RECONNAISSANCE FOR DETERMINING EFFECTS OF LAND USE AND SURFICIAL GEOLOGY ON CONCENTRATIONS OF SELECTED ELEMENTS ON STREAMBED MATERIALS FROM THE COAL-MINING REGION, SOUTHWESTERN INDIANA, OCTOBER 1979 TO MARCH 1980

By William G. Wilber and Rita R. Boje

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 82-4013

November 1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
6023 Guion Road, Suite 201
Indianapolis, Indiana 46254

Copies of this report
can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Lakewood, Colorado 80225
(Telephone: [303] 234-5888)

CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING THE INCH-POUND UNITS IN THIS REPORT TO THE INTERNATIONAL SYSTEM OF SI UNITS

Multiply inch-pound units	By	To obtain SI units
acre	0.0040	square kilometer (km^2)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square mile (mi^2)	2.590	square kilometer (km^2)
ton (short)	0.907	megagram (Mg)
micromho per centimeter (μmho/cm)	1.0	microsiemens per centimeter (μS/cm)

DATUM

National Geodetic Vertical Datum of 1929 (NGVD) is a geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada. It was formerly called "Sea Level Datum of 1929" or "mean sea level" in this series of reports. Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, it does not necessarily represent local mean sea level at any particular place.

ABBREVIATIONS AND SYMBOLS

Abbreviation	Description
ANOV	analysis of variance
Br	branch
°C	degree Celsius
Cr	creek
C.V.	coefficient of variation
e	base of the natural logarithm, 2.71828
Eh	oxidation-reduction potential
Fk	fork
ft	foot
ft/mi	foot per mile
g/kg	gram per kilogram
ln	natural logarithm, base e
Max	maximum
μg/g	microgram per gram
μg/L	microgram per liter
mg/L	milligram per liter
mi	mile
mm	millimeter
Min	minimum
Mn^{+2}	divalent manganese ion
N.	north
N	number of observations
NGVD of 1929	National Geodetic Vertical Datum of 1929
nr	near
n_i	individual observation
pH	logarithm of the reciprocal of the hydrogen ion activity, in moles per liter
R	river
S.	south
trib	tributary
W.	west
$\bar{X}_A$	arithmetic average
$\bar{X}_G$	geometric average

RECONNAISSANCE FOR DETERMINING EFFECTS OF LAND USE AND SURFICIAL GEOLOGY ON CONCENTRATIONS OF SELECTED ELEMENTS ON STREAMBED MATERIALS FROM THE COAL-MINING REGION, SOUTHWESTERN INDIANA, OCTOBER 1979 TO MARCH 1980

By William G. Wilber and Rita R. Boje

ABSTRACT

Streambed materials were collected from 69 sampling sites in areas of predominantly forested, agricultural, and reclaimed and unreclaimed mined land in the glaciated and unglaciated parts of southwestern Indiana to determine whether concentrations of sorbed metals and other trace elements were affected by land use and surficial geology.

Streambed materials smaller than 0.062 millimeter were collected in October 1979 and analyzed for sorbed and acid-soluble metals including aluminum, cadmium, chromium, copper, cobalt, iron, lead, manganese, mercury, nickel and zinc and several nonmetals, total arsenic, boron, and selenium.

Analysis of variance indicated that differences in land use accounted for 10 percent or more of the variation in aluminum, arsenic, cobalt, iron, nickel, selenium, and zinc concentrations on streambed materials. Differences in glacial province (surficial geology) did not significantly affect the concentrations of metals and other trace elements on streambed materials. Concentrations of aluminum, cobalt, iron, nickel, selenium, and zinc on the less than 0.062-millimeter fraction of streambed materials from mined watersheds were significantly greater than the concentrations of these elements on streambed materials from agricultural and forested watersheds. The greater concentrations of these elements are due to (1) their concentrations in mine drainage and their subsequent adsorption and (or) coprecipitation with the oxides and hydroxides of aluminum and iron and (2) their concentrations in coal and pyritic material in streambed materials.

Concentrations of aluminum and iron on streambed materials from reclaimed, mined watersheds were significantly less than the concentrations of these metals on streambed materials from unreclaimed, mined watersheds.

INTRODUCTION

The effects of coal mining and reclamation on the chemical quality of surface water in much of the continental United States are well documented (Hoehn and Sizemore, 1977; King and others, 1974). Acid mine drainage in old mining areas results from the oxidation of pyrite and marcasite left on the surface after the coal has been removed. In Indiana these areas were mined before passage of the Indiana Surface Mine Act of 1967 (Indiana Code 13-46), which mandated that new spoil piles be graded and that a cover crop be established. Although acid mine drainage has been reduced in some newer mining operations, acid production from the pre-1967 mining continues to be a water-quality problem.

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. Higher concentrations of most major dissolved and suspended constituents, including iron, aluminum, and some trace metals, have been detected in streams from both old and new mining areas than in unmined areas (Dyer and Curtis, 1977).

Some concentrations of metals are toxic to aquatic organisms. Metals are nondegradable and persist in the environment for extended periods of time. In addition, dissolved metals may precipitate out of solutions with neutral pH and some alkalinity and may be adsorbed on clay particles or bound by the hydrous oxides of iron and manganese. As a result, metals are concentrated in the solid phases of aquatic systems. Consequently, even though the water may contain only small quantities of these constituents, the suspended sediment and especially the benthic or streambed materials may contain considerable quantities of metals.

Because metals are nondegradable, they may undergo biological magnification in the food chain and reach concentrations in the upper trophic levels that are several orders of magnitude greater than concentrations in water (Harding and Whitton, 1981).

Before this study, few data were available on the concentrations of metals in the water and on streambed materials in the coal-mining region of southwestern Indiana. The need for these data has become critical since the passage of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Section 507 (b)(11) of the Act requires that extensive information about the probable hydrologic consequences of mining and reclamation be included in permit applications so that the regulatory authority can determine the probable cumulative impact of mining on the area. Hydrologic and water-quality information on the general area surrounding proposed mining sites is necessary for this determination. To help meet the goals of the Act, this report presents information on the concentration and the distribution of metals and some nonmetals on streambed materials from southwestern Indiana.

The objectives of the streambed-materials reconnaissance were to: (1) provide baseline concentrations of selected elements sorbed on streambed materials and (2) determine the effect of land use and surficial geology on the concentration of selected elements on streambed materials from southwestern Indiana.

POSSIBLE SOURCES OF METALS AND OTHER ELEMENTS

Metals and other elements may enter receiving waters from a variety of sources. Rocks and soils directly exposed to surface water and ground water are usually the largest natural sources. Dead and decomposing vegetation and animal matter also contribute small quantities of metals and other elements to the environment.

High concentrations of some metals have been observed in dry and wet atmospheric precipitation (Lazrus and others, 1970; Morrow and Brief, 1971). Most of these metals were associated with the combustion of fossil fuels and processing of metals (Chow and Earl, 1970; Buchauer, 1973).

Urban runoff has been shown to contain significant concentrations of lead, zinc, copper, and other metals (Wilber and Hunter, 1975). The origin of these metals was attributed to precipitation, automotive exhaust, and other activities in the watershed.

Mining may also contribute metals to receiving streams. In southwestern Indiana, most of the mining is for coal, but some sand and gravel, gypsum, clay, and shale are also mined. No commercially significant metal deposits have been discovered there. The consolidated sedimentary rocks in Indiana do not contain commercially minable quantities of metals because the environmental conditions needed for such mineralization have not been present during geologic time. Lead, in the mineral galena, copper, gold, and silver have been found in the unconsolidated Pleistocene materials, especially in the outwash sand and gravel in front of moraines along glacial sluiceways (Wier and Patton, 1966, p. 151).

Other man-induced sources of metals and other elements in the environment include domestic wastewater; the industrial processes metal plating and oil refining; and the manufacturing of paints, biocides, and fertilizers.

DESCRIPTION OF STUDY AREA

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

The topography and the geology 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 study area 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--Tipton Till Plain, Wabash Lowland, and Crawford Upland (Mallot, 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 in the north part of the study area. The major soils in the Tipton Till Plain are derived from till and outwash of Wisconsin age. Soils of the Tipton Till Plain are underlain by loam and silty-clay loam of early and late Wisconsin age.

The Wabash Lowland, the largest physiographic unit in southern Indiana, is south of the Tipton Till Plain. This region is described by Schneider (1966, p. 48) as a broad, lowland area having an average elevation of about 500 ft above the NGVD of 1929. The predominant unconsolidated deposits are Illinoian till and, in places, thick lake beds, outwash, and alluvium.

The Crawford Upland unit is south of the Tipton Till Plain and east of the Wabash Lowland physiographic units. This deeply dissected upland area has local relief of 300 to 350 ft (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. The bedrock

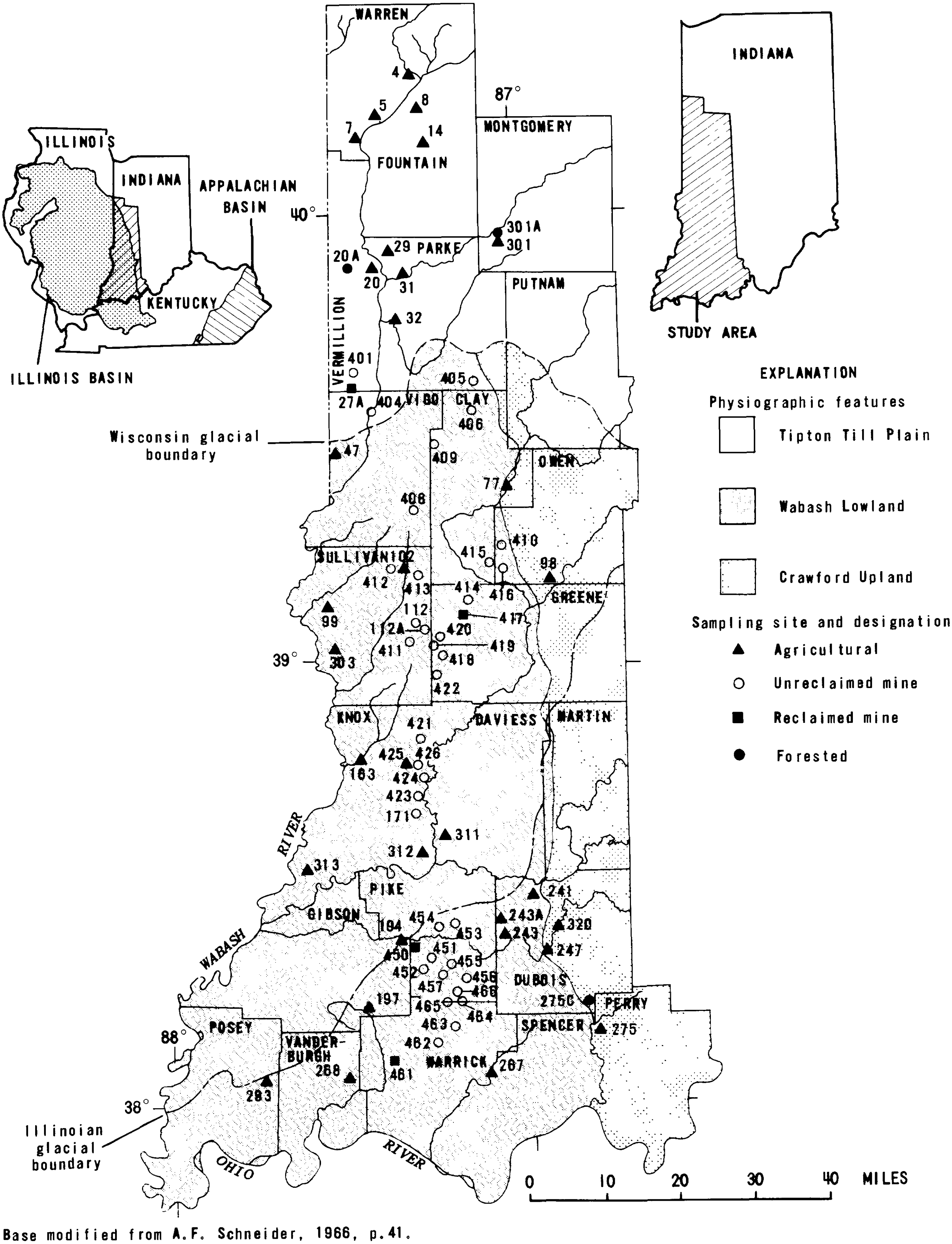

Figure 1.-- Locations of glacial provinces, physiographic units, and streambed sampling sites in the coal-mining region, southwestern Indiana.

underlying the Crawford Uplands consists of alternating layers of sandstone, shale, and limestone of the Chesterian Series (Mississippian). These rocks are overlain by resistant sandstone and softer rock of the Mansfield Formation (Pennsylvanian).

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 deposits that dip generally southwest into the Illinois Basin at an average slope of 25 ft/mi (Powell, 1972, p. 3).

Land Use

Land use in the 23 counties making up the study area is 62.4 percent agricultural, 29 percent forested, 2.5 percent residential, 0.5 percent commercial and industrial, 1.3 percent recreational and open, 1.2 percent wetlands and water, 1.1 percent surface mining and unreclaimed derelict lands, and 2.0 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).

Coal Mining in Indiana

Most of the coal mining in Indiana is in six counties: Vigo, Sullivan, Warrick, Pike, Greene, and Clay (fig. 1). 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 have been disturbed by surface mining, either directly by coal 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 was mined in Indiana in 1977 (Indiana Bureau of Mines and Mining, 1978), and the rate of removal is expected to increase.

WATER QUALITY OF STREAMS

A brief discussion of the water quality of streams in southwestern Indiana is appropriate because of the relation between the quality of water and the physical, chemical, and biological reactions that affect metals and some other elements on streambed materials. A more detailed assessment of the water quality of streams in southwestern Indiana for samples collected in May and October 1979 was presented by Wilber and others (1981).

Average concentrations of water-quality constituents in streams draining forested, agricultural, reclaimed, mined, and unreclaimed, mined watersheds are presented in table 1. Differences in average concentrations of specific constituents were greatest between streams draining mined and unmined watersheds. Differences were smaller between streams draining forested and agricultural watersheds and between streams draining reclaimed mined and unreclaimed mined watersheds.

One of the most important water-quality properties affecting the distribution and transport of metals in aqueous systems is pH. For example, in streams where acid mine drainage is neutralized, iron and manganese may precipitate from solution. As the pH of the stream increases, the rates of oxidation of reduced forms of iron and manganese increase. Lee (1975, p. 141) showed that the rate of oxidation of these metals increases by a factor of 100 for each unit increase in pH. The oxidized forms of iron and manganese are much less soluble than the reduced forms, and, thus, as the pH increases, these metals precipitate from solution. Changes in pH may also affect the sorption capacity of streambed materials. Morgan and Stumm (1964) showed that the sorption capacity of freshly precipitated manganese dioxide increases as pH increases.

The median pH of streams from most mined watersheds was not significantly different from the median pH of streams from forested and agricultural watersheds. The pH of several streams in watersheds having unreclaimed, mined land was less than 4.0, whereas the pH of streams in all other watersheds was greater than 6.2. The acidity of all samples from watersheds with forested, agricultural, and reclaimed, mined land use was zero. The acidity of approximately 20 percent of the samples from watersheds with unreclaimed, mined land use was greater than zero.

The average dissolved-solids concentrations of streams in agricultural and mined watersheds were 1.4 and 10 times the average concentration of streams in forested watersheds, respectively. The average dissolved-solids concentration of streams in reclaimed, mined watersheds was 17 percent less than the average concentration of streams in unreclaimed, mined watersheds.

Average sulfate concentrations were also affected by land use. The difference in average sulfate concentration was greatest between streams in mined and unmined watersheds.

Table 1.--Statistical summary of water-quality analyses of streams representing different land uses in the coal-mining region, southwestern Indiana, May and October 1979

[Source of data, Wilber and others, 1981]

		Land use			
		Forest	Agriculture	Reclaimed mining[1]	Unreclaimed mining[2]
	Number of observations	3	60	6	69
	Median pH	7.2	7.8	7.6	7.3
Geometric average[3]	Acidity as $CaCO_3$ (mg/L)	0	0	0	150
Geometric average[3]	Alkalinity as $CaCO_3$ (mg/L)	210	180	250	140
Geometric average[3]	Dissolved solids, residue at 180° C (mg/L)	206	296	1,750	2,100
Geometric average[3]	Sulfate, dissolved (mg/L)	38	47	910	1,200
Geometric average[3]	Aluminum, total (µg/L)	18	150	100	610
Geometric average[3]	Arsenic, total (µg/L)	1	2	1	1
Geometric average[3]	Boron, total (µg/L)	40	40	140	120
Geometric average[3]	Cadmium, total (µg/L)	<1	<1	<1	<1
Geometric average[3]	Chromium, total (µg/L)	20	20	20	20
Geometric average[3]	Copper, total (µg/L)	1	2	2	4
Geometric average[3]	Iron, total (µg/L)	80	590	370	2,600
Geometric average[3]	Iron, dissolved (µg/L)	30	40	70	580
Geometric average[3]	Lead, total (µg/L)	<1	2	1	2
Geometric average[3]	Manganese, total (µg/L)	40	120	510	3,000
Geometric average[3]	Manganese, dissolved (µg/L)	30	80	490	2,800
Geometric average[3]	Nickel, total (µg/L)	1	2	7	36
Geometric average[3]	Selenium, total (µg/L)	<1	<1	<1	<1
Geometric average[3]	Zinc, total (µg/L)	10	10	10	100

[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.

[3]Geometric average $(X_G) = (n_1 \times n_2 \times \ldots n_j)^{1/\underline{N}}$,

where

$\underline{N}$ is the number of observations, and

n_1, n_2 and n_j are individual observations.

Average concentrations of aluminum, copper, iron, manganese, nickel, and zinc in streams in unreclaimed, mined watersheds were significantly greater than in streams in reclaimed, mined, agricultural, and forested watersheds. Iron in stream samples was primarily in the suspended particulate phase, whereas manganese was primarily in the dissolved phase, regardless of land use. Average concentrations of boron in streams in reclaimed, and unreclaimed, mined watersheds were significantly greater than in streams in agricultural and forested watersheds.

METHODOLOGY

Sampling Medium

Streambed materials are a good sampling medium for an areawide assessment of metals and some other elements in aquatic systems. Concentrations of many of these elements in water are generally low. Additionally, nonpoint-source contributions of metals and some other elements may be intermittent or storm related, and, as a result, the constituents may not be detected in single or periodic water samples. Because many metals and some elements strongly associate with particulate material, streambed materials can accumulate these constituents during periods of low velocity, when the streambed is not being scoured. During these periods, the streambed becomes a depository for incoming sediment. This sediment, as well as the streambed materials already in place, can accumulate dissolved metals and other elements from the stream. Thus, analyses of streambed materials provide information on the distribution of these constituents over an extended period.

Field Reconnaissance

A field reconnaissance of 293 sites was done in March 1979 to provide data that would describe the range in the types of water quality and to improve knowledge of land use, and surficial geology. Most of the sites were on first- or second-order streams identified on topographic maps.

Field measurements during the reconnaissance included pH, specific conductance, water temperature, dissolved oxygen, 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. Data collected during the reconnaissance are reported in Renn and others (1980).

Selection of Sampling Sites

Data collected and observations made during the field reconnaissance were used to select 84 of the 293 reconnaissance sites for sampling during October 1979. Sixty-nine of the 84 sites are in watersheds where land use (forest, agriculture, and unreclaimed mining, and reclaimed mining) is predominantly homogeneous. Data from these homogeneous sites were used in statistical analyses.

The distinction between reclaimed and unreclaimed, mined watersheds in this study is the difference between surface-mine-reclamation techniques used before and after passage of Indiana's 1967 Surface Mine Act. The Act requires grading of all slopes affected by surface mining of coal, clay, and shale to a maximum of 33 percent or less, depending on land-use capability. In addition to grading, other reclamation may include covering pyritic material with nonacidic material and establishing a cover crop of grasses. Unreclaimed, mined watersheds are areas that were mined before passage of the Act. In these areas, slope, exposure of pyritic material, and establishment of vegetal cover are variable.

Only three completely forested watersheds were found, and only four reclaimed, mined watersheds were accessible. Sampling sites were selected in the glaciated (Wisconsin and Illinoian) region and the unglaciated parts of the study area. Locations and descriptions of the sites sampled are presented in table 2 and in figure 1.

Collection and Analysis of Samples

The concentration of metals on streambed materials has been shown to be strongly dependent on the particle-size distribution of the sample (Rickert and others, 1977; Wilber and Hunter, 1979). In general, the concentration of metals on streambed materials increases as particle size decreases.

To determine the effect of land use and surficial geology on the concentration of metals and other elements on streambed materials, the authors attempted to minimize the effect of differences in the particle-size distribution. This action is especially important in determining the effect of mining on the concentraton of these elements on streambed materials. Streambed materials from mined areas may contain more fine particles than those from unmined areas because of greater erosion and sedimentation in the mined areas. As a result, the concentrations of metals on the streambed materials may be higher than those from unmined areas because of the particle-size distribution rather than some chemical reaction.

Fine-grained streambed materials were collected from each sampling site during stable low flows in October 1979. After all samples were oven-dried at 105° C, they were sieved through a 0.062-mm stainless-steel sieve to eliminate particles larger than silt size. The <0.062-mm fraction, consisting of silt- and clay-sized material, was saved for analysis. Concentrations of metals (aluminum, cadmium, chromium, copper, cobalt, iron, lead, manganese, mercury, nickel, and zinc) and nonmetals (arsenic, boron, and selenium) on streambed materials were determined at the Geological Survey Laboratory in Doraville, Ga. The preceding 14 elements were selected for analysis because (1) they are widespread by-products of man's activities and are potentially toxic to aquatic organisms and (or) man; and (2) iron, manganese, and aluminum form hydrous oxides that play an important role in the control of metals on streambed materials (Jenne, 1968).

The digestion procedure used in the analysis of streambed materials is described in Skougstad and others (1979, p. 19). This procedure is designed to ensure dissolution of all sorbed metals and other minor elements as well as all readily acid-soluble components of the streambed materials without appreciably attacking the mineral structure of the sediment (Malo, 1977).

Ten streambed samples were collected for analysis of coal fines in March 1980.

Statistical Analysis

Analysis of variance (ANOV) was used to determine the significance of several factors on the concentration of metals and other elements on streambed materials in southwestern Indiana. The SAS general-linear models procedure for unbalanced ANOV (Barr and others, 1979, p. 237) was used in this analysis. The main factors tested in the model were land use (fixed effect) and glacial province (fixed effect). The interaction between land use and glacial province was also included in the model. Sampling sites (random effect) were nested within combinations of land use and glacial province. The mean square of this nested term was used to test the significance of land use, glacial province, and the interaction of these two factors on the concentration of the 14 elements on streambed materials. 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 that have empty cells. For example, the cell "forest x Illinoian" is considered to be empty because no homogeneous forested sites were found in the Illinoian region.

For the valid application of parametric analysis of variance and related procedures, certain basic assumptions must be satisfied. First, the data for each group must have been obtained randomly from a normally distributed population. Second, variances of the sampled populations must be equal. Third, the effects of the factor levels must be additive.

Several statisticians have shown that valid conclusions can still be made from analysis of variance, even if the data deviate somewhat from the requirements of normality, equality of variance, and additivity (Box, 1954; Box and Anderson, 1955; and Tiku, 1971). However, where these assumptions are not met, the data are frequently "corrected" by transforming the data from their original form (X values) to a different form (X'values).

Several statistical procedures were used to determine whether the data met the requirements for use in analysis of variance. The SAS procedure univariate (Barr and others, 1979, p. 427) was used to calculate several descriptive statistics (mean, median, minimum, maximum, variance, coefficient of variation, and the Kolmogorov-Smirnov D statistic). The Kolmogorov-Smirnov D statistic was used to test the hypothesis that the data are a random sample from a normally distributed population. Residuals were examined (Draper and Smith, 1966, p. 86) to determine if the variances for different land uses and glacial provinces were similar. These procedures were applied to both untransformed and natural-log transformed data. The natural-log transformation was done by the following equation:

$$X' = \ln (X+1) \qquad (1)$$

where
- X' is the transformed value,
- X the untransformed value, and
- ln the natural logorithm, base e.

The number "1" was added to all values in the transformation because the natural log of zero cannot be computed. In some instances, variations of metal concentrations for different land uses were proportional to the corresponding mean concentrations. According to Zar (1974, p. 184), the natural-log transformation is particularly applicable for this situation. The data (transformed or untransformed) that best met the required assumptions were used in the analysis of variance.

Analysis of variance was used to determine which factors (for example, land use) in the model were significant.

Duncan's multiple-range test (Duncan, 1955) was used to identify significantly different means within a given factor (for example, agricultural compared with unreclaimed, mined lands). This procedure is more sensitive to differences between means than some other multiple-range tests. However, the possibility of declaring means to be significantly different, when in fact there is no difference, is also increased.

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

RESULTS AND DISCUSSION

Concentration of Metals and Other Elements on Streambed Materials

Statistical summaries of concentrations of the metals and other elements on streambed materials for each land use and combination of land use and glacial province are presented in table 3. Arithmetic averages are reported for data that are assumed to be normally distributed, and geometric averages are reported for data that are assumed not to be normally distributed.

Of the 11 metals and 3 nonmetals studied, 98 percent of the total concentration of these constituents is from iron (72 percent), aluminum (21 percent), and manganese (5 percent). This is to be expected because iron, aluminum, and manganese compose approximately 99 percent of the metals in the Earth's crust (table 4). The average concentrations of aluminum and iron on streambed materials and those in the Earth's crust differ by several orders of magnitude, probably because of differences in the analytical procedures used rather than in environmental factors. The concentration of metals on streambed materials only include metals that were sorbed or readily soluble in dilute acid (Skougstad and others, 1979, p. 19), whereas the average concentrations of metals in the Earth's crust probably include metals incorporated into the crystal-lattice structure.

Zinc represents about 1 percent of the total concentration of metals and nonmetals studied. Other elements individually represent less than 0.2 percent of the total concentration.

The concentration of some metals and nonmetals on streambed materials were highest at station 77 on Jordan Creek in an agricultural watershed (arsenic, 11 µg/g; boron, 80 µg/g; chromium, 340 µg/g; cobalt, 290 µg/g; copper, 430 µg/g; nickel, 280 µg/g; and zinc, 570 µg/g). These concentrations are anomalously high compared with concentrations of the constituents on streambed materials from other agricultural watersheds. The reason for the anomalous concentrations is not known.

Variation of Metal and Other Element Concentrations on Streambed Materials

The concentrations of metals and nonmetals on streambed materials were variable. Arsenic, boron, mercury, and selenium had the highest coefficients of variation (table 3) because the concentrations of these constituents were near the detection limit and (or) they were detected in only a few of the

Table 4.--Concentrations of selected elements in the Earth's crust, in Indiana coals, and on streambed materials in the coal-mining region, southwestern Indiana

[Concentrations in micrograms per gram]

Element	Earth's crust[1]	Indiana coal[2]			<0.062-mm streambed materials October 1979			
		Min	Max	Arithmetic average	Forest	Agriculture	Reclaimed mining[3]	Unreclaimed mining[4]
Aluminum	823,000	71,000	172,000	110,000	[5]3,400	[5]4,400	[5]5,500	[5]6,100
Arsenic	1.8	2.3	34	9.7	<1	[5]1	[5]1	[5]1
Boron	10	110	180	142	[5]3	[5]7	[5]5	[5]3
Cadmium	.2	<.1	.7	---------	[5]10	[5]10	[5]10	[5]10
Chromium	100	7.0	30	17	[6]13	[6]16	[6]10	[6]15
Cobalt	25	3.0	22	7.3	[6]15	[6]18	[6]42	[6]32
Copper	55	9.5	30	15.5	[6]10	[6]14	[6]14	[6]15
Iron	563,000	100,000	260,000	210,000	[6]11,000	[6]10,000	[6]20,000	[6]35,000
Lead	12.5	.7	3.1	2.1	[5]23	[5]19	[5]18	[5]27
Manganese	950	11	80	45	[6]1,300	[6]620	[6]1,900	[6]1,000
Mercury	.08	---------	---------	---------	<.1	<.1	<.1	<.1
Nickel	75	7.6	68	21	[6]28	[6]23	[6]48	[6]32
Selenium	.05	.7	3.1	2.1	[6]1.8	[6].3	[6]2	[6]1.5
Zinc	70	10	100	51	[6]68	[6]68	[6]90	[6]130

[1]Arithmetic average (Taylor, 1964).
[2]Statistics determined from 10 coal samples from southwestern Indiana (Gluskoter and others, 1977).
[3]Reclaimed mining: areas mined after passage of Indiana's Surface Mine Act of 1967.
[4]Unreclaimed mining: areas mined before passage of Indiana's Surface Mine Act of 1967.
[5]Arithmetic average.
[6]Geometric average.

samples collected. Aluminum, iron, and manganese had the lowest cofficients of variation. These metals were detected in all the samples collected, and their concentrations were high relative to the other metals studied.

Estimates of the percentage variation in metal and nonmetal concentrations on streambed materials that can be attributed to land use, glacial province, and the interaction of these two factors are presented in table 5. These estimates were determined by dividing the partial sum of squares for each term in the analysis of variance by the corrected total sum of squares and multiplying by 100. Because of the potential effect of outliers on the results of the analysis of variance, the estimates of the percent variation in constituent concentrations were determined without the data for Jordan Creek collected in October 1979.

Table 5.--Variation of selected element concentrations attributed to land use, glacial province, and the interaction of land use and glacial province on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979

[All values expressed as percent of total variation]

Element	Land use[1]	Glacial province[1]	Interaction of land use and glacial province[1]
Aluminum	[2]17	3.9	5.6
Arsenic	11	2.6	5.8
Boron	1.4	3.4	9.6
Cadmium	0	0	0
Chromium	2.6	.4	2.3
Cobalt	[2]22	.7	4.6
Copper	1.7	2.2	1.7
Iron	[2]40	2.6	1.2
Lead	6.7	1.8	7.0
Manganese	8.1	2.9	5.8
Mercury	0	0	0
Nickel	[2]11	.4	2.2
Selenium	[2]19	1.8	5.9
Zinc	[2]18	1.7	4.3

[1]Values determined without October 1979 data for Jordan Creek (site 77).
[2]Statistically significant at the 95-percent confidence level or greater.

Metals Affected by Differences in Land Use

Land use was the only factor examined in the analysis of variance that explained a significant (statistical confidence level of at least 95 percent) part of the total variation in the concentration of metals and nonmetals on streambed materials. Ten percent or more of the total variation in aluminum, arsenic, cobalt, iron, nickel, selenium, and zinc concentrations on streambed materials was attributed to differences in land use.

Aluminum and iron.--Analysis of variance indicated that land use is a significant factor affecting the concentration of aluminum on streambed materials. Land use accounted for 17 percent of the variation in aluminum concentrations on streambed materials. The average aluminum concentration on streambed materials from unreclaimed mined watersheds was significantly greater (39 and 79 percent) than the average of samples from agricultural and forested watersheds, respectively. The average concentration of aluminum on streambed materials from reclaimed mined watersheds was not significantly different from the average concentration of aluminum on streambed-material samples representing other land use.

The effect of land use on the concentration of iron on streambed materials was similar to its effect on the concentration of aluminum. The concentration of iron on streambed materials from mined watersheds is significantly greater than the average for samples from forested and agricultural watersheds. The average iron concentration on the streambed materials from unreclaimed mined watersheds was 75 and 250 percent greater than the average on samples from reclaimed mined and agricultural watersheds, respectively. The average iron concentration on streambed materials from agricultural watersheds was not significantly different from the average iron concentration on streambed materials from forested watersheds.

The concentrations of aluminum and iron are probably greater on streambed materials from mined areas than from other areas because of precipitation and (or) sorption of these metals from the water column. The precipitation of iron and aluminum is not unexpected. In streams with near neutral pH and sufficient sulfate, iron and aluminum can form insoluble polymers with hydroxide and sulfate ions (Hem, 1970, p. 111-126).

The concentration of iron on streambed materials from unreclaimed mined areas was lowest in streams whose pH exceeded 6.0 (fig. 2). The Spearman rank-correlation coefficient (Spearman, 1904) for these data, -0.53, is statistically significant at the 99-percent confidence level. None of the other elements on streambed materials showed a significant correlation with pH. The high concentrations of iron on streambed materials and the low pH result from oxidation of the sulfide in pyrite to sulfate, which releases dissolved ferrous iron and acidity into the water. The dissolved ferrous iron is oxidized to ferric iron, which hydrolyzes to form an insoluble ferric hydroxide coating on the streambed.

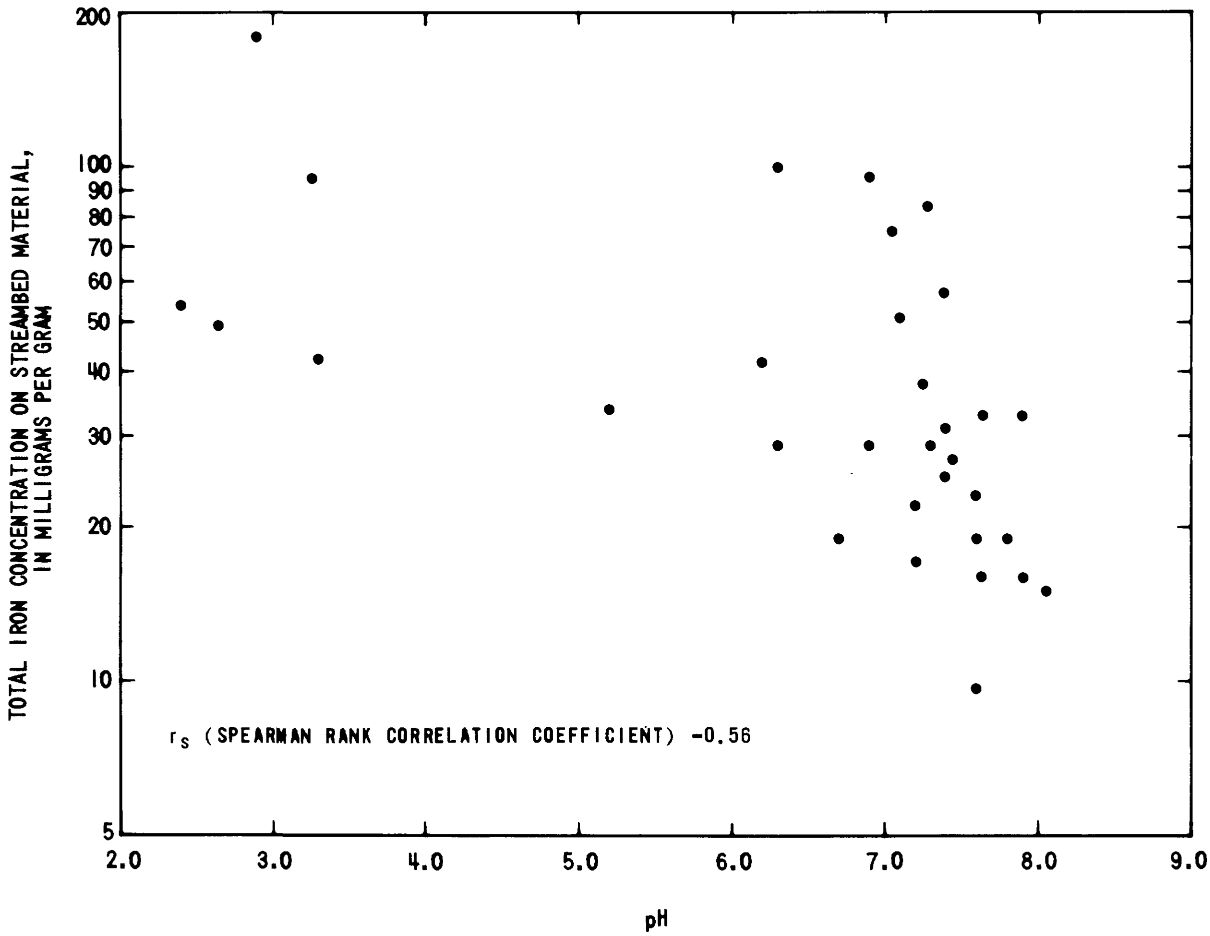

Figure 2.-- Relation of recoverable iron on streambed materials smaller than 0.062 mm to pH of streams in unreclaimed mined areas in the coal-mining region, southwestern Indiana, October 1979.

Cobalt, nickel, and zinc.--The concentrations of cobalt, nickel, and zinc on streambed materials also varied significantly with land use. The average concentrations of cobalt, nickel, and zinc on streambed materials from mined watersheds were 86, 85, and 43 percent greater, respectively, than the average concentrations of these metals on streambed materials from forested and agricultural watersheds. The greater concentrations of these metals on streambed materials from mined areas are probably due to adsorption and (or) coprecipitation by the oxides and hydroxides of iron and aluminum.

Metals Unaffected by Differences in Land Use

Analysis of variance indicated no significant differences between the average concentrations of cadmium, chromium, copper, lead, manganese, and mercury on streambed materials for different land uses. Except for manganese and copper, these results agree with those of water samples collected during the same sampling period. The observation that manganese and copper are not accumulating on streambed materials of mined watersheds suggests that they are being transported in the dissolved phase and are not being removed from solution to any appreciable extent by sorption or precipitation.

Manganese in surface water samples was primarily in the dissolved phase, regardless of land use. For a fixed Eh, manganese dioxide precipitates at higher pH than ferric oxide (Jenne, 1968, p. 350). Morgan (1967) observed that a pH greater than 8 is required for precipitation of manganese from Mn^{+2} solutions, but, as soon as some manganese hydroxide has precipitated, oxidation of Mn^{+2} to Mn^{+4} proceeds rapidly.

Nonmetals Enriched in Indiana Coals

Of the constituents studied, only the average concentrations of arsenic, boron, and selenium in Indiana coal are greater than the average concentration of these elements in the earth's crust (table 4). The concentration of coal fines in streambed materials was determined for 10 of the streams sampled in March 1980. These concentrations are presented in table 6. Although the data are variable, they indicate that the concentrations of coal fines in streambed materials from mined watersheds are higher than those in agricultural watersheds.

Arsenic.--The concentration of arsenic on most streambed-material samples was low. No arsenic was detected on streambed materials from the three streams draining forested watersheds. Average arsenic concentrations on streambed materials from unreclaimed and reclaimed, mined watersheds were not significantly different from the average arsenic concentration on streambed materials from agricultural watersheds.

Boron.--The results from the analysis of variance for determining the effect of land use on the concentration of boron on streambed materials are inconclusive. Boron was detected on only 27 percent of the streambed samples. Because of the large number of samples having no detectable boron (50), the analysis of variance indicated that land use does not signifcantly affect the boron concentration on streambed materials.

Table 6.--Concentrations of coal fines in streambed materials (2.0-0.062 mm) in the coal-mining region, southwestern Indiana, March 1980

Site	Site description	Land use	Coal fines[1] (g/kg)
32	Leatherwood Cr nr Midway	Agriculture	0.9
77	Jordan Cr nr Bowling Green	do.	5
27a	Unnamed trib to Gin Cr draining Universal Mine nr Universal	Reclaimed mining[2]	1
417	Lattas Cr nr Midland	do.	20
450	Unnamed trib to S. Fork Patoka R nr Oakland City	Unreclaimed mining[3]	160
112a	Mud Creek nr Dugger	do.	57
401	Unnamed trib to Brouilletts Cr nr Centenary	do.	73
415	Pond Cr nr Coal City	do.	2
456	Unnamed trib to Houchin ditch nr Stendal	do.	25
464	Unnamed trib to S. Fork Patoka R nr Scalesville	do.	120

[1]The part of a streambed material sample that can be separated by floating it on a bromoform-active solution with a specific gravity of 1.65.
[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.

Concentrations of boron in water samples from mined areas were significantly greater than in samples from forested and agricultural watersheds. The absence of boron on streambed materials suggests that it is being transported in the dissolved phase and is not being removed from solution by physical or chemical processes.

Selenium.--The chemistry of selenium is similar to that of sulfur (Hem, 1970, p. 207), but selenium is a much less common element. Only 64 percent of the streambed samples collected had selenium concentrations greater than 1 µg/g.

The average concentration of selenium on streambed materials from unreclaimed, mined watersheds was significantly greater than the average selenium concentration on streambed materials from agricultural watersheds. This difference may be due to the increased concentration of coal fines on streambed materials from unreclaimed, mined watersheds. Additional samples from forested and reclaimed, mined lands would be needed before differences in the average concentration of selenium from these land uses could be determined.

Future Studies

Other Sources of Variation

Differences in land use accounted for an average of only 10 percent of the total variation in concentrations for metals studied in the <0.062-mm fraction of streambed materials from southwestern Indiana. The concentration of iron on streambed materials from unreclaimed mined areas was lowest in streams whose pH exceeded 6.0. Although the effect of land use and pH are important, other factors may contribute to the variation of metal concentrations on streambed materials; for example, variations in parent material and type and amount of clay content (Malcolm and Kennedy, 1970); organic matter and sulfide contents (Toth and Ott, 1970); iron and manganese oxide contents (Jenne, 1968); and sampling and analytical variance. All or some of these potential sources of variation may contribute to the magnitude of the error term in the analysis of variance. Further study would be needed if the significance of these factors on the concentration of metals on streambed materials of southwestern Indiana is to be determined.

Biological Availability of Metals on Streambed Materials

The data collected indicate that several metals and nonmetals are accumulating on streambed materials in mined watersheds. However, the availability of these sediment-bound elements to aquatic organisms, the water column, and, possibly, man remains unknown. Luoma and Jenne (1976), in one of the few studies on the biological availability of metals, determined that the assimilation of solid forms of trace elements by a deposit-feeding clam, *Macoma balthica*, is very slow relative to solute metal uptake. If the biological availability of trace elements accumulating on streambed materials is to be determined, the following additional information will probably be needed: (1) the physiological and ecological characteristics of the organisms, (2) the chemical forms of dissolved metals in solution and in ingested solids, and (3) the chemical and physical characteristics of the water.

SUMMARY AND CONCLUSIONS

A reconnaissance of selected elements on streambed materials in southwestern Indiana was done in October 1979 to provide baseline information for future comparison and to determine whether the concentration of these elements varied between streams because of differences in land use and surficial geology. Streambed-material samples were collected from 69 sampling sites representing predominantly forested, agricultural, and reclaimed and unreclaimed, mined lands in the glaciated (Wisconsin and Illinoian) and unglaciated parts of southwestern Indiana.

Samples collected in October 1979 were separated into two fractions-- $\geq$0.062 mm and $<$0.062 mm to minimize the effect of differences in the particle-size distribution between samples on the concentration of metals and other elements. The $<$0.062-mm fraction was analyzed for concentrations of sorbed and acid-soluble aluminum, boron, cadmium, chromium, copper, cobalt, iron, lead, manganese, mercury, nickel, selenium, zinc, total arsenic, and total selenium.

Analysis of variance indicated that 10 percent or more of the total variation in aluminum, arsenic, cobalt, iron, nickel, selenium, and zinc concentrations on streambed materials is accounted for by differences in land use. Differences in surficial geology did not significantly affect the concentrations of metals and nonmetals on streambed materials. Concentrations of aluminum, cobalt, iron, nickel, selenium, and zinc on streambed materials in mined watersheds are significantly greater than the concentrations of these elements in agricultural and forested watersheds. The greater concentrations of elements in mined areas is probably due to adsorption and (or) coprecipitation of the elements with the oxides and hydroxides of aluminum and iron. Aluminum and iron concentrations on streambed materials draining reclaimed, mined watersheds were significantly less than those on streambed materials from unreclaimed, mined watersheds. However, additional data would be needed from streams draining reclaimed, mined watersheds to determine if any significant reduction in the concentration of other metals on streambed materials is caused by current reclamation practices.

The effects of variations in parent material, type and amount of clay content, organic matter and sulfide contents, and iron and manganese oxide contents on the concentrations of metals and other elements sorbed on streambed materials were not investigated. This information, as well as information on the availability of these materials to aquatic organisms, the water column, and man would be useful for future planning and management.

REFERENCES

Barr, A. J., Goodnight, J. H., Sall, J. P., Blair, W. H., Chilko, D. M., 1979, SAS User's Guide (1979 ed.): Raleigh, N.C., SAS Institute, Inc., 494 p.

Box, G. E. P., 1954, Some theorems on quadratic forms applied in the study of analysis of variance problems, I. Effect of inequality of variance in the one-way classification: Annals of Mathematical Statistics, v. 40, p. 290-302.

Box, G. E. P., and Anderson, S. L., 1955, Permutation theory in the derivation of robust criteria and the study of departures from assumption: Journal of the Royal Statistical Society, B17:1-34.

Buchauer, M. J., 1973, Contamination of soil and vegatation near a zinc smelter by zinc, cadmium, copper, and lead: Environmental Science and Technology, v. 7, no. 2, p. 131-135.

Chow, T. J., and Earl, S. L., 1970, Lead aerosols in the atmosphere, increasing concentrations: Science, v. 169, p. 157.

Draper, N. R., and Smith, Harry, 1966, Applied regression analysis: New York, John Wiley and Sons, Inc., 407 p.

Duncan, D. B., 1955, Multiple range and multiple F tests: Biometrics, v. 11, p. 1-42.

Dyer, K. L., and Curtis, W. R., 1977, Effects of strip mining on water quality in small streams in eastern Kentucky: U.S. Department of Agriculture, Forest Service Research Paper NE-372, 13 p.

Gluskoter, H. J., Ruch, R. R., Miller, W. G., Cahill, R. A., Dreher, G. B., and J. K. Kuhn, 1977, Trace elements in coal: Occurrence and distribution: Illinois Geological Survey, Circular 499, 154 p.

Harding, J. P. C., and Whitton, B. A., 1981, Accumulation of zinc, cadmium, and lead by field populations of Lemanea: Water Research, v. 15, p. 301-319.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hoehn, R. C., and Sizemore, D. R., 1977, Acid mine drainage (AMD) and its impact on a small Virginia stream: Water Resources Bulletin, v. 13, no. 1, p. 153-160.

Indiana Bureau of Mines and Mining, 1978, Annual Report of the Bureau of Mines and Mining: State of Indiana, 16 p.

Jenne, E. A., 1968, Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water: The significant role of hydrous Mn and Fe oxides, in Trace inorganics in water, Advances in Chemistry Series, no. 73: American Chemical Society, p. 337-387.

King, D. L., Simmler, J. J., Decker, C. S., and Ogg, C. W., 1974, Acid strip mine lake recovery: Journal Water Pollution Control Federation, v. 46, no. 10, p. 2301-2315.

Lazrus, A. L., Lorange, E., and Lodge, J. P., Jr., 1970, Lead and other metal ions in United States precipitation: Environmental Science and Technology, v. 4, no. 1, p. 55-58.

Lee, G. F., 1975, Role of hydrous metal oxides in the transport of heavy metals in the environment, in Krenkel, P. A., ed., Heavy metals in the aquatic environment: Oxford, Great Britain, Pergamon Press, p. 137-147.

Luoma, S. N., and Jenne, E. A., 1976, Factors affecting the availability of sediment-bound cadmium in the estuarine, deposit-feeding clam, Macoma balthica, in Cushing, C. E., ed., Radioecology, and energy resources, Fourth National Symposium on radioecology, Stroudsbury, Pa.: Dowden, Hutchinson, and Ross, Inc., p. 283-291.

Malcolm, R. L., and Kennedy, V. C., 1970, Variation of cation exchange capacity and rate with particle size in stream sediment: Journal Water Pollution Control Federation, v. 42, no. 5, p. R153-R160.

Malo, B. A., 1977, Partial extraction of metals from aquatic sediments: Environmental Science and Technology, v. 11, no. 3, p. 277-282.

Malott, C. A., 1922, The physiography of Indiana, in Handbook of Indiana geology: Indiana Department of Conservation, Division of Geology, 1,120 p.

Morgan, J. J., 1967, Chemical equilibrium and kinetic properties of manganese in natural waters, in Faust, S. J., and Hunter, J. V., eds., Principles and applications of water chemistry: New York, John Wiley and Sons, p. 561-624.

Morgan, J. J., and Stumm, Werner, 1964, Colloid-chemical properties of manganese dioxide: Journal Colloidal Science, v. 19, p. 347-369.

Morrow, N. L., and Brief, R. S., 1971, Elemental composition of suspended particulate matter in Metropolitan New York: Environmental Science and Technology, v. 5, no. 9, p. 786-789.

Powell, R. L., 1972, Coal strip-mined land in Indiana: Indiana Department of Natural Resources, 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.

Rickert, D. A., Kennedy, V. C., McKenzie, S. W., and Hines, W. G., 1977, A synoptic survey of trace metals in bottom sediments of the Willamette River, Oregon: U.S. Geological Survey Circular 715-F, 27 p.

Schneider, A. F., 1966, Physiography, in Lindsey, A. A., ed., Natural features of Indiana: Indiana Academy of Science and Indiana State Library, p. 40-56.

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

Spearman, C., 1904, The proof and measurement of association between two things: American Journal of Psychology, v. 15, p. 72-101.

Taylor, S. R., 1964, Abundance of chemical elements in the continental crust; a new table: Geochimica et Cosmochimica Acta, v. 28, p. 1273-1285.

Tiku, M. L., 1971, Power function of F-test under non-normal situations: Journal of the American Statistical Association, v. 66, p. 913-916.

Toth, S. J., and Ott, A. N., 1970, Characterization of bottom-sediments: Cation exchange capacity and exchangeable cation status: Environmental Science and Technology, v. 4, p. 935-939.

Wayne, W. J., 1966, Ice and land, in Lindsey, A. A., ed., Natural features of Indiana: Indiana Academy of Science and Indiana State Library, p. 21-39.

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

Wier, C. E., and Patton, J. B., 1966, Mineral resources, in Lindsey, S. S., ed., Natural features of Indiana: Indiana Academy of Science and Indiana State Library, p. 131-155.

Wilber, W. G., and Hunter, J. V., 1975, Contributions of metals resulting from stormwater runoff and precipitation in Lodi, New Jersey, in Whipple, William, Jr., Urbanization and water-quality control: Minneapolis, Minn., American Water Resources Association, p. 45-54.

______1979, The impact of urbanization on the distribution of heavy metals in bottom sediments of the Saddle River: Water Resources Bulletin, v. 15, no. 3, p. 790-800.

Wilber, W. G., Crawford, C. G., Ragone, S. E., Renn, D. E., and Wangsness, D. J., 1981, Preliminary analysis of the factors affecting water quality in the coal-mine region of southwestern Indiana, in Warner, R. E., and Clark, P. E., eds., Water Resources and Land-Use Management in Indiana: Indianapolis, Ind., Indiana Water Resources Association, p. 215-234.

Zar, J. H., 1974, Biostatistical analysis: Englewood Cliffs, N.J., Prentice-Hall, Inc., 620 p.

Tables 2-3

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
		Forested, Wisconsin Glacial Province		
20a	39°53'16" 87°28'10"	Vermillion	Unnamed trib to Little Vermillion R nr Cayuga.	Sand and gravel.
301a	39°56'44" 87°03'10"	Montgomery	Unnamed trib to Sugar Creek nr Deer Mill.	Do.
		Forested, Unglaciated Region		
275c	38°18'21" 86°47'51"	Dubois	Unnamed trib to Friday Br nr St. Meinrad.	Sand and gravel.
		Agricultural, Wisconsin Glacial Province		
4	40°19'03" 87°17'26"	Warren	Big Pine Cr nr Williamsport.	Twenty percent clay, 30 percent sand, and 50 percent gravel.
5	40°12'42" 87°23'39"	Warren	Redwood Cr nr Covington.	Gravel and some clay.
7	40°10'18" 87°26'27"	Warren	Opposum Run nr Covington.	Sand and gravel.
8	40°14'48" 87°16'28"	Fountain	Big Shawnee Cr nr Fountain.	--------------------
14	40°10'14" 87°15'41"	Fountain	Coal Cr at Stone Bluff.	--------------------
20	39°53'35" 87°25'41"	Vermillion	Little Vermillion R nr Newport.	Sand and gravel, and some coal fines.
29	39°54'29" 87°21'38"	Parke	Mill Cr nr Howard.	--------------------
31	39°52'56" 87°19'32"	Parke	Rush Cr nr West Union.	Sand and gravel and some cobbles.

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana--Continued

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
Agricultural, Wisconsin Glacial Province--Continued				
32	39°46'31" 87°19'45"	Parke	Leatherwood Cr nr Midway.	-------------------
301	39°56'48" 87°03'37"	Montgomery	Sugar Cr nr Alamo.	-------------------
Agricultural, Illinoian Glacial Province				
47	39°29'05" 87°31'59"	Vigo	Sugar Cr at State line.	-------------------
77	39°23'16" 87°00'58"	Clay	Jordan Cr nr Bowling Green.	Sand and gravel and some clay.
98	39°10'38" 86°54'04"	Owen	Fish Cr nr Farmers.	Sand and gravel.
99	39°07'14" 87°35'42"	Sullivan	Turman Cr nr Graysville.	Clay and sand.
102	39°12'54" 87°35'42"	Sullivan	Busseron Cr nr Hymera.	Sand and gravel.
163	38°46'24" 87°28'03"	Knox	Maria Cr nr Bruceville.	Clay and sand.
303	39°01'58" 87°32'22"	Sullivan	Turtle Cr nr Merom.	Sand.
311	38°36'23" 87°13'20"	Daviess	Veale Cr nr Cumback.	-------------------
312	38°34'13" 87°16'35"	Knox	Kessinger ditch nr Petersburg.	-------------------
313	38°36'41" 87°31'03"	Knox	Deshee R nr Decker.	Sand.
425	38°45'30" 87°18'19"	Knox	Indian Cr nr Johnston.	Clay; flock present.

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana--Continued

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
		Agricultural, Unglaciated Region		
197	38°12'37" 87°26'29"	Gibson	Pigeon Cr nr Buckskin.	Clay and sand in pools; sand and gravel in riffles.
241	38°28'52" 86°28'52"	Dubois	Mill Cr nr Jasper.	Sand and some clay.
243	38°24'00" 87°03'35"	Dubois	Little Flat Cr nr Otwell.	Clay and sand.
243a	38°25'20" 87°04'06"	Dubois	Little Flat Cr nr Otwell.	--------------------
247	38°21'19" 86°53'32"	Dubois	Straight R nr Huntingburg.	Sand.
267	38°03'38" 87°28'56"	Warrick	Little Pigeon Cr nr Tennyson.	Clay; leaf litter on streambed.
268	38°02'58" 87°28'56"	Vanderburgh	Blue Grass Cr nr Daylight.	Clay.
275	38°11'32" 86°46'19"	Perry	Anderson R nr Adyeville.	Clay and sand.
293	38°04'58" 87°46'10"	Posey	Big Cr nr Wadesville.	Clay, some sand.
320	38°24'49" 86°52'36"	Dubois	Patoka R nr Jasper.	Sand.
		Reclaimed mining[1], Wisconsin Glacial Province		
27a	39°36'49" 87°27'52"	Vermillion	Unnamed trib to Gin Cr draining Universal Mine nr Universal.	Clay, sand, and gravel.
		Reclaimed mining[1], Illinoian Glacial Province		
417	39°06'54" 87°09'02"	Greene	Lattas Cr nr Midland.	One percent clay, 49 percent sand, and 50 percent gravel.

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana--Continued

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
Reclaimed mining[1], Unglaciated Region				
450	38°20'28" 87°17'22"	Pike	Unnamed trib to S. Fk Patoka R nr Oakland City.	--------------------
461	38°05'30" 87°21'55"	Warrick	Unnamed trib to Squaw Cr nr Boonville.	Clay, sand, and gravel.
Unreclaimed mining[2], Wisconsin Glacial Province				
401	39°38'45" 87°28'47"	Vermillion	Unnamed trib to Brouilletts Cr nr Centenary.	Fifteen percent clay, 50 percent sand, and 35 percent gravel.
404	39°32'40" 87°25'33"	Vigo	Coal Cr nr Tecumseh.	Sand with some coal fines; iron precipitate on streambed.
Unreclaimed mining[2], Illinoian Glacial Province				
112a	39°05'56" 87°15'45"	Sullivan	Mud Cr nr Dugger.	One percent clay, 96 percent sand, and 3 percent gravel.
171	38°40'00" 87°96'25"	Knox	Nimnicht Cr nr Wheatland.	Clay and sand; some coal fines.
194	38°22'44" 87°20'12"	Gibson	S. Fk Patoka River nr Glezen.	Clay, coal fines, and iron precipate.
405	39°36'52" 87°06'25"	Parke	N. Br Otter Cr nr Carbon.	-------------------
406	39°33'07" 87°06'28"	Clay	Benwood Run nr Brazil.	Clay.
408	39°19'08" 87°16'37"	Vigo	Splunge Cr nr Blackhawk.	Sand and gravel.
409	39°29'33" 87°14'02"	Clay	Lost Cr nr Staunton.	Sand; some clay and gravel.

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana--Continued

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
Unreclaimed mining[2], Illinoian Glacial Province--Continued				
410	39°15'24" 87°02'43"	Owen	Lenning Branch nr Clay City.	--------------------
411	39°04'13" 87°17'49"	Sullivan	Buttermilk Cr nr Dugger.	Clay; some sand and gravel.
412	39°12'56" 87°20'36"	Sullivan	Unnamed trib to W. Fk Busseron nr Hymera.	Sand and gravel.
413	39°11'36" 87°15'55"	Sullivan	Sulphur Cr nr Hymera.	Clay, sand, and gravel; iron precipitate on streambed.
414	39°08'37" 87°08'37"	Greene	Unnamed trib to Howesville ditch nr Jasonville.	Sand and gravel.
415	39°12'43" 87°03'40"	Clay	Pond Cr nr Coal City.	Sand.
416	39°12'03" 87°16'28"	Owen	Turkey Cr nr Coal City.	Gravel.
418	39°01'23" 87°13'20"	Greene	White Rose Cr nr White Rose.	Clay; some sand and gravel.
419	39°02'36" 87°13'36"	Greene	Unnamed trib to Black Cr nr Ellis.	Sand and gravel; orange color on streambed.
421	38°49'35" 87°16'43"	Knox	Purdy Marsh ditch nr Edwardsport.	Clay.
422	38°49'35" 87°14'04"	Greene	Spencer Cr nr Pleasantville.	Clay and some sand.
423	38°41'49" 87°17'54"	Knox	Bens Cr nr Wheatland. Cr nr Ragsdale.	Silt and clay. -----

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana--Continued

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
		Unreclaimed mining[2], Illinoian Glacial Province--Continued		
424	38°41'49" 87°16'54"	Knox	Unnamed trib to Indian Cr nr Ragsdale.	--------------------
426	38°45'28" 87°17'22"	Knox	Unnamed trib to Indian Cr nr Bicknell.	Hard clay bottom.
		Unreclaimed mining[2], Unglaciated Region		
451	38°19'08" 87°19'08"	Pike	Hat Cr nr Oakland City.	Clay, sand, and gravel.
452	38°17'40" 87°17'15"	Pike	Wheeler Cr nr Enos Corner.	Clay, sand, and gravel; some coal fines.
453	38°23'28" 87°11'00"	Pike	Bruster Br nr Winslow.	--------------------
454	38°23'40" 87°13'12"	Pike	Stone Coe Cr nr Winslow.	Sand and gravel; some clay.
455	38°18'14" 87°13'20"	Pike	Unnamed trib to S. Fk Patoka River nr Scottsburg.	Clay; some sand and coal fines.
456	38°16'32" 87°10'29"	Pike	Unnamed trib to Houchin ditch nr Stendal.	Sand and gravel; some cobbles.
457	38°17'08" 87°14'32"	Pike	Rough Cr nr Scottsburg.	Sand and gravel.
462	38°07'36" 87°13'32"	Warrick	Ellison W. ditch nr Folsomville.	Clay and sand.
463	38°09'22" 87°12'22"	Warrick	Barren Fk nr Folsomville.	--------------------
464	38°13'52" 87°11'10"	Pike	Unnamed trib to S. Fk Patoka R nr Scalesville.	Clay and sand; some coal fines.

Table 2.--Sampling site locations and descriptions and principal characteristics of streambed materials in the coal-mining region, southwestern Indiana--Continued

Site	Latitude/ longitude	County	Site description	Principal streambed materials (field observations)
		Unreclaimed mining[2], Unglaciated Region		
465	38°13'57" 87°12'16"	Pike	S. Fk Patoka R nr Spurgeon.	Clay and sand; some coal fines; iron precipitate on streambed.
466	38°14'44" 87°11'23"	Pike	Unnamed trib to S. Fk Patoka R nr Stendal.	Clay, sand, and gravel, some coal fines.

[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.

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979

[N, number of observations; $\overline{X}_A$, arithmetic average; $\overline{X}_G$, geometric average[1]; Min, minimum; Max, maximum; C.V., coefficient of variation; µg/g, microgram per gram]

Land use and glacial province	Aluminum, total recoverable					Arsenic, total				
	N	$\overline{X}_A$ (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)	N	$\overline{X}_G$[1] (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)
Forest	3	3,400	2,400	5,300	48	3	<1	<1	<1	0
Forest x Wisconsin	2	2,500	2,400	2,500	2.9	2	<1	<1	<1	0
Forest x unglaciated	1	5,300	5,300	5,300	----	1	<1	<1	<1	---
Agriculture	29	4,400	430	8,900	40	20	2	<1	11	69
Agriculture x Wisconsin	9	3,800	2,300	7,000	36	9	1	<1	1	57
Agriculture x Illinoian	10	4,400	430	8,900	49	10	1	<1	11	68
Agriculture x unglaciated	10	4,900	2,700	8,000	32	10	1	<1	2	59
Reclaimed mining[2]	4	5,500	3,700	7,400	28	4	1	<1	2	120
Reclaimed mining x Wisconsin	1	3,700	3,700	3,700	----	1	<1	<1	<1	---
Reclaimed mining x Illinoian	1	5,200	5,200	5,200	----	1	1	1	1	---
Reclaimed mining x unglaciated	2	6,500	5,500	7,400	21	2	1	<1	2	140
Unreclaimed mining[3]	33	6,100	2,500	9,200	28	33	1	<1	4	67
Unreclaimed mining x Wisconsin	3	6,600	4,300	7,900	30	3	1	<1	3	100
Unreclaimed mining x Illinoian	18	6,300	2,500	9,200	28	18	1	<1	4	75
Unreclaimed mining x unglaciated	12	5,700	3,400	8,000	28	12	1	<1	2	53

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use and glacial province	Boron, total recoverable					Cadmium, total recoverable				
	N	$\overline{X}^1$ G (μg/g)	Min (μg/g)	Max (μg/g)	C.V. (percent)	N	$\overline{X}$ A (μg/g)	Min (μg/g)	Max (μg/g)	C.V (percent)
Forest	3	<10	<10	10	170	3	10	10	10	0
Forest x Wisconsin	2	<10	<10	10	140	2	10	10	10	0
Forest x unglaciated	1	<10	<10	<10	---	1	10	10	10	-
Agriculture	29	<10	<10	80	250	29	10	10	10	0
Agriculture x Wisconsin	9	<10	<10	10	200	9	10	10	10	0
Agriculture x Illinoian	10	4	<10	80	110	10	10	10	10	0
Agriculture x unglaciated	10	<10	10	10	320	10	10	10	10	0
Reclaimed mining	4	<10	<10	10	120	4	10	10	10	0
Reclaimed mining x Wisconsin	1	10	10	10	---	1	10	10	10	-
Reclaimed mining x Illinoian	1	10	10	10	---	1	10	10	10	-
Reclaimed mining x unglaciated	2	<10	<10	<10	0	2	10	10	10	0
Unreclaimed mining	33	<10	<10	13	180	33	10	10	10	0
Unreclaimed mining x Wisconsin	3	<10	<10	10	90	3	10	10	10	0
Unreclaimed mining x Illinoian	18	<10	<10	10	170	18	10	10	10	0
Unreclaimed mining x unglaciated	12	<10	<10	13	350	12	10	10	10	0

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use and glacial province	Chromium, total recoverable					Cobalt, total recoverable				
	N	$\overline{X}^1$ G (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)	N	$\overline{X}^1$ G (µg/g)	Min (µg/g)	Max (µg/g)	C.V (percent)
Forest	3	13	10	20	14	3	15	10	30	22
Forest x Wisconsin	2	10	10	10	0	2	17	10	30	25
Forest x unglaciated	1	20	20	20	--	1	10	10	10	----
Agriculture	29	16	10	340	28	27	18	10	290	26
Agriculture x Wisconsin	9	14	10	20	13	9	16	10	40	22
Agriculture x Illinoian	10	22	10	340	37	10	22	10	290	35
Agriculture x unglaciated	10	14	10	70	24	9	18	10	30	18
Reclaimed mining	4	10	10	10	0	4	42	30	50	6.3
Reclaimed mining x Wisconsin	1	10	10	10	--	1	50	50	50	----
Reclaimed mining x Illinoian	1	10	10	10	--	1	50	50	50	----
Reclaimed mining x unglaciated	2	10	10	10	0	2	35	30	40	5.5
Unreclaimed mining	33	15	10	50	18	32	36	10	310	25
Unreclaimed mining x Wisconsin	3	16	10	40	27	3	51	10	310	43
Unreclaimed mining x Illinoian	18	18	10	50	19	17	26	10	110	25
Unreclaimed mining x unglaciated	12	12	10	30	14	12	36	10	100	19

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use and glacial province	Copper, total recoverable					Iron, total recoverable				
	N	$\overline{X}_G$[1] (μg/g)	Min (μg/g)	Max (μg/g)	C.V. (percent)	N	$\overline{X}_G$[1] (μg/g)	Min (μg/g)	Max (μg/g)	C.V (percent)
Forest	3	10	10	10	0	3	11,000	7,900	22,000	6.3
Forest x Wisconsin	2	10	10	10	0	2	7,950	7,900	8,000	.10
Forest x unglaciated	1	10	10	10	--	1	22,000	22,000	22,000	----
Agriculture	29	14	10	430	32	29	10,000	5,800	16,000	2.9
Agriculture x Wisconsin	9	12	10	20	11	9	9,200	6,600	14,000	2.6
Agriculture x Illinoian	10	20	10	430	45	10	11,000	5,800	16,000	3.1
Agriculture x unglaciated	10	13	10	50	19	10	11,000	7,000	16,000	2.9
Reclaimed mining[2]	4	14	10	20	14	4	20,000	14,000	27,000	2.8
Reclaimed mining x Wisconsin	1	10	10	10	--	1	14,000	14,000	14,000	----
Reclaimed mining x Illinoian	1	20	20	20	--	1	22,000	22,000	22,000	----
Reclaimed mining x unglaciated	2	14	10	20	17	2	23,000	19,000	27,000	2.5
Unreclaimed mining[3]	33	15	10	30	15	33	35,000	9,600	180,000	6.3
Unreclaimed mining x Wisconsin	3	15	10	30	22	3	28,000	16,000	84,000	9.2
Unreclaimed mining x Illinoian	18	15	10	30	14	18	34,000	15,000	180,000	5.8
Unreclaimed mining x unglaciated	12	13	10	30	14	12	39,000	9,600	100,000	6.7

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use and glacial province	Lead, total recoverable					Manganese, total recoverable				
	N	$\overline{X}$ A (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)	N	$\overline{X}^1$ G (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)
Forest	3	23	10	40	65	3	1,300	550	3,200	12
Forest x Wisconsin	2	15	10	20	47	2	1,300	550	3,200	17
Forest x unglaciated	1	40	40	40	---	1	1,200	1,200	1,200	----
Agriculture	26	19	10	70	84	29	620	220	2,300	8.5
Agriculture x Wisconsin	9	23	10	50	71	9	620	430	920	4.4
Agriculture x Illinoian	8	14	10	40	77	10	770	220	2,300	10
Agriculture x unglaciated	9	20	10	70	100	10	490	250	1,700	8.4
Reclaimed mining[2]	4	18	10	40	86	4	1,900	680	3,300	9.2
Reclaimed mining x Wisconsin	1	10	10	10	---	1	3,300	3,300	3,300	----
Reclaimed mining x Illinoian	1	10	10	10	---	1	680	680	680	----
Reclaimed mining x unglaciated	2	20	10	40	30	2	2,300	2,300	2,300	0
Unreclaimed mining[3]	32	27	10	100	92	33	1,000	60	29,000	27
Unreclaimed mining x Wisconsin	3	43	10	80	81	3	5,000	1,900	29,000	18
Unreclaimed mining x Illinoian	17	28	10	100	97	18	940	60	17,000	27
Unreclaimed mining x unglaciated	12	21	10	50	80	12	810	90	18,000	30

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use and glacial province	Mercury, total recoverable					Nickel total recoverable				
	N	$\overline{X}^1$ G (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)	N	$\overline{X}^1$ G (µg/g)	Min (µg/g)	Max (µg/g)	C.V (percent)
Forest	3	<0.1	<0.1	<0.1	0	3	28	20	40	10
Forest x Wisconsin	2	<.1	<.1	<.1	0	2	23	20	30	9
Forest x unglaciated	1	<.1	<.1	<.1	--	1	40	40	40	----
Agriculture	29	<.1	<.1	<.1	0	28	23	10	280	29
Agriculture x Wisconsin	9	<.1	<.1	<.1	0	9	20	10	90	27
Agriculture x Illinoian	10	<.1	<.1	<.1	0	9	23	10	280	33
Agriculture x unglaciated	10	<.1	<.1	<.1	0	10	24	10	230	30
Reclaimed mining[2]	4	<.1	<.1	<.1	0	4	48	30	70	8.8
Reclaimed mining x Wisconsin	1	<.1	<.1	<.1	--	1	50	50	50	----
Reclaimed mining x Illinoian	1	<.1	<.1	<.1	--	1	50	50	50	----
Reclaimed mining x unglaciated	2	<.1	<.1	<.1	0	2	46	30	70	15
Unreclaimed mining[3]	33	<.1	<.1	<.1	0	32	32	11	260	25
Unreclaimed mining x Wisconsin	3	<.1	<.1	<.1	0	2	48	10	260	41
Unreclaimed mining x Illinoian	18	<.1	<.1	<.1	0	17	26	10	110	23
Unreclaimed mining x unglaciated	12	<.1	<.1	<.1	0	12	39	10	140	24

Table 3.--Statistical summary of selected element concentrations on streambed materials smaller than 0.062 mm in the coal-mining region, southwestern Indiana, October 1979--Continued

Land use and glacial province	Selenium, total					Zinc, total recoverable				
	N	$\overline{X}_G$[1] (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)	N	$\overline{X}_G$[1] (µg/g)	Min (µg/g)	Max (µg/g)	C.V. (percent)
Forest	3	1.8	<1	10	120	3	68	30	140	18
Forest x Wisconsin	2	2.3	<1	10	140	2	64	30	140	26
Forest x unglaciated	1	1	1	1	---	1	80	80	80	--
Agriculture	29	<1	<1	1	120	29	68	20	570	20
Agriculture x Wisconsin	9	<1	<1	1	95	9	88	30	220	18
Agriculture x Illinoian	10	<1	<1	1	100	10	84	30	570	23
Agriculture x unglaciated	10	<1	<1	1	210	10	44	20	80	10
Reclaimed mining[2]	4	<1	1	4	43	4	9	40	140	13
Reclaimed mining x Wisconsin	1	1	1	1	---	1	148	140	140	--
Reclaimed mining x Illinoian	1	4	4	4	---	1	90	90	90	--
Reclaimed mining x unglaciated	2	1.8	1	3	47	2	7	40	130	19
Unreclaimed mining[3]	33	1.5	<1	12	70	33	138	30	610	17
Unreclaimed mining x Wisconsin	3	1	1	1	0	3	224	80	610	19
Unreclaimed mining x Illinoian	18	1.3	<1	12	95	18	118	40	470	17
Unreclaimed mining x unglaciated	12	2.0	<1	4	39	12	135	30	440	17

[1]Geometric average ($\overline{X}_G = (n_1 \times n_2 \times \ldots n_j)^{1/N}$

where

N is the number of observations

and

$n_1, n_2 \ldots n_j$ are individual observations.

[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.

☆USGPO: 1982 — 660-224/20