 million tons. Approximately 27 million tons of coal were mined in Indiana in 1977 (Indiana Bureau of Mines and Mining, 1978).

Climate

Indiana has warm summers and cool winters because of its location in the middle latitudes in the interior of a large continent. The average-annual temperature in the study area ranges from about 50° F for the north to about 56° F for the south. Mean annual precipitation (fig. 3) is 44 inches, little of which is snow. Mean monthly precipitation is generally greatest during spring (5.10 inches in March) and least during autumn (2.3 inches in October). (Alfred Shipe, National Weather Service, written commun., January 1980).

APPROACH

Numerous environmental factors can influence stream quality. Some of the factors that may be significant in the coal-mining region are land use, surficial and bedrock geology, soil type, season, and hydrology. The approach used in this study consisted of two phases. In the first phase, a reconnaissance and two synoptic surveys of many stream sites throughout the study area were done to (1) provide general information on the water-quality of streams in the region and (2) determine the influence of land use and surficial geology on water quality. Information from the first phase was used to design the second phase of the study which entailed a monthly sampling program at 16

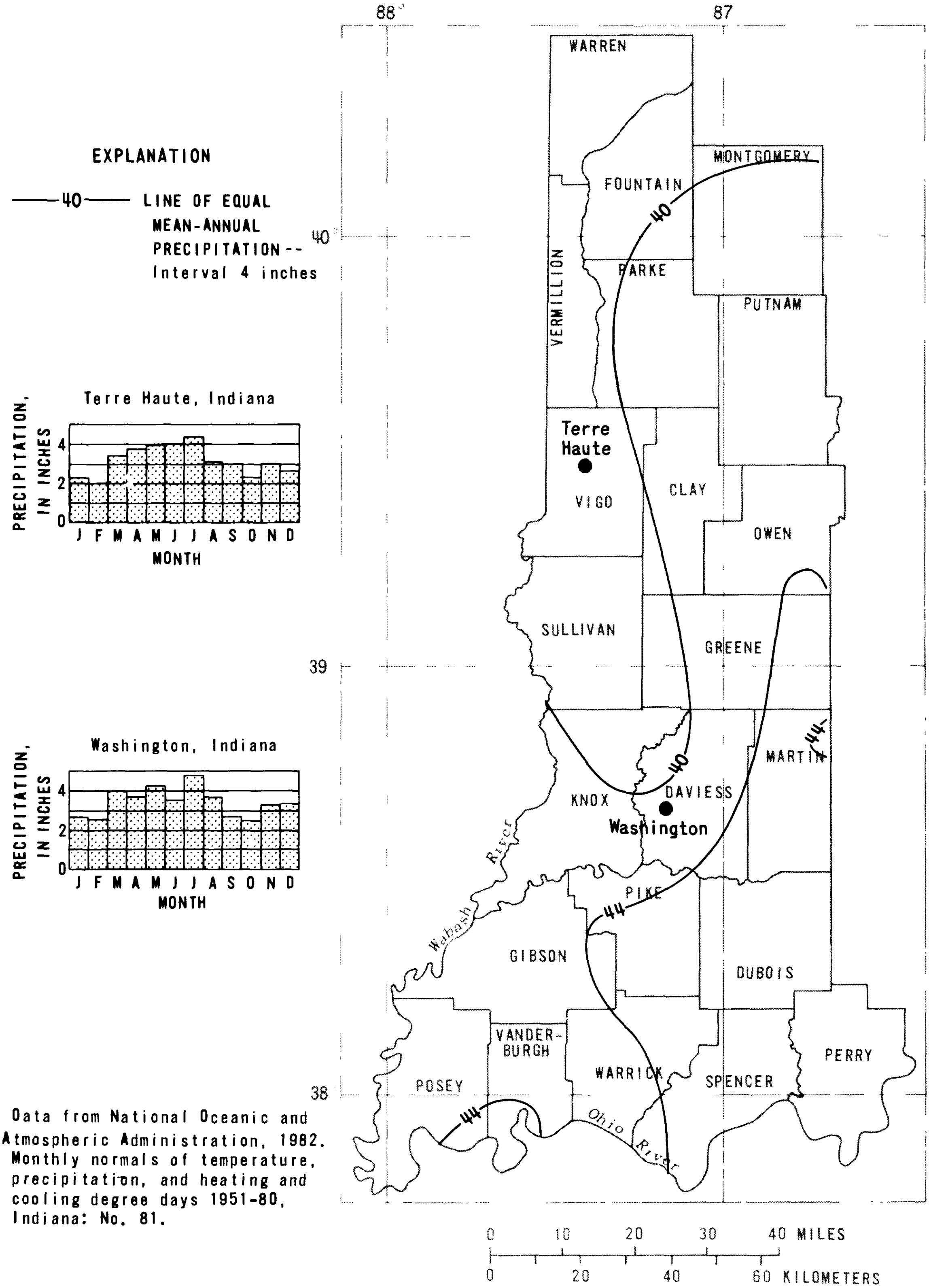


Figure 3.-- Mean annual precipitation and selected mean monthly precipitation in the coal-mining region, southwestern Indiana (1951-80).

stream sites to determine seasonal variations in water quality. However, as will be discussed later, the duration of the sampling program was not sufficient to evaluate seasonal variations in stream quality.

Reconnaissance

The reconnaissance of 293 stream sites was done in March 1979 to provide general information on water-quality and land use. Most of the sites were on first- or second-order streams identified on topographic maps. Measurements during the reconnaissance included pH, specific conductance, water temperature, dissolved oxygen concentration, and, at some sites, Eh. Specific conductance, a surrogate for dissolved-solids concentration, and, at some sites, pH seemed to be the best indicators of streams affected by mining.

Regional Synoptic Studies

Data collected and observations made during the reconnaissance were used in selecting 84 of the 293 sites for sampling during May and October 1979. Seventy-three of the 84 sites are in watersheds where land use (forest, agriculture, unreclaimed mining, and reclaimed mining) is predominately homogeneous. Data from these homogeneous watersheds were used to do a preliminary analysis of the effects of land use and surficial geology on variations in water quality (Wilber and others, 1981).

The distinction made in this study between reclaimed and unreclaimed mined areas is the difference between surface-mine reclamation techniques used before and after passage of Indiana's Surface Mine Act of 1967. Unreclaimed mined watersheds are areas that were mined before passage of the Act. Within these unreclaimed areas, slope, exposure of pyritic material, and establishment of plant cover are quite variable.

Only three homogeneous, forested watersheds were found, and only four homogeneous reclaimed mined watersheds were accessible. Sites were selected both in the glaciated (Wisconsin and Illinoian) regions and the unglaciated part of the study area. Locations and descriptions of the sites sampled are given in Renn and others (1980).

Samples of water were collected in May 1979 during high flows typical of spring and in October 1979 during low flows. No forested sites were sampled in May 1979. Water samples were collected to determine water-quality properties and concentrations of constituents in the dissolved, suspended, and total phases. Concentrations of major ions were determined because they represent a high percentage of the dissolved inorganic constituents and indicate general water quality. Metals and nonmetals include constituents whose determinations are required by Public Law 95-87 (iron and manganese), those that may affect the health of people (for example, arsenic, copper, and lead), and those that are enriched in coals (for example, arsenic, boron, and selenium). Concentrations of nutrients (phosphorus and nitrite plus nitrate) were determined because of their effect on biological productivity in streams and lakes, and concentrations of organic carbon and suspended sediment were determined because of their effect on the transport of metals and nutrients. Instantaneous discharge, specific conductance, pH, water temperature, and concentrations of dissolved oxygen, acidity, and alkalinity were measured in the field. Methods described by Skougstad and others (1979) were used for collection and analysis of all samples. All samples were analyzed by the U.S. Geological Survey. Data collected during the study are reported in Renn and others (1980) and Renn (1983).

Monthly Monitoring

Beginning in January 1980, sixteen of the streams draining watersheds with predominantly homogeneous land use were selected for monthly sampling to provide information on seasonal variations in water quality. Six of the watersheds were in the Wisconsin glacial province, five were in the Illinoian glacial province, and five were in the unglaciated part of the study area. Plans were to monitor these sites for several years. However, sampling had to be curtailed after September 1980, owing to funding constraints. The sampling program used during the second phase of the study is illustrated in Figure 4.

All samples were collected during periods of nearly steady flow to reduce the effect of variations in streamflow on the concentrations of constituents. All samples were collected and were analyzed as described in the section "Regional Synoptic Studies". Flow durations, the period of time that a discharge was equaled or exceeded, for gaged streams in the area generally ranged from 10 percent in March 1980, to 70 percent in June, July and August 1980.

Statistical Analysis

Classical or parametric statistical methods were not applicable for analysis of data in this study. These methods generally require that the data be normally distributed. The Shapiro-Wilk procedure (SAS Institute Inc., 1982a, p. 580) was used to test the hypothesis that the data came from a normally distributed population. The hypothesis was rejected at the 0.05 significance level for virtually all the water-quality constituents tested. The hypothesis was also rejected after natural-log transformations of the data had been made.

Consequently, data for each water-quality variable were ranked in order from low to high and the individual values were then replaced by these ranks in an appropriate parametric, statistical procedure. Statistical procedures based on ranks do not require normally distributed data. A discussion of rank statistical procedures is given in Conover and Iman (1976) and Conover (1980). These methods were used by Helsel (1983) to analyze water-quality data in the coal-mining region of Ohio.

Glacial province	Land-use	Site number	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
WISCONSIN	Forest	20A	●	●	●	●	●	●		●	
	Forest	301A	●	●	●	●	●	●	●	●	
	Agriculture	4	●	●	●	●	●	●	●		●
	Agriculture	32			●		●	●	●	●	●
	Reclaimed mining[1]	27a	●	●	●	●	●	●	●	●	
	Unreclaimed mining[2]	401	●	●	●	●	●	●	●	●	
ILLINOIAN	Agriculture	77	●	●	●	●	●	●	●		●
	Agriculture	470	●			●	●	●			
	Reclaimed mining[1]	417	●	●	●	●	●	●	●	●	
	Unreclaimed mining[2]	112a	●	●	●	●	●	●	●	●	
	Unreclaimed mining[2]	415	●	●	●	●	●	●	●	●	
UNGLACIATED	Forest	275C	●	●		●		●		●	
	Agriculture	243a	●	●	●	●	●	●	●	●	●
	Reclaimed mining[1]	45D	●	●	●	●	●	●	●	●	
	Unreclaimed mining[2]	456	●	●	●	●	●	●	●	●	
	Unreclaimed mining[2]	464	●	●	●	●	●	●	●	●	
			1980								

EXPLANATION

● Sample collected during month

1 Reclaimed mining: areas mined after passage of Indiana's Surface Mine "Act of 1967.

2 Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

Figure 4.-- Design of monthly stream-sampling program in the coal-mining region, southwestern Indiana, January-September 1980.

Analysis of variance (ANOV) was used to test the significance of several factors on the concentration of constituents in streams in southwestern Indiana. The procedure General-Linear Models for unbalanced ANOV (SAS Institute, Inc., 1982b, p. 139) was used in this analysis. The model used in this analysis is described by equation 1.

$$Yijk = u + Li + Gj + LGij + P(ij)k + Eijk, \quad (1)$$

where

- Yijk is the rank of the concentration of the water-quality constituent of interest obtained from the kth stream in the ith land use in the jth glacial province,
- u the mean rank of the concentration of the population of interest,
- Li the effect of the ith land use (fixed effect),
- Gj the effect of the jth glacial province (fixed effect),
- LGij the effect of the interaction of the ith land use with the jth glacial province,
- P(ij)k the effect of the kth stream in the ith land use in the jth glacial province (random effect), and
- Eijk the random-error component.

The mean square of the term P(ij)k was used as the divisor in the F-test to determine the significance of land use, glacial province, and the interaction of these two factors on the concentration of constituents in streams. Type IV (partial) sums of squares were used in the analysis. The calculation of type IV sums of squares is independent of the order of terms in the model. Further, type IV sums of squares are designed for use in experiments where there are empty cells. For example, the cell "forest x Illinoian" was classified as empty because no data from homogeneous forested sites in the Illinoian region were available.

Data collected from October 1979 through September 1980 from the 16 watersheds with predominantly homogeneous land use were used to test the significance of land use and surficial geology on the concentration of most constituents in streams during steady-state flows. Data collected in May 1979 were not used in the analysis because flows during this period were nonsteady state. Concentrations of trace elements (arsenic, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc) were not determined for samples collected in 1980. Statistical analyses for these elements were done by using data collected from the 73 homogeneous watersheds in October 1979. The significance of seasonal differences was not evaluated as originally planned because data were collected for only 1 year. A sampling program spanning several years is needed to evaluate the significance of seasonal variations of water quality in the coal-mining region.

Analysis of variance was used to determine which factors (for example, land use) in the model were significant. Tukey's honestly significant difference test (SAS Institute 1982b, p. 172) was used to identify significant different means within a given factor (for example, agricultural versus unreclaimed mined lands). The reader is reminded that failure to reject the hypotheses that two or more means are equal should not lead to the conclusion that the population means are in fact equal. Failure to reject the null hypothesis implies only that the difference between population means, if any, is too small to be detected with the given size of sample.

All conclusions in this report are based on a statistical-confidence level of at least 95 percent.

EFFECTS OF LAND USE AND SURFICIAL GEOLOGY

Streamflow

Streamflow in southwestern Indiana is influenced by geology, topography, land use, and size of the drainage basins. Average monthly and annual flows are low. According to Wangsness and others (1981, p 28), near zero monthly mean flows have been recorded in almost every month at all gaged sites. The relation of drainage area to mean annual discharge is shown in figure 5 and the locations of these sites in figure 6. The small variation around the curve in figure 5 indicates that mean annual flow is predictable and that size of the drainage area is a dominant factor influencing streamflow.

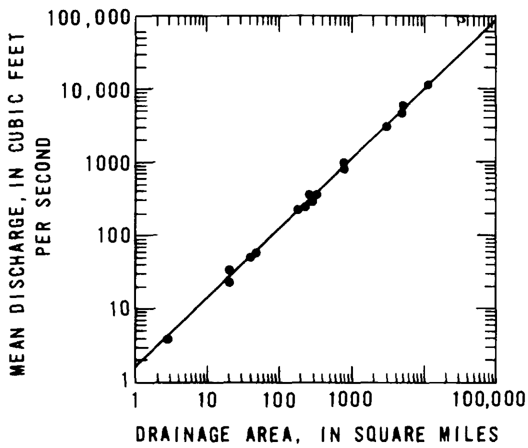


Figure 5.-- Relation of mean discharge to drainage area for selected sites in the coal-mining region, southwestern Indiana.

EXPLANATION

▲374500 CONTINUOUS-RECORD GAGING STATION AND NUMBER

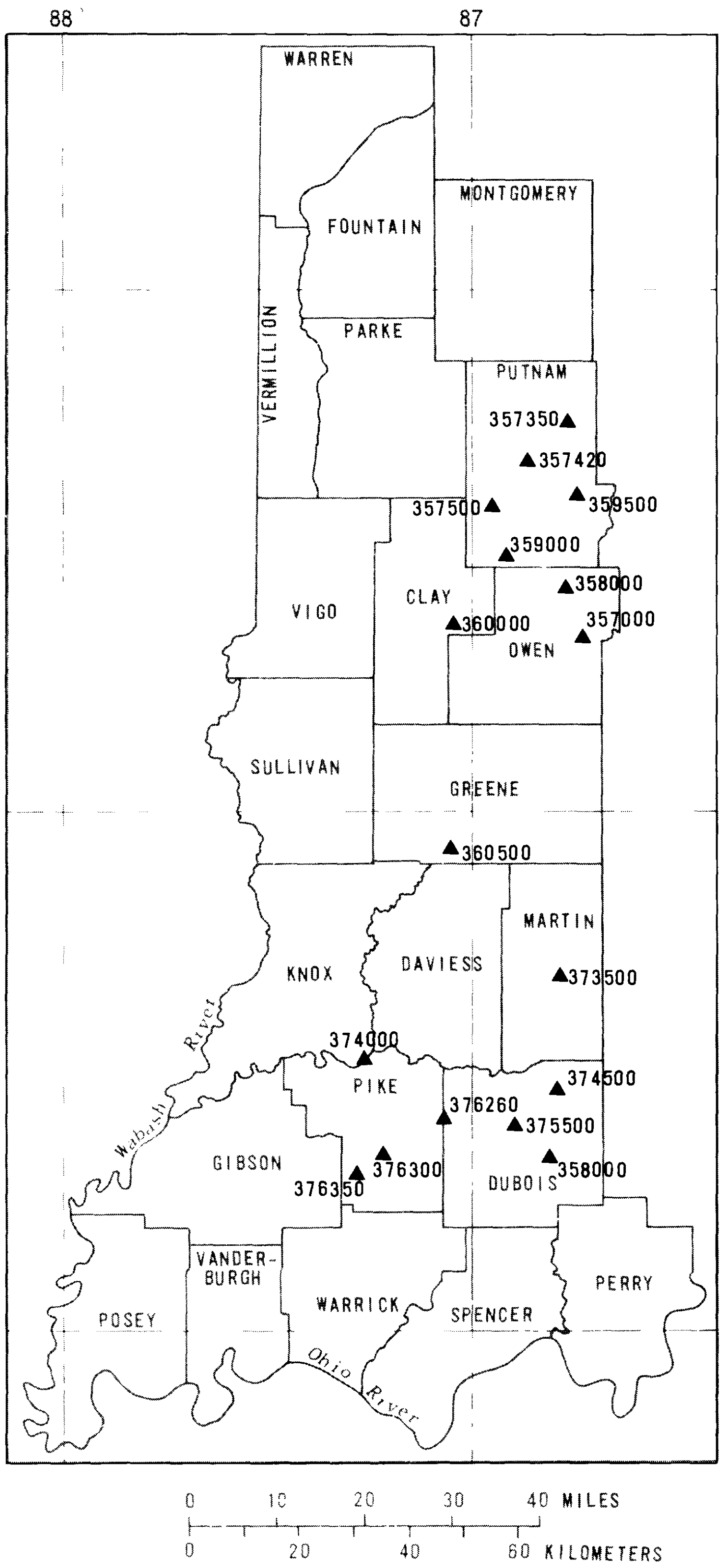


Figure 6.-- Locations of stream-gaging sites for mean discharge calculations, coal-mining region, southwestern Indiana.

Surficial aquifers in southwestern Indiana are minimal and usually of very low yield. Thus, streamflow is primarily due to overland runoff from precipitation. Springs are numerous in some parts of the Crawford Upland unit, where erosion has resulted in penetration of the Karst limestone (Schneider, 1966).

Land use may also affect streamflows. For example, the average unit-area streamflow for mined watersheds [(0.25 $ft^3/s)/mi^2$] was five times the average unit-area streamflow for unmined watersheds [(0.05 $ft^3/s)/mi^2$] during the October 1979 synoptic survey. Average flow duration of gaged, unregulated streams during the October 1979 survey was 62 percent. Thus, surface mining may help sustain low flows in streams by increasing the ground-water storage in the watershed. However, an in-depth study would be needed to quantify the effect of mining on streamflows in Indiana.

Stream quality

Water-quality limits recommended by the Indiana State Board of Health (1977), the U.S. Environmental Protection Agency (EPA) (1976, 1979a, and 1979b), and McKee and Wolff (1963), for the constituents studied (except aluminum) are presented in table 1. Results from the analysis of variance to determine the effects of land use and surficial geology or water quality are summarized in table 2. Summary statistics of the water-quality properties and constituents studied for each land use and glacial province are presented in tables 3 through 9. These data and the results of the analysis of variance indicate that land use is a statistically significant factor affecting water quality in the coal-mining region. The effect of glacial province (surficial geology) on water quality is evident for several dissolved constituents in forested and agricultural watersheds.

pH, Alkalinity, and Acidity

The pH of natural water is a measure of the acid-base equilibrium achieved by various dissolved salts and gases. The principal system regulating pH in natural water is the carbonate system which consists of carbon dioxide, carbonic acid, and bicarbonate and carbonate ions. The pH of streams not influenced by pollution generally ranges from 6.5 to 8.5 (Hem, 1970, p. 93). A departure from near-neutral pH may be caused by the influx of acidic or alkaline wastes, or, for poorly buffered water, fluctuations in algal photosynthesis.

On the basis of data primarily from bioassays, the EPA (1976, p. 337-341) indicated that water with a pH in the range from 6.5 to 9.0 provides adequate protection for freshwater fish and bottom dwelling invertebrates. Fish may suffer adverse physiological effects in water with a pH outside this pH range.

Table 1.--Limits recommended for constituents and properties for domestic or public-water supplies freshwater aquatic life, and irrigation use in Indiana

Constituent	Domestic or public water supplies	Reference	Freshwater aquatic life	Reference	Irrigation	Reference
Arsenic (μg/L)	50	(1)	50	(3)	100	(6)
Boron (μg/L)	--	--	--	--	750	(6)
Cadmium (μg/L)	10	(1)	12.0	(2)	--	--
Chromium (μg/L)	50	(1,2)	100	(2)	--	--
Copper (μg/L)	1,000	(1)	20	(3)	--	--
Dissolved Solids (mg/L)	250	(1,2,5)			500-1,000	(6)
Iron (μg/L)	300	(1,2)	1,000	(2)	--	--
Lead (μg/L)	50	(1)	50	(3)	--	--
Manganese (μg/L)	50	(1,2)	1,000	(4)	--	--
Mercury (μg/L)	2.0	(1)	0.05	(2)	--	--
Nickel (μg/L)	--	--	390-420	(2)	--	--
	--	--	430	(5)	--	--
	--	--	500	(3)	--	--
Nitrate (as N) (mg/L)	10	(1,2)	--	--	--	--
pH (units)	5.0-9.0	(2)	6.5-9.0	(2)	4.5-9.0	(6)
Selenium (μg/L)	10	(1)	--	--	--	--
Sulfate (mg/L)	500	(1)	--	--	--	--
Zinc (μg/L)	5,000	(1)	330	(5)	--	--
			1,000	(3)	--	--

[1]U.S. Environmental Protection Agency, 1979a.
[2]Indiana State Board of Health, 1977.
[3]Used by Indiana State Board of Health for the National Pollution Discharge Elimination System Program, (L. Bridges, Indiana State Board of Health, oral commun., July 16, 1982).
[4]McKee and Wolf, 1963.
[5]U.S. Environmental Protection Agency, 1979b.
[6]U.S. Environmental Protection Agency, 1976.

Table 2.--Summary of results from analysis of variance on ranks to determine the effects of land use, surficial geology, and the interaction of land use and surficial geology on concentrations of water-quality constituent in the coal-mining region, southwestern Indiana, October 1979 through September 1980 (All values are attained significance levels: probabilities that observed differences are due to chance rather than the tested effect)

Constituent	Factor		
	Land use	Surficial geology	Land Use X surficial geology
pH, alkalinity, and acidity			
pH	0.04	0.15	0.51
Alkalinity	.63	.44	.50
Acidity	.41	.77	.82
Major dissolved constituents			
Dissolved solids (residue at 180° C)	.01	.63	.58
Calcium	<.01	.20	.40
Magnesium	<.01	.47	.35
Sodium	<.01	.80	.22
Potassium	<.01	.62	.28
Chloride	.61	.19	.59
Sulfate	.02	.91	.78
Fluoride	.13	.14	.20
Silica	.14	.21	.82
Nutrients			
Nitrogen, nitrite plus nitrate	<.01	.12	.04
Phosphate, total	<.01	.07	<.01
Metals and trace elements			
Aluminum, total	.20	.40	.98
Iron, total	.06	.82	.94
Iron, dissolved	.05	.85	.86
Manganese, total	<.01	.09	.54
Manganese, dissolved	<.01	.15	.78
Arsenic, total	.05	.06	.70
Boron, total	<.01	.50	.40
Cadmium, total	.24	.01	.17
Chromium, total	.58	.65	.29
Copper, total	.18	.44	.97
Lead, total	.64	<.01	.96
Mercury, total	.31	.09	.74
Nickle, total	<.01	.17	.68
Selenium, total	.72	.80	.64
Zinc, total	<.01	.33	.39
Suspended sediment	.54	.57	.20
Organic carbon, dissolved	.04	.79	.57

Streams in southwestern Indiana are generally well buffered--pH is 7.0 or greater. Statistical summaries of pH and concentrations of alkalinity and acidity are presented in table 3. Generally pH was highest in streams draining forested and agricultural watersheds, followed by streams draining reclaimed mined watersheds and was lowest in streams draining unreclaimed mined watersheds. The median pH of streams draining unreclaimed mined watersheds (7.1) was significantly lower than the median pH of streams draining forested and agricultural watersheds (8.0). Ranges of pH, alkalinity, and acidity of streams draining unreclaimed mined watersheds were considerably greater than in streams draining watersheds with other land use. For example, several streams draining unreclaimed mined watersheds had pH values less than 5.0 whereas the pH of all streams draining watersheds with other land use was greater than 6.3.

The effect of reclamation on the pH of streams in the coal-mining region of Indiana is unclear. Although the median pH of streams draining reclaimed mined watersheds (7.9) was similar to the median pH of streams draining forested and agricultural watersheds and greater than the median pH of streams draining unreclaimed mined watersheds, this difference was not statistically significant.

Median pH values and alkalinities of streams draining the Wisconsin glacial province were generally greater than those of streams draining the Illinoian and the unglaciated regions, suggesting that there is greater dissolution of carbonate minerals in surficial materials in the Wisconsin glacial province than in the other regions. These differences were more evident in samples from streams draining forested and agricultural watersheds than in samples from streams draining mined watersheds; however, the initial analysis of variance indicated that these differences were not statistically significant. A second statistical model was tested, with data collected from streams draining agricultural watersheds, to reduce confounding in the analysis that may have been caused by the unbalanced nature of the original design and masking of these more subtle differences by the effect of mining.

The second model was

$$Yjk = u + Gj + Ejk, \tag{2}$$

where

Yjk	is the rank of the concentration of the water quality constituent of interest from the kth stream in the jth glacial province,
u	the mean rank of the concentration of the population of interest,
Gj	the effect of the jth glacial province (fixed effect), and
Ejk	the random-error component.

Attained significance levels (probabilities that observed differences in concentration were due to chance rather than differences in surficial geology) were: pH (0.03), alkalinity (<0.01), dissolved solids (0.33), and calcium (<0.01). These results support the hypothesis that there is greater dissolution of carbonate minerals in the Wisconsin glacial province than the Illinoian glacial province and the unglaciated region.

Table 3.--Statistical summary of pH, alkalinity, and acidity in streams at near steady-state flows representing major land uses and glacial provinces in the coal mining region, southwestern Indiana, October 1979 through September 1980

Land use	Glacial province	pH (units)				
		N	Median	Minimum	Maximum	Interquartile range[1]
Forest	Wisconsin	17	8.0	7.7	8.4	0.3
	Unglaciated	6	6.9	6.3	7.3	.8
	Total	23	8.0	6.3	8.4	.8
Agriculture	Wisconsin	14	8.1	7.8	8.7	.3
	Illinoian	11	7.8	7.2	8.0	.4
	Unglaciated	10	7.9	7.1	8.8	1.1
	Total	35	8.0	7.1	8.8	.5
Reclaimed mining[2]	Wisconsin	9	7.8	6.8	8.1	.2
	Illinoian	9	7.6	7.5	8.0	.3
	Unglaciated	9	7.7	7.3	8.3	.7
	Total	27	7.8	6.8	8.3	.4
Unreclaimed mining[3]	Wisconsin	9	7.4	7.0	7.8	.5
	Illinoian	17	6.6	4.8	7.9	1.8
	Unglaciated	18	6.9	3.8	7.6	1.2
	Total	44	7.1	3.8	7.9	1.4

Table 3.--Statistical summary of pH, alkalinity, and acidity in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	Alkalinity as CaCO3 (mg/L)					Acidity as $CaCO_3$ (mg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	260	230	320	35	8	0	0	10	4
	Unglaciated	6	16	13	47	18	5	0	0	10	5
	Total	23	260	13	320	220	13	0	0	10	2.5
Agriculture	Wisconsin	14	240	170	270	45	6	0	0	10	10
	Illinoian	12	110	54	210	67	5	0	0	10	7.5
	Unglaciated	10	190	110	230	55	5	0	0	15	15
	Total	36	195	54	270	110	16	0	0	15	10
Reclaimed mining[2]	Wisconsin	9	240	200	340	65	4	0	0	10	8
	Illinoian	9	280	240	370	55	4	0	0	25	19
	Unglaciated	9	120	110	150	30	4	0	0	15	11
	Total	27	240	110	370	150	12	0	0	25	7.5
Unreclaimed mining[3]	Wisconsin	9	170	140	230	20	5	0	0	25	18
	Illinoian	16	130	0	190	160	12	43	0	194	107
	Unglaciated	18	170	0	310	270	13	10	0	89	20
	Total	43	160	0	310	180	30	10	0	194	34

[1] Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2] Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3] Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

Dissolved Solids and Major Cations and Anions

The occurrence of chemical constituents dissolved in surface and ground water is due to: (1) the physical and the chemical characteristics of the material through which the water moves, (2) natural weathering processes, and (3) point and nonpoint sources of dissolved constituents.

Statistical summaries of the concentrations of dissolved solids and major cations and anions are presented in table 4.

The predominant ions in streams draining forested and agricultural watersheds in southwestern Indiana are calcium and bicarbonate resulting from the dissolution of calcite and dolomite in unconsolidated surface deposits and bedrock. Concentrations of major dissolved constituents in streams affected by coal mining were significantly higher than those in streams draining forested and agricultural watersheds. The predominant ions in streams draining mined areas were calcium, magnesium, and sulfate. The higher concentrations of dissolved constituents in mined areas is caused by the oxidation of sulfide in pyrite and marcasite to sulfate, which releases dissolved metals and acidity into the water and increases the dissolution of calcite and dolomite.

High concentrations of dissolved constituents may adversely affect water quality in several ways: (1) Water with high dissolved-solids concentrations generally does not taste good and may unfavorably affect the occasional consumer, and (2) highly mineralized water is unsuitable for some industrial applications and may require costly treatment for use.

The physiological effects directly related to dissolved solids include the laxative effect, principally from sodium sulfate and magnesium sulfate, and the adverse effects of sodium on certain individuals afflicted with heart disease and women afflicted with toxemia during pregnancy. Median sulfate concentrations in streams draining mined areas were significantly greater than 250 mg/L, the concentration indicated by the Environmental Protection Agency (1976, p. 395) as reasonable to protect occasional consumers from laxative effects. The general population is not adversely affected by sodium, but various limits have been recommended by physicians for a significant part of the population. The EPA (1976, p. 395) calculated that for very restrictive diets, 20 mg/L of sodium should be the maximum concentration in drinking water. Concentrations of sodium in streams from some mined watersheds were greater than 20 mg/L, and, as a result, the use of these streams as a potential water supply for persons with heart disease or toxemia may be limited.

Table 4.--Statistical summary of concentration of major dissolved constituents in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980

Land use	Glacial province	Dissolved solids residue at 180° C (mg/L)				
		N	Median	Minimun	Maximum	Interquartile range[1]
Forest	Wisconsin	17	342	304	415	50
	Unglaciated	6	61	54	94	17
	Total	23	336	54	425	274
Agriculture	Wisconsin	14	365	270	425	35
	Illinoian	12	156	124	316	130
	Unglaciated	10	338	287	365	36
	Total	36	328	124	425	122
Reclaimed mining[2]	Wisconsin	9	1,160	603	1,950	930
	Illinoian	9	2,470	695	2,800	960
	Unglaciated	9	1,950	1,410	2,040	305
	Total	27	1,840	603	2,800	830
Unreclaimed mining[3]	Wisconsin	9	2,470	1,860	4,530	1,200
	Illinoian	17	1,860	949	2,950	955
	Unglaciated	18	3,380	963	6,110	4,150
	Total	44	2,030	949	6,110	1,800

Table 4.--Statistical summary of concentration of major dissolved constituents in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	Calcium (mg/L)					Magnesium (mg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	78	56	90	11	17	29	25	38	6
	Unglaciated	5	5.4	4.7	8.1	2.4	5	3.3	2.7	4.1	1
	Total	22	73	4.7	90	35	22	29	2.7	38	12
Agriculture	Wisconsin	14	76	64	92	6.5	14	31	25	36	4.3
	Illinoian	12	35	23	61	25	12	9.5	6.2	21	7
	Unglaciated	9	54	47	64	9.5	9	22	17	26	3.5
	Total	35	59	23	92	33	35	22	6.2	36	19
Reclaimed mining[2]	Wisconsin	9	150	100	210	50	9	72	41	110	45
	Illinoian	8	210	170	250	55	8	175	88	220	58
	Unglaciated	7	190	170	260	70	7	170	100	200	80
	Total	24	180	100	260	55	24	130	41	220	97
Unreclaimed mining[3]	Wisconsin	9	270	190	350	80	9	210	170	260	55
	Illinoian	16	170	110	250	80	16	170	85	240	100
	Unglaciated	16	160	83	310	90	16	230	77	890	530
	Total	41	190	83	350	120	41	190	77	890	120

Table 4.--Statistical summary of concentration of major dissolved constituents in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	Sodium (mg/L)					Potassium (mg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	12	5.5	21	7.6	17	1.9	0.8	2.5	0.5
	Unglaciated	6	3.7	2.6	5.8	1.7	6	1.0	.5	1.5	.8
	Total	23	7.8	2.6	21	8.5	23	1.7	.5	2.5	.7
Agriculture	Wisconsin	14	8.6	5.6	11	1.9	14	1.9	.9	2.7	1.3
	Illinoian	12	5.1	4.0	17	6.3	12	1.5	.9	2.9	1.3
	Unglaciated	10	29	19	32	7.3	10	2.6	1.6	5.7	2.9
	Total	36	9.3	4.0	32	15	36	2.0	.9	5.7	1.3
Reclaimed mining[2]	Wisconsin	9	38	18	210	150	9	4.5	1.7	9.3	4.6
	Illinoian	9	190	140	230	70	9	6.9	5.1	9.1	1.8
	Unglaciated	8	28	20	32	4.2	8	5.0	3.8	5.8	.9
	Total	26	61	18	230	170	26	5.3	1.7	9.3	2.5
Unreclaimed mining[3]	Wisconsin	9	79	63	91	11	9	5.5	4.3	9.0	3.0
	Illinoian	17	39	16	130	67	17	4.0	2.9	5.5	1.3
	Unglaciated	18	33	24	56	12	18	4.7	2.3	55	1.7
	Total	44	40	16	130	44	44	4.7	2.3	55	1.7

Table 4.--Statistical summary of concentration of major dissolved constituents in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	Chloride (mg/L)					Sulfate (mg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	16	4.4	35	14	17	41	31	67	15
	Unglaciated	6	1.4	1.1	1.6	.4	6	23	20	27	4
	Total	23	5.7	1.1	35	17	23	39	20	67	23
Agriculture	Wisconsin	14	18	12	30	8.3	14	53	40	73	21
	Illinoian	12	4.8	3.6	18	6.5	12	27	13	64	41
	Unglaciated	10	17	12	24	4.3	10	59	53	69	7.8
	Total	36	15	3.6	30	12	36	56	13	73	23
Reclaimed mining[2]	Wisconsin	9	13	8.1	34	16	9	520	250	1,000	480
	Illinoian	9	5.4	4.0	14	1.8	9	1,400	920	1,600	480
	Unglaciated	9	6.7	5.2	8.2	1.1	9	1,200	890	1,300	205
	Total	27	7.2	4.0	34	5.1	27	1,100	250	1,600	630
Unreclaimed mining[3]	Wisconsin	9	9.4	6.8	33	18	9	1,500	1,100	2,100	650
	Illinoian	17	7.3	4.2	11	4.1	17	1,100	490	1,900	720
	Unglaciated	18	3.4	2.6	12	1.7	18	1,900	570	3,600	2,300
	Total	44	6.0	2.6	33	4.7	44	1,300	450	3,600	1,000

Table 4.--Statistical summary of concentration of major dissolved constituents in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	Floride (mg/L)					Silica, dissolved (mg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	0.2	0.2	0.3	0	17	10	7.7	14	1.5
	Unglaciated	6	.1	<.1	.1	<.1	6	13	12	17	4.2
	Total	23	.2	<.1	.3	.1	23	11	7.7	17	3.3
Agriculture	Wisconsin	14	.2	.2	.3	0	14	7.1	3.4	10	2.6
	Illinoian	12	.1	.1	.2	<.1	12	11	3.3	14	3.5
	Unglaciated	10	.3	.2	.4	<.1	10	10	4.3	16	5.5
	Total	36	.2	.1	.4	.2	36	8.7	3.3	16	4.2
Reclaimed mining[2]	Wisconsin	9	.2	.2	1.8	.1	9	4.3	2.2	8.9	3.0
	Illinoian	9	.3	.2	.3	0	9	5.3	2.9	8.0	4.0
	Unglaciated	9	.4	.4	.5	0	8	4.7	3.6	6.5	2.1
	Total	27	.3	.2	1.8	.2	26	4.7	2.2	8.9	2.9
Unreclaimed mining[3]	Wisconsin	9	.2	.2	.3	<.1	9	4.1	2.8	11	6.5
	Illinoian	17	.4	.2	.5	.2	17	14	4.4	21	10
	Unglaciated	18	.6	.3	.8	.4	18	14	5.9	29	1.3
	Total	44	.4	.2	.8	.2	44	13	2.8	29	8.5

[1]Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2]Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3]Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

Nutrients

Plants, including algae, require potassium, nitrogen, and phosphorus as well as trace amounts of other elements to grow. Potassium, a common constituent in streams, seldom limits plant growth. Forms of nitrogen in water include organic nitrogen, ammonia, nitrite, and nitrate. Of these forms, nitrate is usually predominant and most readily available for plant growth. Forms of phosphorus in water include the simple ionic orthophosphate and bound phosphate in soluble or particulate form. Bound phosphate may be released by bacterial action. Dissolved forms of nitrate and phosphate are rapidly taken up by plants. Consequently, their concentrations in natural water are usually low.

Nutrient enrichment may encourage blooms of nuisance algae. Such blooms are common in lakes (Wetzel, 1975, p. 659), but are seldom seen in streams. The effects of nutrient enrichment from agricultural practices and wastewater effluent seem to be reduced by increased stream turbidity from erosion and effluents.

Statistical summaries of concentrations of dissolved nitrite plus nitrate concentrations and total-phosphate are presented in table 5. Concentrations of nitrite plus nitrate-nitrogen and total phosphate were highly variable.

Median concentrations of nitrite plus nitrate were significantly greater in streams draining agricultural and reclaimed-mined watersheds than in streams draining forested and unreclaimed-mined watersheds. Median concentrations of total phosphate were significantly greater in streams draining agricultural watersheds than in streams draining forested and mined watersheds. Fertilizer applied to soils for plant growth is the most probable source of nitrogen and phosphorus in these streams. The interaction of land use and glacial province was statistically significant for concentrations of nitrite plus nitrate as well as of total phosphate. However, except for the effect of land use explained previously, differences between median concentrations do not seem to have any practical significance and may reflect variation in fertilizer application rates in different areas.

Metals and Trace Elements

Statistical summaries of concentrations of metals (aluminum, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc) and some nonmetals (arsenic, boron, and selenium) are presented in tables 6 and 7. Water-quality limits (table 1) are generally based on the toxicity of the metals to sensitive freshwater organisms. The toxicity of metals to aquatic life is dependent on several factors that include the species considered, water temperature, hardness, and pH. As a result, a single metal concentration is not applicable as a limit for all species and environmental conditions. Water-quality standards for some metals, such as copper, lead, nickel, and zinc, are based on the concentration that is lethal to 50 percent of a

Table 5.--Statistical summary of concentrations of selected nutrients in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980

Land use	Glacial province	Nitrogen, nitrite plus nitrate, dissolved (mg/L)					Phosphorus, orthophosphate, total (mg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	0.21	<0.01	0.78	0.19	15	0.03	<0.01	0.06	0.03
	Unglaciated	6	.10	.02	.34	.14	5	.06	<.01	.09	.08
	Total	23	.21	<.01	.78	.24	20	.03	<.01	.09	.03
Agriculture	Wisconsin	14	2.3	.19	9.7	7.0	12	.05	<.01	.18	.08
	Illinoian	12	.73	.03	2.7	.43	11	.03	<.01	.12	.06
	Unglaciated	10	2.0	.34	14	1.4	9	.21	.06	.43	.13
	Total	36	1.5	.03	14	2.1	32	.06	<.01	.43	.15
Reclaimed mining[2]	Wisconsin	9	2.8	.02	4.8	2.5	8	<.01	<.01	.03	.02
	Illinoian	9	4.0	.40	9.4	5.5	8	.06	<.01	.34	.08
	Unglaciated	9	.05	<.01	.13	.1	8	<.01	<.01	.03	.02
	Total	27	.8	<.01	9.4	3.8	24	<.01	<.01	.34	.03
Unreclaimed mining[3]	Wisconsin	9	.11	.05	.19	.05	8	<.01	<.01	.06	.05
	Illinoian	17	.17	.01	.55	.15	15	<.01	<.01	<.01	0
	Unglaciated	18	.06	<.01	.78	.09	16	<.01	<.01	.25	0
	Total	44	.12	<.01	.78	.13	39	<.01	<.01	.25	0

[1] Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2] Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3] Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

Table 6.--Statistical summary of concentrations of aluminum, iron, and manganese in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980

Land use	Glacial province	Aluminum, total (μg/L)					Aluminum, dissolved (μg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	200	10	400	280	15	30	<10	330	20
	Unglaciated	6	150	60	300	140	5	40	30	60	25
	Total	23	200	10	400	240	20	30	<10	330	20
Agriculture	Wisconsin	14	250	20	2,800	360	12	40	20	100	18
	Illinoian	12	300	<10	1,400	440	11	30	<10	70	20
	Unglaciated	10	450	300	1,700	550	9	60	30	200	100
	Total	36	300	<10	2,800	320	32	40	<10	200	30
Reclaimed mining[2]	Wisconsin	9	200	30	200	130	8	20	<10	60	20
	Illinoian	9	130	20	300	140	8	40	20	100	40
	Unglaciated	9	200	100	520	340	7	50	30	200	20
	Total	27	200	20	520	100	23	30	<10	200	40
Unreclaimed mining[3]	Wisconsin	9	300	60	900	250	9	60	<10	200	55
	Illinoian	17	5,000	60	15,000	8,200	15	30	<10	9,700	170
	Unglaciated	18	1,300	100	11,000	3,300	16	170	20	4,000	290
	Total	44	650	60	15,000	5,200	39	100	<10	9,700	170

Table 6.--Statistical summary of concentrations of aluminum, iron, and manganese in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	N	Iron, total (µg/L)				N	Iron, dissolved (µg/L)			
			Median	Minimum	Maximum	Inter-quartile range[1]		Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	190	30	880	200	17	20	<1	90	25
	Unglaciated	6	220	30	620	360	6	40	20	70	35
	Total	23	190	30	880	240	23	20	<1	90	30
Agriculture	Wisconsin	14	345	150	3,700	500	14	15	<1	40	23
	Illinoian	12	700	240	1,700	300	12	20	10	210	28
	Unglaciated	10	640	30	1,900	600	10	20	10	50	30
	Total	36	590	30	3,700	450	36	20	<1	210	30
Reclaimed mining[2]	Wisconsin	9	370	40	550	120	9	40	10	50	25
	Illinoian	9	670	410	1,100	510	9	120	50	330	95
	Unglaciated	9	500	130	1,400	420	8	60	40	140	40
	Total	27	490	40	1,400	360	26	60	10	330	70
Unreclaimed mining[3]	Wisconsin	9	1,700	850	14,000	2,150	9	380	250	1,400	690
	Illinoian	17	23,000	340	50,000	37,000	17	18,000	20	50,000	34,000
	Unglaciated	18	2,400	760	10,000	2,200	18	1,200	70	4,700	2,200
	Total	44	2,400	340	50,000	8,500	44	810	20	50,000	4,000

Table 6.--Statistical summary of concentrations of aluminum, iron, and manganese in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980--Continued

Land use	Glacial province	N	Managanese, total (µg/L)				N	Managanese, dissolved (µg/L)			
			Median	Minimum	Maximum	Inter-quartile range[1]		Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	17	60	10	130	95	17	10	3	110	90
	Unglaciated	6	25	10	380	130	6	20	10	360	120
	Total	23	30	10	380	90	23	20	3	360	84
Agriculture	Wisconsin	14	40	20	120	25	14	40	7	40	10
	Illinoian	12	110	70	180	68	12	90	40	160	50
	Unglaciated	10	320	90	430	310	10	270	50	420	290
	Total	36	90	20	430	120	36	70	7	420	100
Reclaimed mining[2]	Wisconsin	9	320	100	630	160	9	310	90	640	200
	Illinoian	9	740	480	1,200	460	9	720	400	1,200	450
	Unglaciated	9	710	80	2,400	1,600	8	550	150	2,200	1,500
	Total	27	630	80	2,400	780	26	550	90	2,200	680
Unreclaimed mining[3]	Wisconsin	9	460	250	3,200	1,900	9	490	240	3,400	1,600
	Illinoian	17	6,200	2,200	14,000	7,100	17	6,100	2,400	15,000	6,850
	Unglaciated	18	6,400	2,300	15,000	3,300	18	6,800	10	15,000	2,900
	Total	44	5,600	250	15,000	5,800	44	5,600	10	15,000	5,400

[1]Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2]Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3]Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

Table 7.--Statistical summary of concentrations of trace elements in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979

Land use	Glacial province	Arsenic, total (μg/L)					Boron, total (μg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	2	1	1	1	0	2	45	30	60	30
	Unglaciated	1	1	1	1	0	1	30	30	30	0
	Total	3	1	1	1	0	3	30	30	60	30
Agriculture	Wisconsin	11	1	1	1	0	11	50	20	110	30
	Illinoian	12	2	1	6	4	12	60	20	1,600	210
	Unglaciated	9	4	2	5	.5	9	30	20	100	30
	Total	32	1	1	6	3	32	40	20	1,600	40
Reclaimed mining[2]	Wisconsin	1	1	1	1	0	1	120	120	120	0
	Illinoian	1	2	2	2	0	1	430	430	430	0
	Unglaciated	2	3	1	4	3	2	160	80	240	160
	Total	4	2	1	4	3	4	180	80	430	290
Unreclaimed mining[3]	Wisconsin	3	1	<1	1	1	3	140	110	550	440
	Illinoian	19	1	<1	48	3	19	140	10	570	180
	Unglaciated	12	3	<1	4	3	12	170	10	490	320
	Total	34	1	<1	48	2	34	150	10	570	240

Table 7.--Statistical summary of concentrations of trace elements in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use	Glacial province	Cadmium, total (µg/L)					Chromium, total (µg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	2	<1	<1	<1	0	2	20	20	20	0
	Unglaciated	1	1	1	1	0	1	10	10	10	0
	Total	3	<1	<1	1	1	3	20	10	20	10
Agriculture	Wisconsin	11	<1	<1	<1	0	11	20	10	20	0
	Illinoian	12	<1	<1	4	0	12	20	10	30	10
	Unglaciated	9	<1	<1	1	<1	9	20	20	20	0
	Total	32	<1	<1	4	<1	32	20	10	30	0
Reclaimed mining[2]	Wisconsin	1	<1	<1	<1	0	1	20	20	20	0
	Illinoian	1	1	1	1	0	1	10	10	10	0
	Unglaciated	2	<1	<1	1	1	2	20	20	20	0
	Total	4	<1	<1	1	1	4	20	10	20	10
Unreclaimed mining[3]	Wisconsin	3	<1	<1	<1	<1	3	10	10	30	20
	Illinoian	19	<1	<1	200	<1	19	20	10	120	20
	Unglaciated	12	1	<1	13	5	12	20	20	40	10
	Total	34	<1	<1	200	1	34	20	10	120	10

Table 7.--Statistical summary of concentrations of trace elements in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979--Continued

		Copper, total (µg/L)					Lead, total (µg/L)				
Land use	Glacial province	N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	2	1	1	1	0	2	<1	<1	<1	0
	Unglaciated	1	2	2	2	0	1	2	2	2	0
	Total	3	1	1	2	1	3	<1	<1	2	2
Agriculture	Wisconsin	11	2	1	8	3	11	<1	<1	2	1
	Illinoian	12	2	1	22	1	12	1	<1	5	3
	Unglaciated	9	3	2	5	2	9	3	1	4	2
	Total	32	2	1	22	2	32	1	<1	5	3
Reclaimed mining[2]	Wisconsin	1	2	2	2	0	1	<1	<1	<1	0
	Illinoian	1	2	2	2	0	1	2	2	2	0
	Unglaciated	2	2	2	2	0	2	2	<1	4	4
	Total	4	2	2	2	0	4	1	<1	4	4
Unreclaimed mining[3]	Wisconsin	3	2	2	11	9	3	<1	<1	1	1
	Illinoian	19	2	1	260	2	19	1	<1	3	2
	Unglaciated	12	3	2	13	3	12	3	<1	33	4
	Total	34	3	1	260	3	34	2	<1	33	3

Table 7.--Statistical summary of concentrations of trace elements in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use	Glacial province	Mercury, total (μg/L)					Nickel, total (μg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	2	0.2	0.2	0.2	0	2	<1	<1	1	1
	Unglaciated	1	.1	.1	.1	0	1	1	1	1	0
	Total	3	.2	.1	.2	.1	3	1	<1	1	1
Agriculture	Wisconsin	11	.2	.1	.3	.1	11	1	<1	4	1
	Illinoian	12	.1	.1	.2	0	12	2	<1	170	4
	Unglaciated	9	.1	.1	.2	.1	9	3	<1	7	3
	Total	32	.1	.1	.3	.1	32	2	<1	170	3
Reclaimed mining[2]	Wisconsin	1	.1	.1	.1	0	1	3	3	3	0
	Illinoian	1	.1	.1	.1	0	1	15	15	15	0
	Unglaciated	2	.1	.1	.1	0	2	5	7	3	4
	Total	4	.1	.1	.1	0	4	5	15	3	10
Unreclaimed mining[3]	Wisconsin	3	.1	.1	.2	.1	3	7	110	2	110
	Illinoian	19	.1	.1	.3	0	19	38	670	1	80
	Unglaciated	12	.1	.1	.2	0	12	64	560	20	100
	Total	34	.1	.1	.3	0	34	50	670	1	100

Table 7.--Statistical summary of concentrations of trace elements in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use	Glacial province	Selenium, total (µg/L)					Zinc, total (µg/L)				
		N	Median	Minimum	Maximum	Inter-quartile range[1]	N	Median	Minimum	Maximum	Inter-quartile range[1]
Forest	Wisconsin	2	<1	<1	<1	0	2	20	10	20	10
	Unglaciated	1	<1	<1	<1	0	1	10	10	10	0
	Total	3	<1	<1	<1	0	3	10	10	20	10
Agriculture	Wisconsin	11	<1	<1	<1	0	11	10	<10	30	20
	Illinoian	12	<1	<1	<1	0	12	10	<10	3,700	20
	Unglaciated	9	<1	<1	<1	0	9	10	10	1,900	30
	Total	32	<1	<1	<1	0	32	10	<10	3,700	10
Reclaimed mining[2]	Wisconsin	1	<1	<1	<1	0	1	10	10	10	0
	Illinoian	1	<1	<1	<1	0	1	20	20	20	0
	Unglaciated	2	<1	<1	<1	0	2	5	<10	10	10
	Total	4	<1	<1	<1	0	4	10	<10	20	15
Unreclaimed mining[3]	Wisconsin	3	<1	<1	<1	0	3	20	10	120	110
	Illinoian	19	<1	<1	<1	0	19	40	10	5,000	500
	Unglaciated	12	<1	<1	<1	0	12	80	20	2,100	260
	Total	34	<1	<1	<1	0	34	50	10	5,000	280

[1] Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2] Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3] Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

population of sensitive resident organisms during a 96-hour test (96 hour LC50) of the receiving water or water of similar chemistry. Data for 96-hour LC50 concentrations of copper, lead, nickel, and zinc were not available for Indiana streams. Toxic concentrations for the 96-hour median tolerance limit (96-hour TL50), the concentration of a test material of which just 50 percent of the test animals are able to survive, were estimated from published data (U.S. Environmental Protection Agency, 1976). The 96-hour TL50 concentrations should be approximately equal to the 96-hour LC50. The limits reported here were obtained by multiplying the 96-hour TL50 for fathead minnows, bluegills, brown bullheads, and unnamed fish species by a safety factor of 0.01 for lead, nickel, mercury, and zinc and by 0.1 for copper (U.S. Environmental Protection Agency, 1976).

The percentage of streams sampled in October 1979 whose concentrations of trace elements exceeded those recommended by the Indiana State Board of Health for freshwater aquatic life were: cadmium, 2.3 percent; chromium, 1.2 percent; copper, 3.5 percent; iron, 41 percent; manganese, 49 percent; mercury, 100 percent; nickel, 2 percent; and zinc, 1 percent.

Median concentrations of boron, iron, manganese, nickel, and zinc were significantly greater in streams draining mined areas than in streams draining forested and agricultural watersheds. Concentrations of aluminum, arsenic, cadmium, chromium, cooper, lead, mercury, and selenium generally were not affected by differences in land use except where stream pH was less than 6.0.

Iron and Manganese

As is common for Indiana streams, median concentration of total iron and manganese in streams draining agricultural and mined watershed exceeded recommended limits for domestic and public water supplies. The median concentration of total iron in streams draining unreclaimed mined watersheds was significantly higher than that for streams draining forested watersheds but was not significantly different from the median for streams draining agricultural and reclaimed mined watersheds.

The median concentration of total iron in streams draining unreclaimed mined watersheds was about four times higher than that for streams draining agricultural and reclaimed mined watersheds. Thus, the post-1967 reclamation techniques seem to have been effective in reducing concentrations of iron in streams. However, because of the large variation of concentrations of total iron these differences were not statistically significant.

Iron in streams was generally in the suspended phase except for streams draining unreclaimed mined watersheds where the pH was less than 6.0 (fig. 7). Where pH was less than 6.0, iron in streams was transported primarily in the dissolved phase.

Manganese in streams was transported primarily in the dissolved phase, regardless of differences in pH or land use. Median dissolved-manganese concentrations accounted for about 76 percent of the total manganese in streams draining forested and agricultural watersheds and about 99 percent in streams draining mined watersheds. Median total- and dissolved-manganese concentrations for streams draining unreclaimed mined watersheds were significantly higher than median concentrations for streams draining reclaimed mined watersheds, which in turn were significantly higher than median concentrations for streams draining agricultural and forested watersheds.

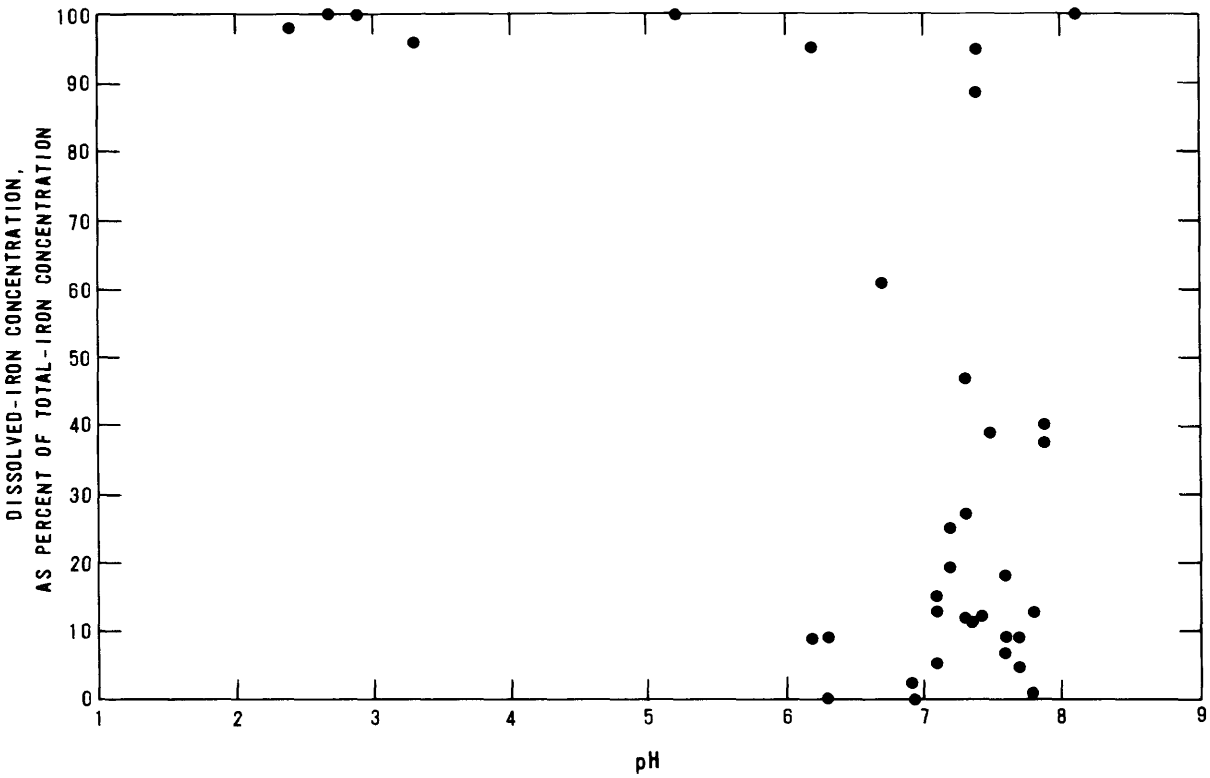


Figure 7.-- Relation of dissolved-iron concentration to pH of streams draining unreclaimed, mined watersheds, coal-mining region, southwestern Indiana, October 1979.

Median total-manganese concentrations of streams draining unreclaimed mined, reclaimed mined, and agricultural watersheds were 186, 21, and 3 times those of streams draining forested watersheds. Thus, manganese seem to be a sensitive indicator of the effect of land use on water quality.

Boron, Nickel, and Zinc

Median concentrations of boron, nickel, and zinc were significantly higher in streams draining mined watersheds than in streams draining forested and agricultural watersheds.

The content of boron in Indiana coals is greater than that in the Earth's crust. The average content of boron in 10 coal samples analyzed by Gluskoter and others (1977) was 142 μg/g, whereas the average in the Earth's crust is only 10 μg/g (Taylor, 1964). Only one water sample, from a stream draining an agricultural watershed, had a total-boron concentration (1600 μg/L) that exceeded 750 μg/L, the limit recommended by the EPA (1976) for irrigation. The reason for the high boron concentration in this agricultural watershed is unknown.

Median concentrations of nickel in streams draining reclaimed and unreclaimed mined watersheds were significantly higher than those in streams draining forested and agricultural watersheds. The median concentration of zinc in streams draining unreclaimed mined watersheds was significantly higher than those in streams draining reclaimed mined, agricultural, and forested watersheds.

The concentration and the distribution of metals in aquatic systems is influenced significantly by pH. In general, a decrease in pH results in an increase in the solubility of many metals and trace elements. Figure 8 shows that concentrations of total aluminum, total and dissolved iron, dissolved manganese, total nickel and total zinc increased significantly as pH decreased below 6.0 in streams draining unreclaimed mined areas. Spearman rank-correlation coefficients (Spearman, 1904) for these metals: total aluminum, -0.77; total and dissolved iron, -0.79; dissolved manganese, -0.77; total nickel, -0.76; and total zinc, -0.79 are significant at the 99-percent confidence level. These results are in agreement with analyses of streambed materials from unreclaimed mined areas in southwestern Indiana (Wilber and Boje, 1982) where concentrations of iron and several other metals were significantly higher on bed materials from streams with pH less than 6.0.

A few water samples from streams draining unreclaimed mined areas had concentrations of arsenic, cadmium, chromium, copper, and lead that were high relative to concentrations of these constituents in other streams. Most of the high concentrations were associated with streams having low pH (less than 3.5) and little or no alkalinity.

Median concentrations of arsenic, lead, and manganese in streams draining the Wisconsin glacial province were significantly lower than those in streams draining the Illinoian glacial province and unglaciated region. The median concentration of cadmium in streams draining the Wisconsin glacial province was significantly lower than that in streams draining the unglaciated region but was not significantly different from the median for streams draining the Illinoin glacial province. The practical significance of these differences is small because, except for manganese, these concentrations are less than limits recommended for water supplies, fresh water aquatic life and irrigation. However, they may be indicative of lower solubilities of metals and trace elements at the higher pH values of streams in the Wisconsin glacial province.

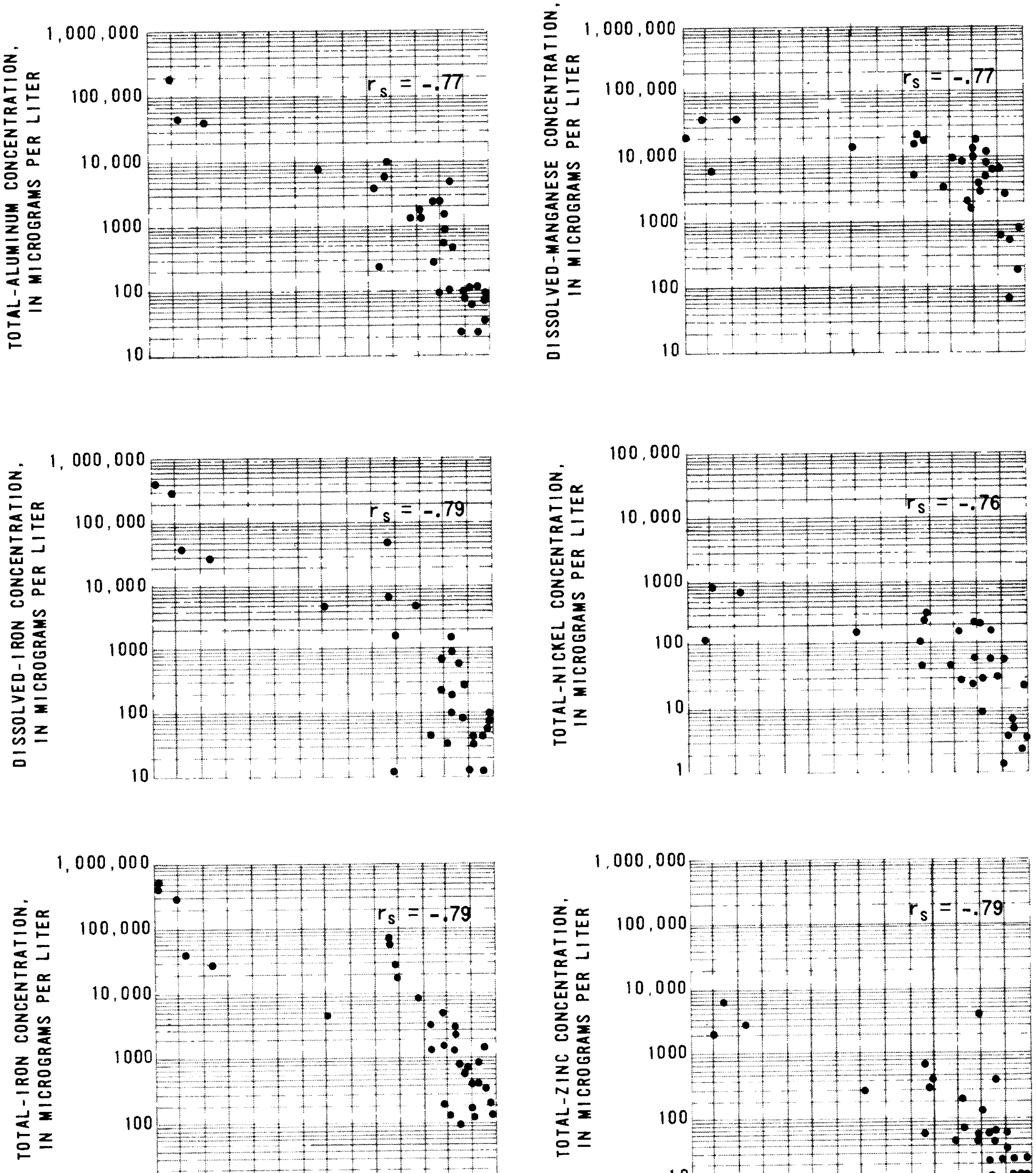


Figure 8.-- Relation of metal concentrations to pH of streams in unreclaimed mined areas, coal-mining region, southwestern Indiana, October 1979. r_s: Spearman rank correlation coefficient (Spearman, 1904)

Suspended Sediment

Suspended sediment may affect water quality in several ways: (1) Streams with high suspended-sediment concentrations are aesthetically unsatisfactory for swimming and other recreation; (2) suspended-sediment particles are effective in adsorbing and transporting some metals, pesticides, and nutrients in streams; (3) increases in sediment loads in streams can adversely affect its biological community; and (4) sediment may deplete the storage capacity of reservoirs, reduce channel-carrying capacities, and increase both the frequency and stage of flooding.

C.G. Crawford and L.J. Mansue (written commun., 1984) analyzed suspended-sediment data collected in Indiana from 1953 to 1980. They found wide ranges of sediment yields and concentrations but no regional trends in the coal-mining region. In this study, suspended-sediment concentrations did not seem to vary as a result of differences in surficial geology (table 8). Median suspended-sediment concentrations of samples from streams draining agricultural and mined watersheds were 1.5 and 5.4 times those of samples from streams draining forested watersheds. However, owing to large variation in concentrations, these differences were not statistically significant. The median suspended-sediment concentration of samples from streams draining reclaimed mined watersheds was lower but was not statistically different from the median concentration of samples from streams draining unreclaimed mined watersheds. High-suspended sediment concentrations in Indiana are generally associated with storms. Water samples were collected during near steady-state flows. Thus, the full effects of agriculture and mining on suspended-sediment concentrations cannot be evaluated from these data.

Most of the suspended sediment transported in streams in the coal-mining region of southwestern Indiana is silt and clay-sized particles (smaller than 0.062 mm). Rhoton and others (1979) found that fine clays were preferentially eroded over larger particles from the soil horizons in five small watersheds in Ohio. Vanoni (1975, p. 472) observed that the concentration of these materials in streams is more dependent on available source material than on stream hydraulics. The average amount of silt and clay-sized particles in samples from streams draining forested, agricultural, and mined watersheds in southwestern Indiana were 85, 89, and 96 percent. Thus, land disturbance resulting from agriculture and mining seems to increase the availability of source materials and, hence, the amount of silt and clay in streams. Because surface area for a given volume of particles increases as the size of the particles decreases, the potential sorption or transport capacity of suspended sediment in streams draining agricultural and mined watersheds seem to be greater than in streams draining forested watersheds.

Organic Carbon

Median concentrations of dissolved and suspended organic carbon in streams (table 9) were low relative to concentrations of inorganic constituents and did not seem to be affected by differences in land use. The degree to which organic matter influences the chemistry of surface water depends not so much on the absolute amount of organic matter as on the ratio of organic to inorganic matter, according to Beck and others (1974).

Table 8.--Statistical summary of concentrations of suspended sediment in streams at near steady-state flows representing major land uses and glacial provinces in the coal-mining region, southwestern Indiana, October 1979 through September 1980

Land use	Glacial province	Suspended sediment (mg/L)				
		N	Median	Minimum	Maximum	Interquartile[1] range
Forest	Wisconsin	16	36	0.5	179	57
	Unglaciated	6	26	4	51	41
	Total	22	33	.5	179	36
Agriculture	Wisconsin	14	50	10	204	63
	Illinoian	12	26	12	58	26
	Unglaciated	10	66	23	144	50
	Total	36	50	10	204	46
Reclaimed mining[2]	Wisconsin	9	111	37	200	90
	Illinoian	9	172	38	540	228
	Unglaciated	9	160	11	376	167
	Total	27	155	11	540	126
Unreclaimed mining[3]	Wisconsin	9	137	25	581	328
	Illinoian	16	171	11	624	167
	Unglaciated	17	195	46	1,375	297
	Total	42	193	11	1,375	247

[1]Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2]Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3]Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

Table 9.--Statistical summary of concentrations of dissolved and suspended organic carbon in streams at near steady-state flows representing major land uses and glacial provnces in the coal-mining region, southwestern Indiana, October 1979 through September 1980

Land use	Glacial province	Organic carbon, dissolved (mg/L)					Organic carbon, suspended (mg/L)				
		N	Median	Minimum	Maximum	Interquartile range[1]	N	Median	Minimum	Maximum	Interquartile range[1]
Forest	Wisconsin	15	3.2	1.4	4.9	1.9	15	0.2	<0.1	0.9	0.3
	Unglaciated	5	5.2	2.4	20	10	5	.4	.3	.6	.2
	Total	20	3.2	1.4	20	1.9	20	.3	<.1	.9	.2
Agriculture	Wisconsin	13	3.1	2.1	11	1.8	13	.5	<.1	2.1	.6
	Illinoian	10	3.9	2.5	8.6	3.1	10	.3	.2	.8	.1
	Unglaciated	7	5.2	4.2	7.7	3.1	7	.4	.1	3.0	.4
	Total	30	3.9	2.1	11	2.6	30	.4	<.1	3.0	.3
Reclaimed mining[2]	Wisconsin	8	5.2	2.3	9.7	4.0	8	.3	.2	1.2	.2
	Illinoian	7	4.1	2.9	11	6.8	7	.3	.2	.8	.2
	Unglaciated	7	4.4	3.7	8.2	1.1	7	.3	<.1	.5	.3
	Total	22	4.4	2.3	11	3.5	22	.3	<.1	1.2	.2
Unreclaimed mining[3]	Wisconsin	8	4.8	2.0	13	5.3	8	.3	.1	1.9	1.1
	Illinoian	13	4.8	2.1	14	3.7	12	.4	<.1	1.2	.6
	Unglaciated	14	4.0	1.9	7.6	3.2	14	.3	<.1	.4	.2
	Total	35	4.2	1.9	14	3.8	34	.3	<.1	1.9	.2

[1] Interquartile range: the difference between the 75th and 25th percentile values of the sample population.
[2] Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[3] Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.

SUMMARY AND CONCLUSIONS

An assessment of streams in the coal-mining region of southwestern Indiana was done to provide baseline hydrologic and water-quality information and to determine the significance of land use, surficial geology, and season on water quality in the region.

Data collected from October 1979 through September 1980 at near steady-state flows indicate that land use (forest, agriculture, and reclaimed and unreclaimed surface mining) is a statistically significant factor affecting several groups of water-quality constituents. Water-quality differences were greatest between streams in mined and unmined watersheds. Differences were least between streams in forested and agricultural watersheds and between streams in reclaimed and unreclaimed mined watersheds.

Streams in southwestern Indiana are generally well buffered. The median pH of streams draining reclaimed mined watersheds (7.8) was similar to those of streams draining forested (8.0) and agricultural watersheds (8.0). The ranges of pH, alkalinity, and acidity of streams draining unreclaimed mined watersheds were considerably greater than those of streams draining watersheds with other land use. The pH of several streams draining unreclaimed mined areas was less than 5.0, whereas the pH of all streams draining watersheds with other land use was greater than 6.3. The low pH, low alkalinity, and high acidity of several streams draining unreclaimed mined watersheds is principally due to continued oxidation of pyrite and marcasite left exposed by mining.

The principal water type of streams draining forested and agricultural watersheds was calcium bicarbonate, whereas the principal water types of streams draining mined watersheds were magnesium sulfate and magnesium calcium sulfate.

Concentrations of dissolved constituents in streams affected by coal mining were significantly higher than in streams unaffected by mining. The high concentrations of dissolved constituents were caused by the oxidation of pyrite and marcasite and subsequent dissolution of calcite and dolomite.

Median concentrations of nitrite plus nitrate were significantly higher in streams draining agricultural and reclaimed mined watersheds than in streams draining forested and unreclaimed mined watersheds. Median concentrations of total phosphate were significantly higher in streams draining agricultural watersheds than in streams draining forested and mined watersheds. Fertilizer applied to soils for plant growth is the most probable source of nitrogen and phosphorus to these streams.

Median concentrations of total boron from streams draining mined watersheds were significantly higher than for streams draining forested and agricultural watersheds. The content of boron in Indiana coals is greater than that of the Earth's crust.

The median concentration of total iron for streams draining unreclaimed mined watersheds was about four times that for streams draining agricultural and reclaimed mined watersheds. Reclamation techniques used since 1967 seem to have been effective at reducing concentrations of iron in streams. However, because of the large variation of concentrations of iron, these differences were not statistically significant.

The median concentration of manganesee in streams draining unreclaimed mined watersheds was significantly higher than that for streams draining reclaimed mined watersheds, which, was significantly greater than median concentrations for streams draining agricultural and forested watersheds.

Median concentrations of nickel and zinc were statistically higher in streams draining mined watersheds than in streams draining forested and agricultural watersheds. Concentrations of aluminum, iron, manganese, nickel, and zinc in streams draining unreclaimed mined watersheds increased significantly as pH decreased below 6.0. Spearman rank correlation coefficients for these metals ranged from -0.76 to -0.79 and were statistically significant at the 99-percent confidence level. The high concentrations of metals in water and the low pH result from the oxidation of the sulfide in pyrite to sulfate, which releases dissolved ferrous iron, other metals, and acidity into the water.

Median concentrations of suspended sediment.of samples from agricultural and mined watersheds were 1.5 and 5.4 times those of samples from streams draining forested watersheds. Median concentrations of suspended sediment from streams draining reclaimed mined and agricultural watersheds were lower but not statistically different, from concentrations from streams draining unreclaimed mined watersheds. Suspended sediment in streams was composed primarily of silt- and clay-sized particles. The average percentage of silt and clay-sized particles in samples from forested, agricultural, and mined watersheds were 85, 89, and 96 percent. Thus, the percentage of silt and clay-sized particles in streams seems to increase as the intensity of land disturbance in the watershed increases.

Median concentrations of dissolved and suspended organic carbon in streams were low relative to concentrations of inorganic constituents and did not seem to be affected by differences in land use.

The effect of glacial province (surficial geology) on water quality of streams was evident for pH, and concentrations of alkalinity, calcium, and magnesium in forested and agricultural watersheds. In general, pH and the concentrations of these constituents were significantly higher in streams in the Wisconsin glacial province than in streams in the Illinoian glacial province and the unglaciated region. These higher values suggest that there is greater dissolution of carbonate minerals in the Wisconsin glacial province than the other regions. Median concentrations of arsenic, lead, and manganese in streams draining the Wisconsin glacial province were significantly lower than in streams draining the Illinoian and unglaciated province. The median concentration of cadmium in streams draining the Wisconsin glacial province was lower than that in streams draining the unglaciated region. These differences may have been due to lower solubilities of metals and trace elements at the higher pH values in streams in the Wisconsin glacial province.

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