UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RECONNAISSANCE OF STREAM BIOTA AND PHYSICAL AND CHEMICAL WATER QUALITY IN AREAS OF SELECTED LAND USE IN THE COAL MINING REGION, SOUTHWESTERN INDIANA, 1979-80

By David J. Wangsness

Open-File Report 82-566

Indianapolis, Indiana

August 1982

CONTENTS

ILLUSTRATIONS

TABLES

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

Multiply inch-pound unit	By	To obtain SI unit
inch (in.)	2.540	centimeter (cm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.093	square meter (m^2)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature

$°C = 5/9\ (°F-32°)$

USE OF TRADE NAMES

RECONNAISSANCE OF STREAM BIOTA AND PHYSICAL AND CHEMICAL WATER QUALITY IN AREAS OF SELECTED LAND USE IN THE COAL MINING REGION, SOUTHWESTERN INDIANA, 1979-80

By David J. Wangsness

ABSTRACT

To help meet the goals of the Surface-Mining Control and Reclamation Act of 1977, the U.S. Geological Survey is assessing the physical, chemical, and biological characteristics of surface water within the coal-mining region of southwestern Indiana. This report discusses benthic-invertebrate and periphytic-algal communities in streams draining homogeneous--agricultural, forested, active/reclaimed-mine, reclaimed-mine, and unreclaimed-mine watersheds--and relates the biological communities to the physical and chemical characteristics of the streams.

Alkalinity and pH were lower and the concentrations of dissolved solids, suspended solids, calcium, magnesium, sodium, potassium, sulfate, iron, manganese, aluminum, and zinc were higher in unreclaimed-mine watersheds than in the other land-use watersheds.

Numbers and community diversity of benthic invertebrates were less at sites affected by mining than at agricultural or forested sites, owing to (1) synergistic effects of low pH, metals, and unsuitable habitat and (2) lack of colonizing drift organisms because of the small drainage area upstream from the mined area. Only a few organisms, such as the caddisflies *Cheumatopsyche* and *Hydropsyche* and the chironomids *Chironomus* and *Cricotopus* were found in streams draining mine areas.

INTRODUCTION

Few hydrologic data are available for the coal-mining region of southwestern Indiana. The need for these data has become critical since passage of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Section 507(b)(11) of the Act states that premining hydrologic information on the proposed mine area is to be made available by an appropriate Federal or State agency and incorporated into the mining-permit application for determining the probable hydrologic consequences of the mining and reclamation.

To help meet the goals of the Act, the U.S. Geological Survey is studying the hydrology of streams in the coal-mining region of southwestern Indiana. The objectives of the study are to (1) emphasize the major factors affecting water quality in proportion to their contribution to the total variation in water quality and (2) design and maintain a data-collection network that will provide the hydrologic and water-quality information needed by the regulatory authority and applicants for coal-mining permits.

Acid mine drainage in old coal-mining areas results from the oxidation of pyrite and marcasite left on the land surface after the coal has been removed. In Indiana, these areas were mined before the Indiana Surface Mine Act of 1967 (Indiana Code 13-46), which mandates that spoil piles be graded and that a cover crop be established. Although acid mine drainage has been eliminated from newer (reclaimed) mining areas by the preferential burial of pyritic and marcasitic materials, acid production from the older, unreclaimed mining areas continues to be a water-quality problem.

Purpose and Scope

Aquatic organisms act as integrators of physical and chemical conditions in water and indicate the overall effects of land disturbance on water quality. This report discusses the benthic-invertebrate and periphytic-algal communities in streams draining five types of land-use areas [agricultural, forested, active/reclaimed mine (active coal mine and adjacent land being reclaimed), reclaimed mine, and unreclaimed mine] and relates the biological communities to the physical and chemical characteristics of the streams.

As a part of the U.S. Geological Survey's water-quality study in southwestern Indiana, 84 sites were sampled for physical and chemical constituents during the week of October 16-20, 1979. Chemical data obtained in analyses of these samples and blogical data collected at 16 of these sites from October 9 to November 7, 1979, are presented in this report. Because rainfall immediately before and during the biological sampling period was insignificant, the author assumed that the physical, chemical, and biological samples all represent similar steady-state low-flow conditions.

Site Selection

The 16 sites where biological samples were collected were selected on the basis of homogeneous land use in the watershed upstream from the sampling site so that the effect of land use on the hydrology of a stream could be determined. Many sites in southwestern Indiana were acceptable representatives of homogeneous agricultural and unreclaimed-mine watersheds (mined before 1967). Five sites in agricultural watersheds and six in unreclaimed-mine watersheds were selected from those sites. However, only three homogeneous forested watersheds could be located and sampled. Only one reclaimed-mine watershed and one active/reclaimed-mine watershed were available to be sampled. The sampling sites are described in table 1, and their locations are shown in figure 1. (Because of the small quantity of data available from active and reclaimed mines in the study area, the conclusions in this report may not accurately represent the effects of active- and reclaimed-mine areas on the hydrology of a small watershed. Additional data would be needed before these effects could be accurately defined.)

METHODS

Discharge was measured at each site by methods described in Buchanan and Somers (1969). Field measurements made at each site included water temperature, dissolved-oxygen concentration, pH, specific conductance, and alkalinity. Samples were collected and analyzed by methods described in Skougstad and others (1979).

Water samples were analyzed for major cations and anions, several metals and trace elements, and nitrite plus nitrate. The samples were analyzed by the Geological Survey Central Laboratory, Doraville, Ga. Methods of sample collection and analysis used are described in Skougstad and others (1979).

Samples of suspended sediment were collected by methods described in Guy and Norman (1970) and were analyzed by the Geological Survey sediment laboratory in Columbus, Ohio, by methods in Guy (1969).

Streambed-material samples were collected, oven dried, and sieved through a 0.062-mm (millimeter) stainless-steel sieve. The material smaller than 0.062 mm was analyzed for sorbed and acid-soluble aluminum, arsenic, boron, cadmium, chromium, copper, cobalt, iron, lead, manganese, mercury, nickel, selenium, and zinc. Samples were collected by methods in Guy and Norman (1970) and were analyzed by methods in Skougstad and others (1979). Additional streambed-material samples were collected from pool and riffle areas at the 16 biological sampling sites and were analyzed for particle-size distribution at the Geological Survey sediment laboratory in Columbus, Ohio, by methods described in Guy (1969). Results of streambed-material analyses were used to help describe the chemical and the physical habitats available to benthic organisms.

As many as six benthic-invertebrate samples were collected at each of the 16 biological sampling sites from November 5 to 7, 1979. This period, and the preceding month, represented steady-state low-flow conditions and a period of stable biological populations and diversities. At each site, three benthic-invertebrate samples were collected with a Surber sampler, and as many as three benthic-invertebrate samples were collected with jumbo multiplate artificial-substrate samplers. Some jumbo multiplate samplers were vandalized or were

Table 1.—Sample site description and discharge at selected sampling sites

[mi^2, square mile; ft^3/s, cubic foot per second; $ft^3/s/mi^2$, cubic foot per second per square mile]

Site number and land use	Stream name	Latitude/ Longitude	Drainage aree (mi^2)	Discharge at time of chemical sampling (ft^3/s)	Unit discharge (Discharge/ dreinage area) [$(ft^3/s)/mi^2$]
		Forested sites			
20a	Trib. to Little Vermillion R. nr Cayuga	395316 0872810	0.54	0.10	0.18
275c	Trib. to Friday Brench nr St. Meinard	381321 0864751	.09	.10	1.11
301a	Trib. to Sugar Cr. nr Deer Mill	395649 0870319	.45	.07	.16
		Agricultural sites			
20	Little Vermillion R. nr Newport	395335 0872541	237	12	.05
32	Leatherwood Cr. nr Midway	394631 0871945	26	7.6	.29
77	Jordan Cr. at Bowling Green	392316 0870058	38	9.0	.24
98	Fish Cr. nr Farmers	391038 0865404	60	1.2	.02
243a	Little Flat Cr. nr Otwell	382520 0870406	8	.65	.08
		Unreclaimed-mine sites			
112a	Mud Creek nr Dugger	390556 0871545	10	2.7	.27
401	Trib. nr Centenary	393845 0872847	2	.1	.05
409	Lost Creek nr Staunton	392933 0871402	2	2.0	1.0
422	Spencer Creek nr Pleasantville	385846 0871404	4	2.3	.58
455	Trib. to S. Fork Patoka R. nr Scottsburg	381814 0871320	6	5.0	.83
456	Trib. to Houchin ditch nr Stendel	381632 0871029	2	.57	.28
		Reclaimed-mine site			
417	Lattas Creek nr Midland	390654 0870902	5	1.4	.28
		Active/reclaimed-mine site			
27	Gin Creek nr Universel	393703 0872633	8	1.2	.15

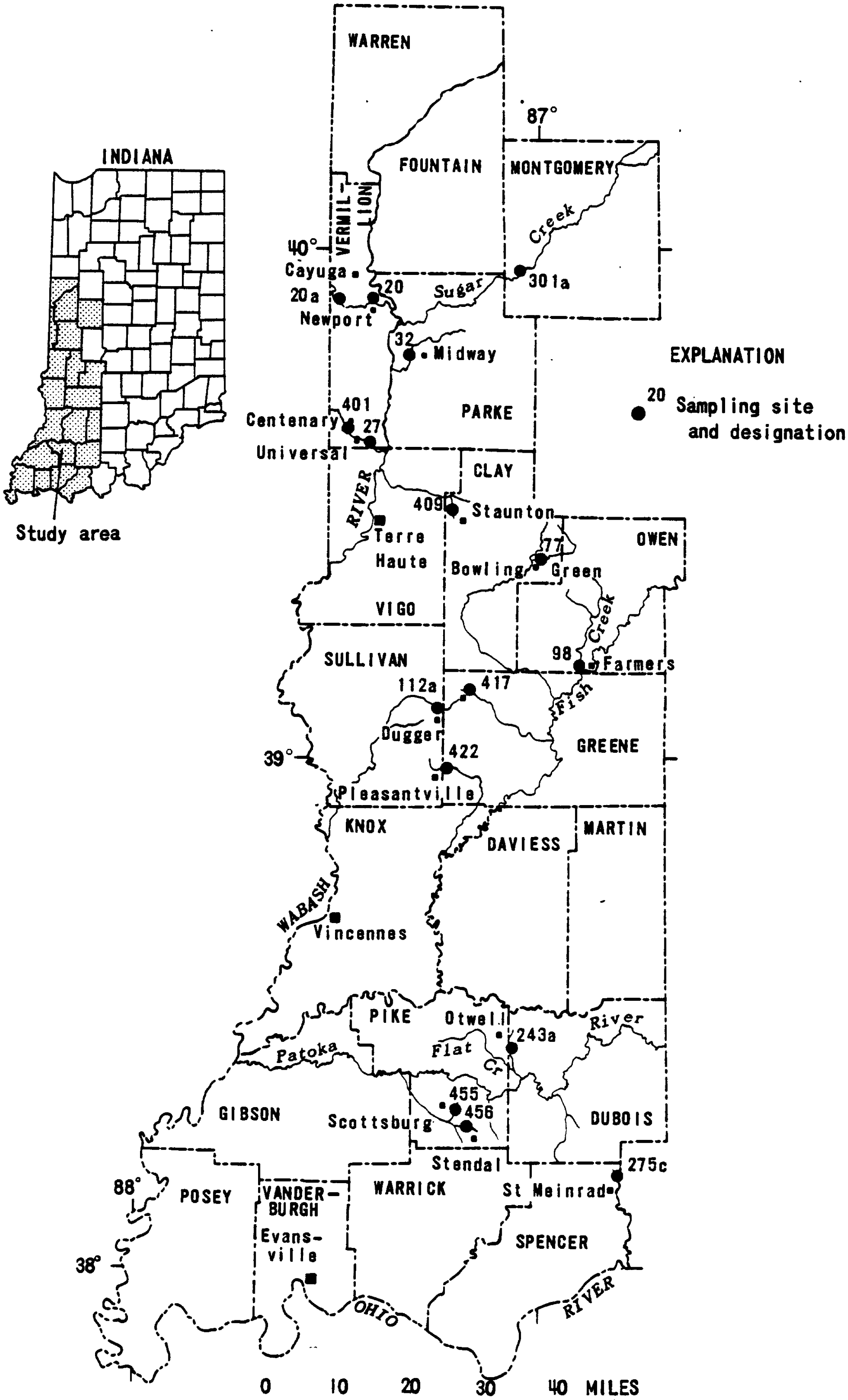

Figure 1.-- Locations of sampling sites in southwestern Indiana.

buried by the sediments. Artificial substrates were used to correct for variation in the streambed-material habitat for benthic organisms. Use of a standardized substrate makes all habitats equal, and chemical quality becomes the main variable controlling biological populations. A 1-hour invertebrate drift sample was also collected from each sampling site.

The Surber samples were collected from sand and gravel substrates in riffle areas. Artificial substrate samplers were placed in moving-water areas in or downstream from riffles to prevent the samplers from becoming buried in fine sediments during the 1-month colonization period. Drift samples were collected upstream from the riffle areas being sampled with the Surber and artificial substrate samplers. Drift and Surber samples were collected at the time that the artificial substrates were retrieved.

Benthic invertebrates from each sample were identified to generic level and were counted. Then the sample biomass was measured. All analyses were made by a commercial laboratory in Atlanta, Ga. Collection and analysis techniques are described by Greeson and others (1977, p. 145-198).

Periphytic algae were collected at all sampling sites with polyethylene strips as artificial substrate samplers to eliminate variability in habitat types. At each site, six strips were tied in pairs to the jumbo multiplates and were allowed to colonize for about 1 month. Some strips were lost, vandalized, buried, or suspended above water as the stage dropped. Biomass and chlorophyll a and b were measured from a composite sample taken from as many as three strips. Concentrations of periphytic algal biomass and chlorophyll were determined by the Geological Survey Central Laboratory at Doraville, Ga. Periphytic algae from the remaining strips were identified to species (where possible), and the organisms were counted. Analyses were made by a commercial laboratory in Paso Robles, Calif. Collection and analysis techniques are described by Greeson and others (1977, p. 127-137).

Invertebrate and periphyton diversities were calculated by Brillouin's Index (Archibald, 1972), Shannon's equation (Wilhm and Dorris, 1968), and the Simpson Index (Simpson, 1949).

RESULTS

This report summarizes (1) field measurements; (2) concentrations of major cations and anions, several metals and trace elements, and nutrients; and (3) concentrations of sorbed and acid-soluble metals on streambed materials presented in Wilber and others (1980).

Invertebrate Drift and Drainage Area

During 1-hour samplings of invertebrate drift, no organisms were captured at sites having small drainage areas (<10 mi^2), and only a few organisms were captured at the sites that had larger drainage areas. Sampling during mid-day, the period of minimum drift, probably affected the number of organisms captured because maximum drift is usually shortly after sunset or before sunrise (Hynes, 1972, p. 263). Even so, the presence of organisms in the drift samples at sites having larger drainage areas and the absence of drift organisms at sites having small drainage areas suggests that drainage area is at least one control on the amount of drift in a stream.

During a catastrophic disturbance, whether natural, such as high flows after an intense rain, or man caused, such as spilling a toxic substance into a receiving stream, the adversely affected reach of stream may experience a decrease in or the elimination of benthic organisms. After the disturbance has ended, and the flow, benthic habitat, and water quality have stabilized, a new biological community can establish itself. The organisms needed for colonization generally enter the disturbed reach as drift organisms that once inhabited the benthic communities of upstream reaches. Another possible source of benthic invertebrates for recolonization is their upstream migration, either by flight after emergence or by nymph and larval stages walking or crawling upstream along the stream bottom (See Hynes, 1972).

In southwest Indiana, much coal is mined near stream headwaters, which results in the disturbance of much or all the drainage area. This condition limits, or eliminates, the number of organisms available to the drift and, therefore, decreases the rate of recolonization of benthic invertebrates in the areas affected by mining.

In small drainage basins, the number of organisms available to drift is small, and, therefore, recovery from a disturbance is slow. Drainage areas of sites affected by mining ranged from 2 to 10 mi^2, and drainage areas of agricultural sites ranged from 8 to 237 mi^2 (table 1). Forested sites had the smallest drainage areas, from 0.09 to 0.54 mi^2.

Discharge

Discharge was measured at the time of chemical sampling during a low-flow, steady-state condition. Discharge ranged from 0.65 to 12 ft^3/s at agricultural sites, 0.07 to 0.10 ft^3/s at forested sites, and 0.1 to 2.7 ft^3/s at sites affected by mining (table 1). In general, discharge was greatest in agricultural watersheds having large drainage areas. But when discharge is divided by drainage area, to eliminate the effect of drainage-area size on discharge, the result is unit discharges that are smaller in agricultural watersheds than at sites representing other land uses (table 1). The mean unit discharge was 0.50 $(ft^3/s)/mi^2$ at unreclaimed-mine sites, 0.48 $(ft^3/s)/mi^2$ at forested sites, 0.28 and 0.15 $(ft^3/s)/mi^2$ at reclaimed-mine and active-mine sites, respectively, and 0.14 $(ft^3/s)/mi^2$ at agricultural sites. These data indicate that discharge from agricultural areas is less sustained than that from other land uses, probably because of higher rates of evaporation and, possibly, transpiration from crop lands than from other land uses. The largest sustained runoff, at the unreclaimed mine sites, can probably be attributed to the large quantity of loose and unconsolidated unreclaimed spoil that acts much like a large sponge that absorbs water during rainstorms and slowly releases it during dry periods.

Field Measurements, Dissolved Solids, and Hardness

Alkalinity and pH

Means, medians, and ranges of alkalinity and medians and ranges of pH of water from five land-use areas are presented in figure 2. The ranges of concentrations for both characteristics are large for each land use, but the median pH and the mean and the median alkalinities are lowest at unreclaimed sites. Parsons (1968; 1977) and Hoehn and Sizemore (1977) reported that pH and alkalinity concentrations for surface water draining mined watersheds were lower than for other surface waters that they studied. None of these authors was specific about other land uses or about the stage of mining in his study area. In the current study, pH and alkalinity at the reclaimed-mine and the active/reclaimed-mine sites were within the range of background concentrations for agricultural and forested sites. The pH at unreclaimed-mine sites was low, probably because of exposure and degradation of pyrite and marcasite. Alkalinity at unreclaimed-mine sites was less than at other land-use sites, probably because the calcareous materials that buffer the surface waters were consumed during the process of neutralizing the acid produced during degradation of pyrite and marcasite. At active- and reclaimed-mine sites the acid-forming minerals are preferentially buried, and the original surface materials are replaced. This action prevents low pH and maintains alkalinities at concentrations similar to the premining concentrations.

Most studies of coal-mining areas have included a discussion of the effects of pH on the chemical and the biological characteristics of streams and lakes in the mined areas; for example, Parsons (1968 and 1977), and Hoehn and Sizemore (1977). In a controlled study by Hall and others (1980), the pH of a stream was decreased to 4 and held constant for 2 years. Two immediate responses that were similar to the response of a stream affected by mine drainage included (1) a sudden increase in the concentrations of aluminum, manganese, iron, and cadmium and (2) an immediate increase in the number of drift organisms leaving the

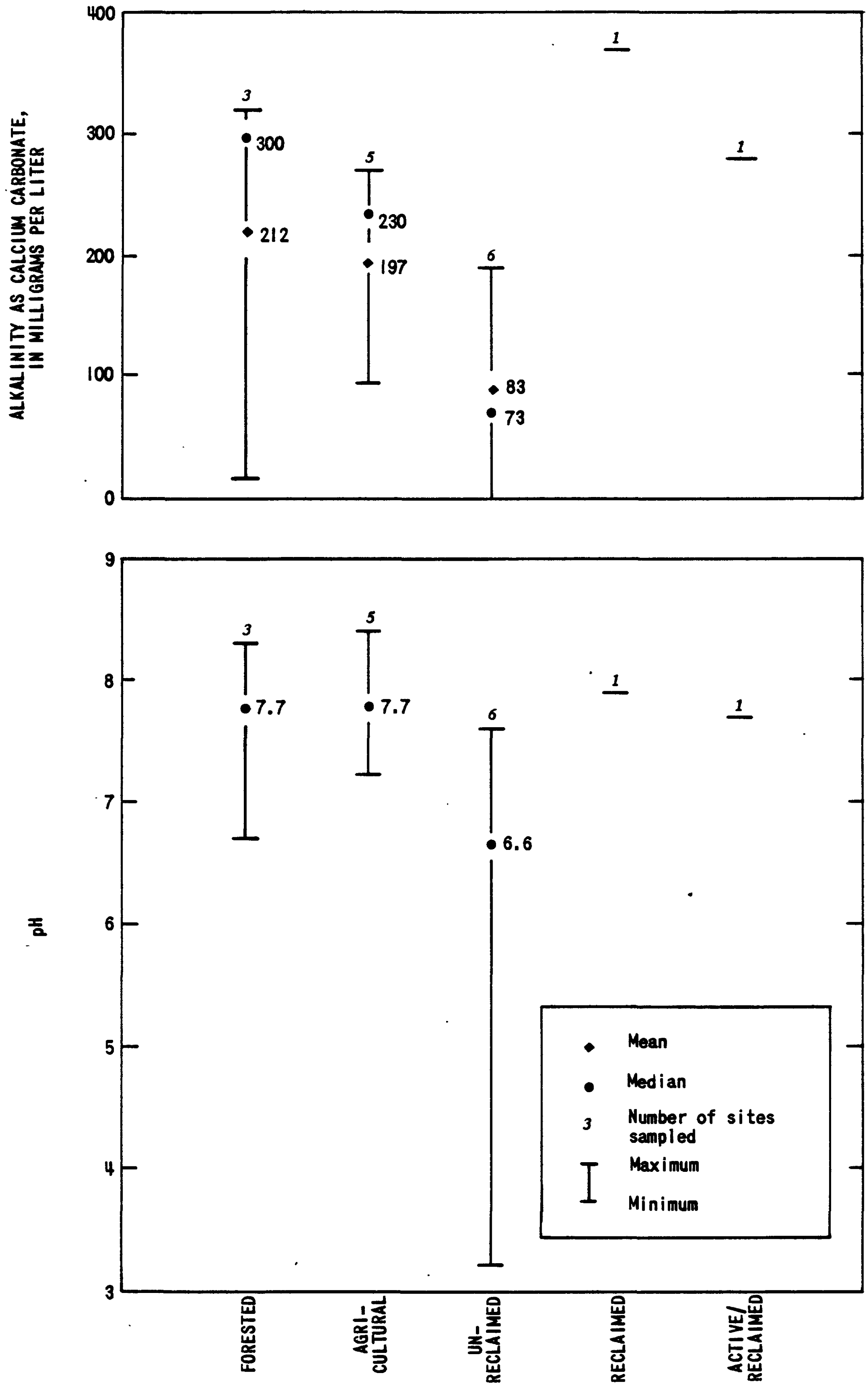

Figure 2.-- Alkalinity concentration and pH of water samples from selected land-use areas, southwestern Indiana, October-November 1979.

affected area, which resulted in a 75-percent decrease in the number of benthic invertebrates. However, the number of drift organisms stabilized after the first week. The decreased emergence of adult invertebrates is explained by Kimmel and Hales (1973), who found that the mayfly Stenoma died in laboratory tests where the pH was 3.3 and metals concentrations were controlled. They also found that a stream pH of 5 eliminated Stenonema and concluded that the toxicity could be caused by a synergism involving pH and other toxicants, perhaps one or several metals. Kimmel and Hales also noted that Stenonema and probably most aquatic insects are most susceptible to pH fluctuations during periods of molt because of the rapid uptake of water during those periods. Stenonema has as many as 30 instars, so this organism, and others like it, has a high probability of failing to mature, or of being eliminated from streams affected by mining. Herricks and Cairnes (1972) also concluded that a minor shift in pH alone can be tolerated by most aquatic communities but that the decrease in pH can cause an increase in metals concentrations and a synergism that alters, damages, or destroys the aquatic community. Periphytic algal communities are generally less affected by pH than invertebrates. Several investigators have shown that a decrease in pH and the associated increase in certain metals not only results in the elimination of some sensitive species and, therefore, a decrease in community diversity, but also in an increase in the populations of several tolerant species which often results in an overall increase in algal biomass (Hall and others, 1980; Muller, 1980; Hendrey, 1976; and Joseph, 1953).

Specific Conductance, Dissolved Solids, and Hardness

Means, medians, and ranges of dissolved-solids and hardness concentrations and specific conductance are presented in figure 3. As in figure 2, the ranges are large for all land uses, but the largest values were measured at unreclaimed-mine sites. Parsons (1968 and 1977), and Hoehn and Sizemore (1977) reported higher dissolved-solids concentrations for surface water affected by mining than for surface water unaffected by mining. Wilber and others (1980) indicated that dissolved-solids concentration of surface water affected by coal-mine drainage in southwestern Indiana is significantly greater than that of surface water affected by agricultural and forested areas. Generally, high specific conductance and concentrations of dissolved solids and hardness in areas affected by mining resulted from leaching of salts from the overburden. Specific conductance and concentrations of dissolved solids and hardness of samples from the reclaimed-mine and active/reclaimed-mine sites were higher than similar data for agricultural and forested land uses. However, no conclusion can be drawn from the few available data.

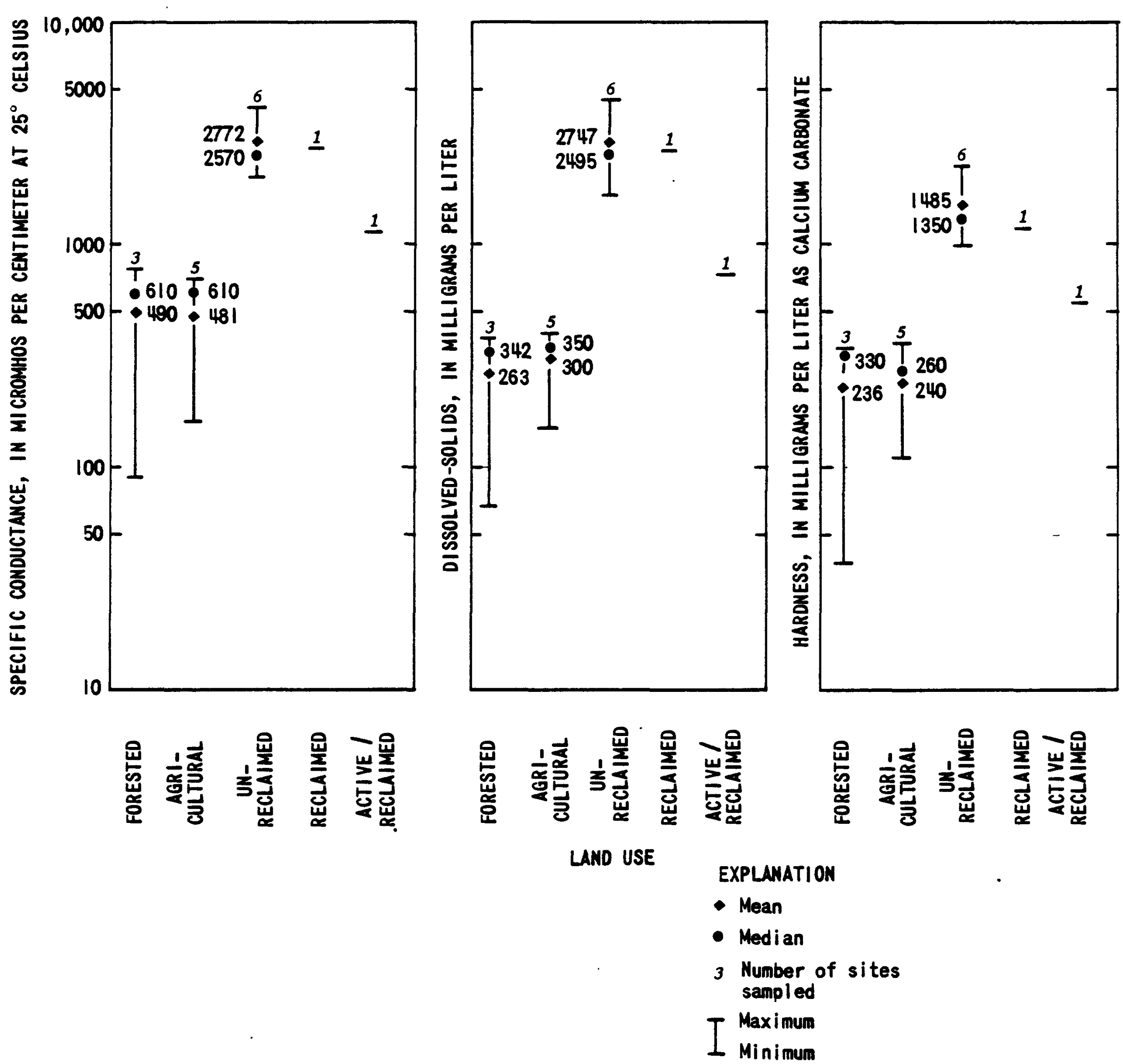

Figure 3.-- Specific conductance, dissolved-solids concentration, and hardness of water samples from selected land-use areas, southwestern Indiana, October-November 1979.

Dissolved Oxygen and Water Temperature

Dissolved-oxygen concentration and water temperature did not seem to be substantially affected by surface mining of coal in southwestern Indiana. Dissolved-oxygen concentrations ranged from 5.6 to 17 mg/L (milligrams per liter) and averaged 9.8 mg/L. The lowest concentration was at an agricultural site, and highest was at a forested site. Water temperature ranged from 4.9° to 17.4° C (degrees Celsius) and averaged 12.4° C. The highest temperature was at an agricultural site, and the lowest temperature was at an unreclaimed-mine site. The data are insufficient to show how dissolved-oxygen concentration is affected by land use, but they indicate that dissolved-oxygen concentration and water temperature were probably controlled as much by season and the time of day at which the sample was measured as by the effects of land use on the watershed.

Chemical Analyses

Major Ions

Means, medians, and ranges of sulfate, magnesium, calcium, and sodium plus potassium concentrations are presented in figure 4. Concentrations of all these constituents, especially sulfate, were higher and more variable at unreclaimed-mine sites and the one reclaimed-mine site than at the other land-use sites. The source of the constituents is probably minerals that have been exposed during mining and have been degraded by weathering. Chloride and fluoride concentrations are probably unaffected by mining. Chloride concentration ranged from 1.5 to 33 mg/L and averaged 11.2 mg/L. Fluoride concentration ranged from 0.1 to 1.9 mg/L and averaged 0.36 mg/L.

Nitrite plus Nitrate

Means, medians, and ranges of dissolved nitrite plus nitrate concentrations are presented in figure 5. Concentrations were highest at the reclaimed-mine and active/reclaimed-mine sampling sites (3.8 and 2.4 mg/L, respectively), possibly because of fertilizers used during the reclamation process. The data from the other three land uses varied, but average concentrations for samples from

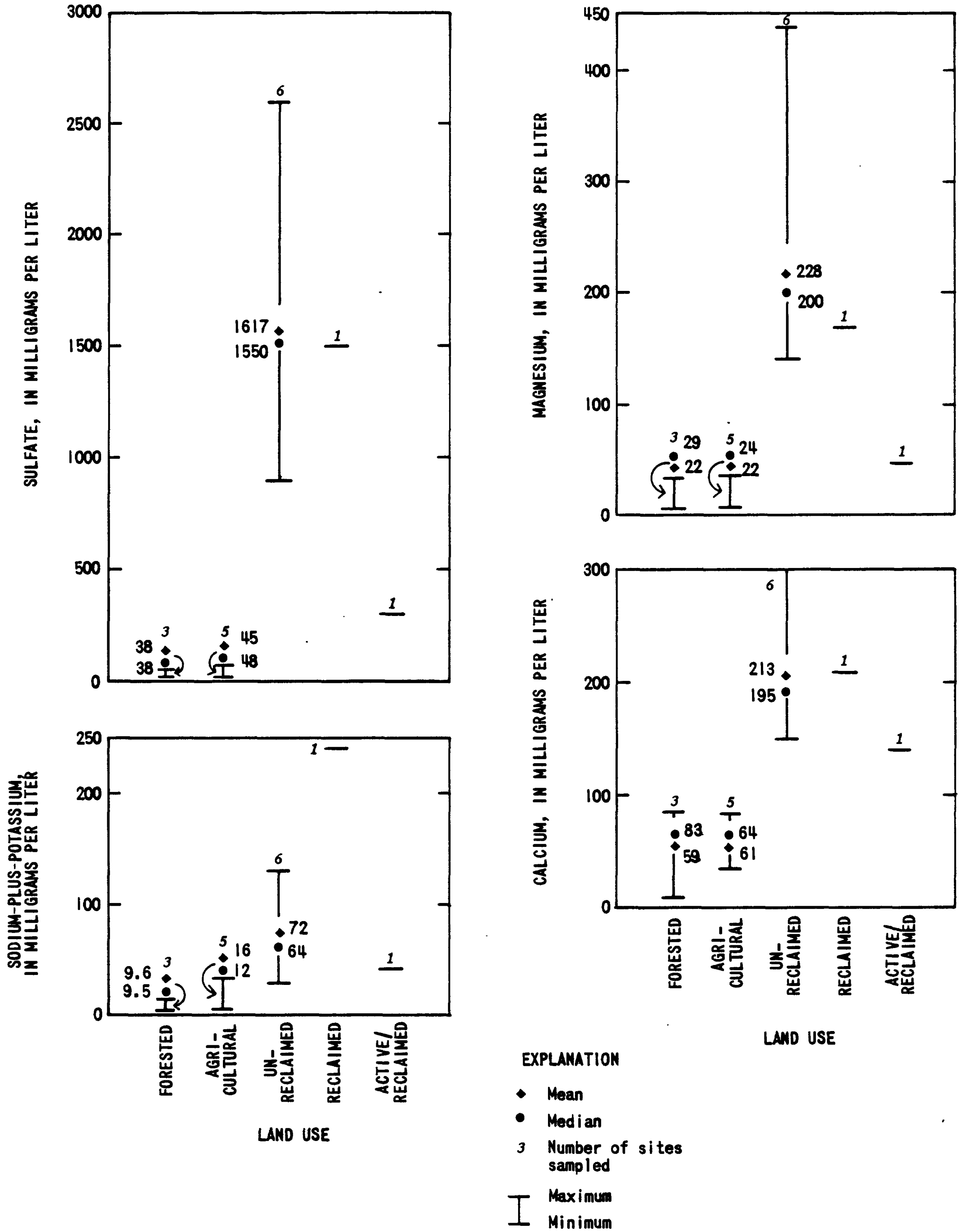

Figure 4.-- Sulfate, sodium-plus-potassium, magnesium, and calcium concentrations of water samples from selected land-use areas, southwestern Indiana, October-November 1979.

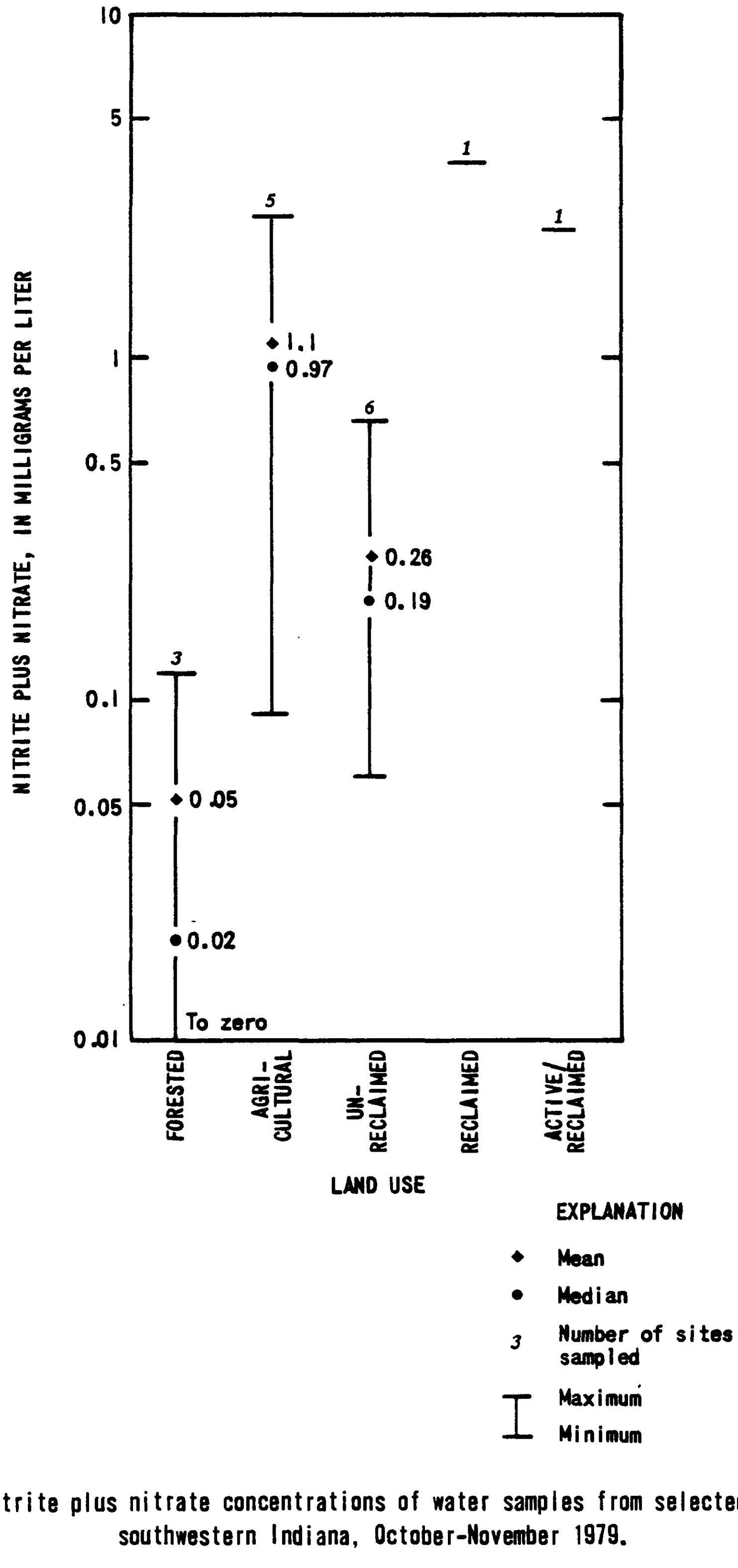

Figure 5.-- Nitrite plus nitrate concentrations of water samples from selected land-use areas, southwestern Indiana, October-November 1979.

agricultural sites were higher than for samples from forested or unreclaimed sampling sites. As with the reclaimed sites, the addition of nitrogenous fertilizers to farm lands is probably the reason for the higher concentrations.

Metals in Water

Means, medians, and ranges of total- and dissolved-iron and total- and dissolved-manganese concentrations are presented in figure 6. Like most other constituents measured during the study, the metal concentrations varied substantially. In general, however, the concentrations of total and dissolved iron and manganese as well as total aluminum, zinc, nickel, and copper were higher in streams draining unreclaimed watersheds than in streams draining other land-use areas. Total-aluminum concentration ranged from 0 to 37,000 μg/L (micrograms per liter) and averaged 8,300 μg/L at unreclaimed-mine sites. Average concentrations at the other land-use sites were less than 211 μg/L. Total-zinc concentration ranged from 0 to 2,100 μg/L and averaged 485 μg/L at unreclaimed-mine sites and less than 21 μg/L at all other sites. Total-nickel concentration ranged from 0 to 100 μg/L and averaged 51.8 μg/L at unreclaimed-mine sites, 15 μg/L at the reclaimed-mine site, and less than 3.1 μg/L at the other sites. Total-copper concentration ranged from 1 to 13 μg/L and averaged 7.2 μg/L at unreclaimed-mine sites and less than 2.3 μg/L in the streams draining the other land-use sites. Parsons (1968 and 1977), Hoehn and Sizemore (1977), and Wilber and others (1980) found concentrations of these metals to be higher at unreclaimed mining areas than at sites unaffected by mining. The source of these metals is probably the minerals disturbed during mining, particularly pyrite, marcasite, and layers of clay and shale.

Several of the studies discussed in the section on pH mentioned that an increase in concentrations of metals, particularly aluminum, iron, manganese, cadmium, copper, and zinc, was associated with a decrease in pH (Hall and others, 1980; Kimmel and Hales, 1973; Herricks and Cairns, 1972; and Hoehn and Sizemore, 1977). These studies indicated that the resultant decrease in diversity, by elimination of groups of invertebrates and periphytic algae, was caused by the synergistic toxicity of pH and metals. From a review of his own work and many other studies of metal toxicity, Chapman (1978) concluded that metals affect different organisms in different ways. An example is 18-μg/L copper affecting the normal adult emergence and first instar survival of caddisfly. This concentration was double the toxicity threshhold for rainbow trout. In a similar test with zinc, the caddisfly was unaffected at concentrations as high as 5,000 μg/L, whereas the rainbow trout was affected by a concentration of 280 μg/L. Chapman also noted that many high metal concentrations are associated with high particulate concentrations during periods of heavy surface runoff. This condition indicates that most metals are adsorbed on, or are present in, particulate material. Chapman also noted that the toxicity of metals is caused by chemical interactions between the metals and certain chemical reactions within the organism. This chemical interaction presumably requires that the metal be (1) soluble, (2) in a form that can be ingested by the organism, and

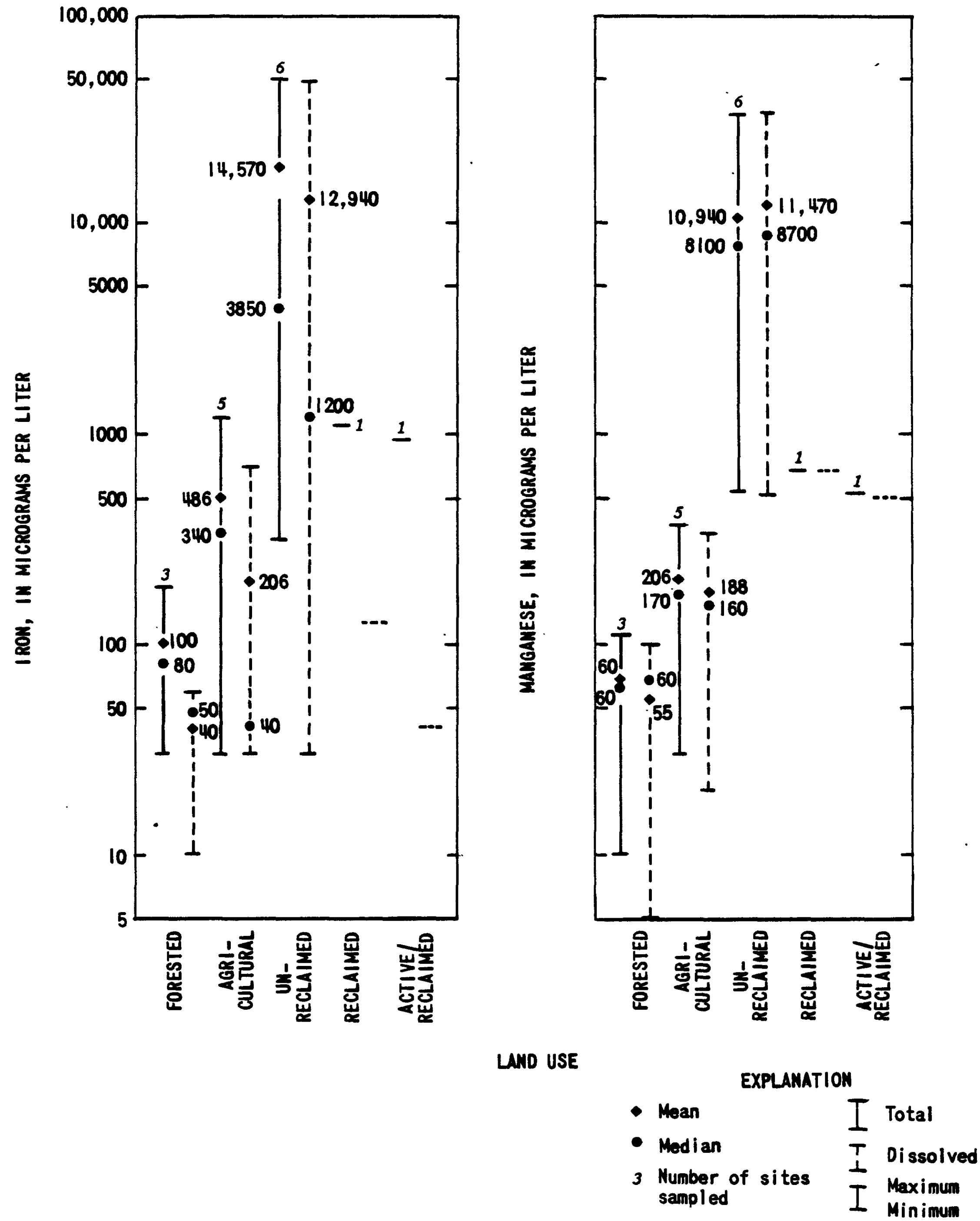

Figure 6.— Iron and manganese concentrations of water samples from selected land-use areas, southwestern Indiana, October-November 1979.

(3) reactive with the physiological processes of the organism. Because of the large number of aquatic organisms to be tested and the variability of the effects by individual metals, additional study would be needed to determine the effect of metals on the life stages and biological function of the organisms.

Metals on Streambed Materials

Water may contain only small quantities of dissolved or total metals, whereas the particulate matter in the water, especially the bottom sediments, may contain considerable quantities (Chapman, 1978). To determine if metals were accumulating on streambed materials in the mining region of southwestern Indiana, W. G. Wilber and R. R. Boje (written commun., 1982) determined concentrations of selected metals and trace elements sorbed on the less-than-0.062-mm fraction of streambed materials from streams draining predominantly agricultural, forested, and reclaimed-mine and unreclaimed-mine land-use areas. Concentrations of aluminum, cobalt, iron, nickel, selenium, and zinc were significantly higher on streambed materials from the reclaimed-mine and unreclaimed-mine areas than from the agricultural or forested areas. The higher concentrations of these elements in mined areas is attributed to their adsorption on streambed materials and (or) co-precipitation with the oxides and hydroxides of aluminum, iron, and manganese.

Means, medians, and ranges of manganese, iron, and aluminum concentrations on streambed materials are presented in figure 7. The concentrations varied widely, particularly manganese, at unreclaimed sites. The average concentrations of these metals were higher at unreclaimed-mine sites than at the other land-use sites. Additional study would be needed to determine if and how the adsorbed metals affect the aquatic biological community.

Storm-Hydrograph Analyses

Unpublished Geological Survey data on chemical variability of runoff during rainstorms of varying duration and intensity show that high-intensity storms affect water quality more than low-intensity storms do (D. E. Renn, U.S. Geological Survey, written commun., January 1981). Alkalinity and pH of samples collected from an unreclaimed-mine site during a high-intensity storm decreased, whereas suspended-solids, total-iron, aluminum, and manganese concentrations increased (fig. 8). Data collected from the same site during a low-intensity storm were less variable than data collected during the more intense storm (fig. 9). Concentrations of dissolved iron, aluminum, and manganese were small percentages of their total concentrations. This condition indicates that, unlike

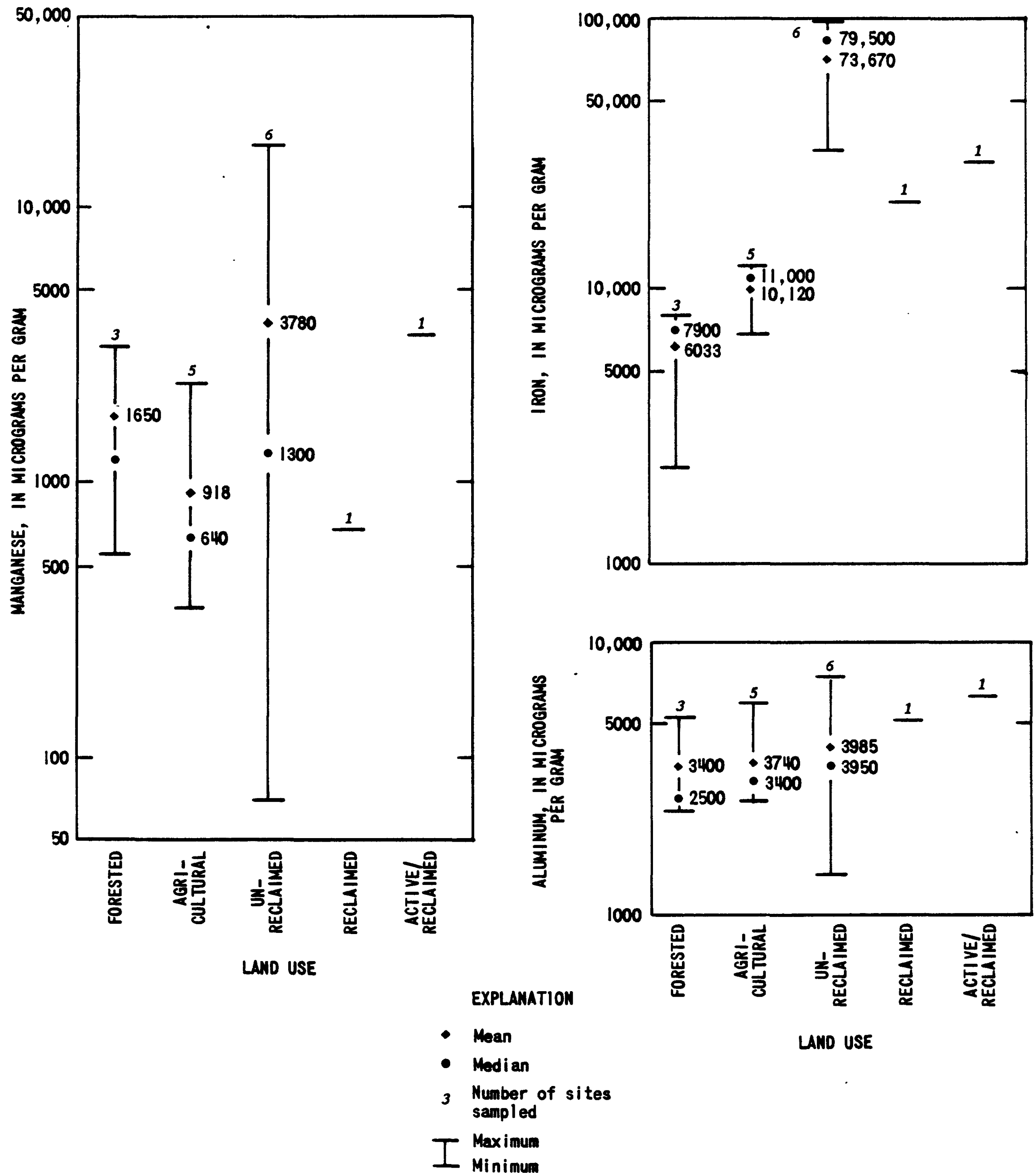

Figure 7.-- Manganese, iron, and aluminum concentrations on stream-bed materials from selected land-use areas, southwestern Indiana, October-November 1979.

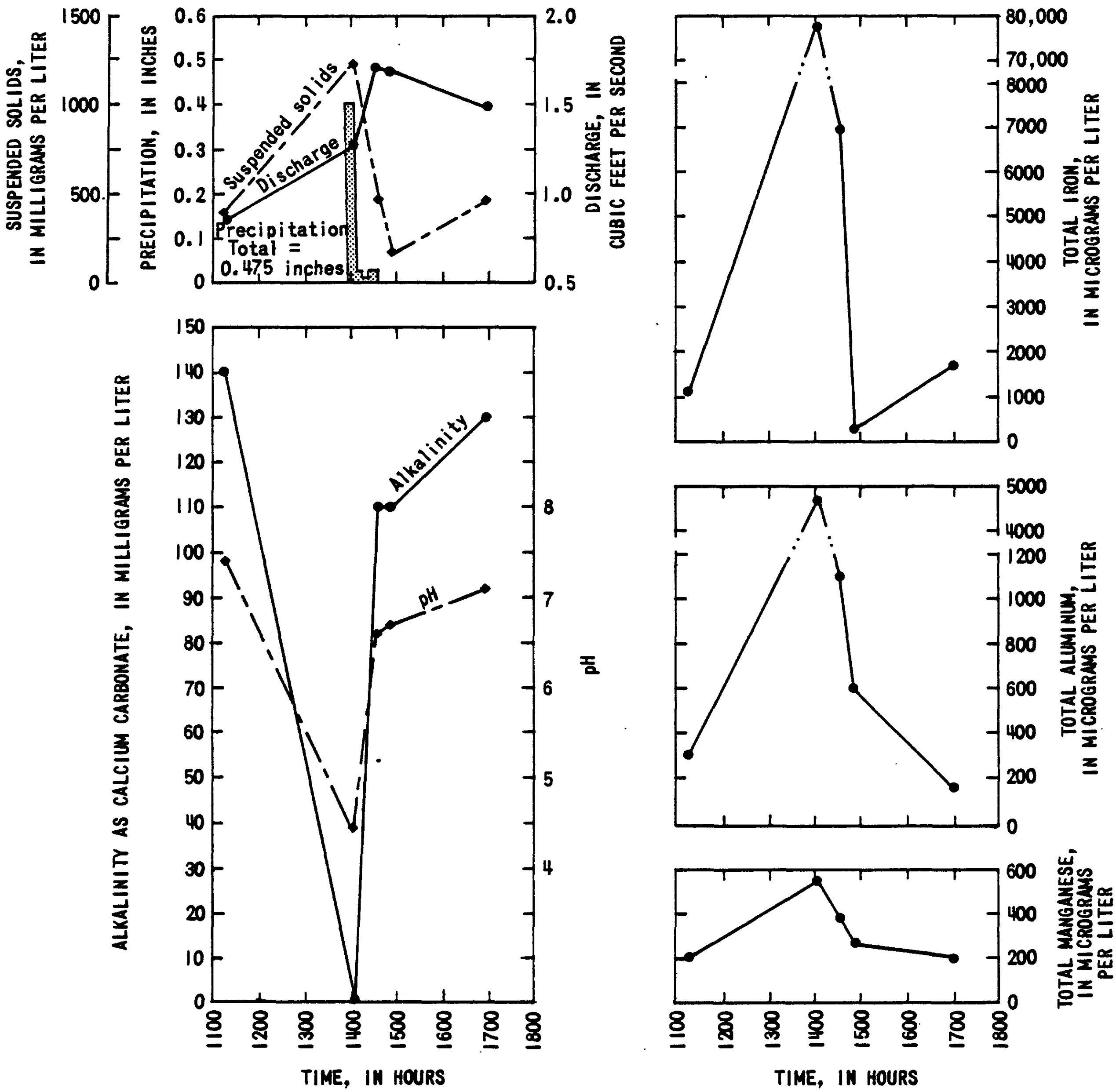

Figure 8.-- Physical and chemical variability of runoff during a high-intensity rainstorm at unreclaimed-mine site 401, June 2, 1980.

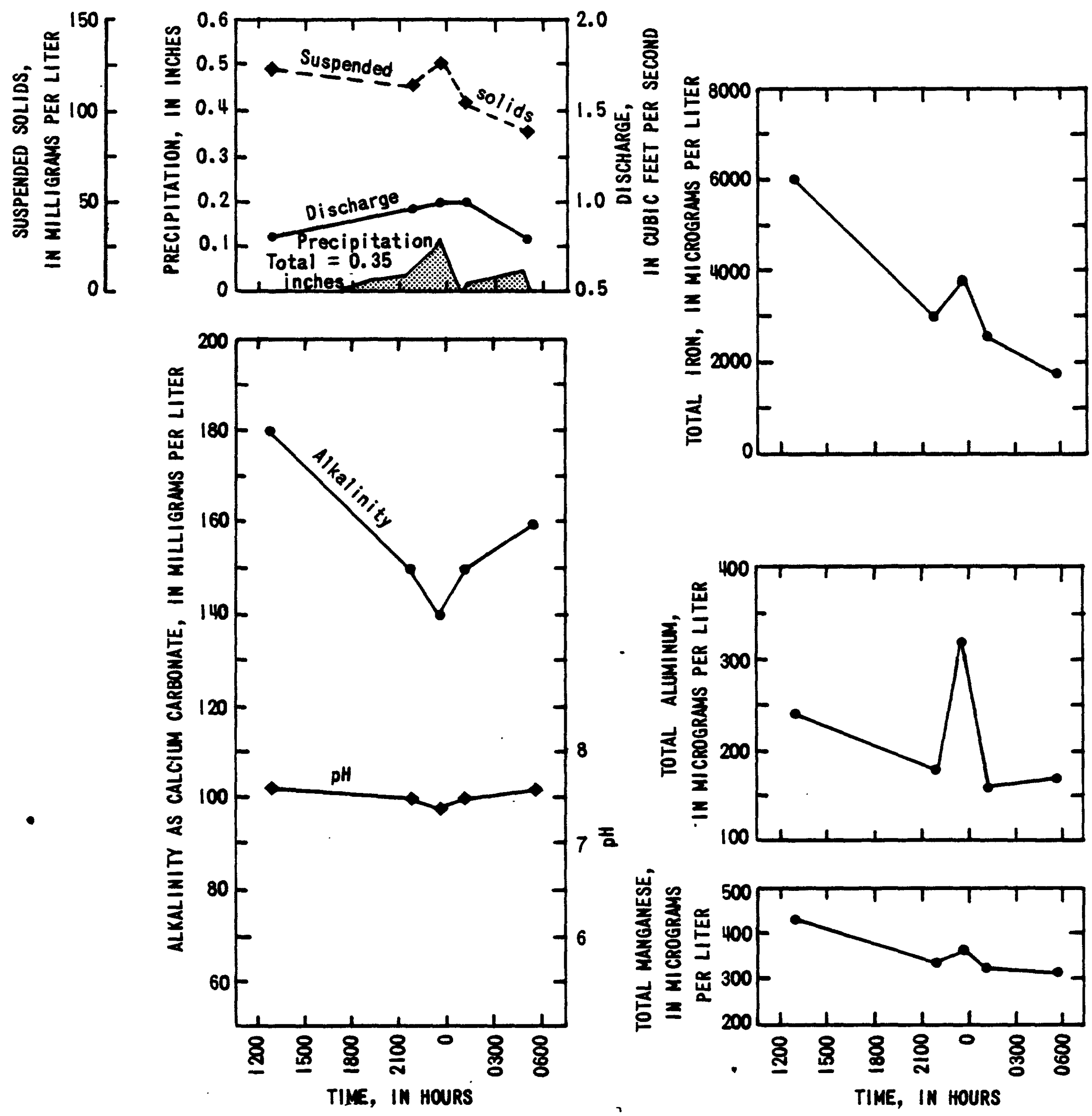

Figure 9.-- Physical and chemical variability of runoff during a low-intensity rainstorm at unreclaimed-mine site 401, March 20-21, 1980.

the steady-state flow, most of the iron, aluminum, and manganese transported by the stream during a storm is on suspended particles rather than in solution. The data collected during storms at agricultural and forested land-use sites were less variable than the data at site 401 and other unreclaimed-mine sites.

On the basis of earlier discussions of pH and metals-toxicity, two conclusions can be drawn from the storm-hydrograph analyses. First, the large decrease in pH during the high-intensity storm at the unreclaimed-mine site was probably enough to damage or destroy invertebrate populations and eliminate sensitive periphytic algae. Parsons (1976) suggested that biological communities in areas affected by mining require about 2 months of a stable environment before drift organisms can sufficiently colonize an area recovering from a storm-water flush and that recovery will occur only after low pH and high concentrations of dissolved metals have been eliminated. Platts and others (1979) suggested that diversity and population of the biological community of a stream never totally recover from the effects of periodic acid mine drainage, even when natural stream reaches are available upstream to supply drift organisms for recolonization. In Indiana, streamflow affected by mining is seldom stable for as long 2 months owing to frequent rains. Much of the mining is done at or near the headwaters of streams and, therefore, eliminates the source of drift organisms for recolonization.

The second conclusion drawn from the storm-hydrograph analyses is that the substantial increase in metals concentrations during storms probably had little toxic effect on the organisms because the increase was in total metals concentrations rather than dissolved. Metals adsorbed on suspended particles could be detrimental to benthic organisms when the particles settle on the streambed materials. However, this effect is not understood.

Streambed-Material Sizes

The average distribution of streambed-material sizes for pools and riffles in each of the five land-use areas is shown in figure 10. Samples collected from pool areas contained more sand and less gravel than the samples collected from the riffles. The percentages of silt and clay were small for all land uses except for the active/reclaimed-mine site, where the sample from the pool area was more than 30 percent silt and clay. Because gravel substrates provide a more stable and diverse aquatic habitat than sand, silt, and clay, the quantity of gravel-size or larger substrates that are free of a silt or clay covering is important to the stability and the diversity of the aquatic biological community (Lium, 1974). Forested sites had more gravel-size streambed materials and less sand than the other land-use sites. If the forested land-use sites are considered to be background sites, then the higher percentage of sand in the streambed materials at the other land-use sites is caused by sand-size particles entering the streams during and after land disturbance in the agricultural or mining areas. The higher percentage of sand in agricultural and mining areas suggests that these land-use areas have habitats that are less stable than the habitats at the forested sites.

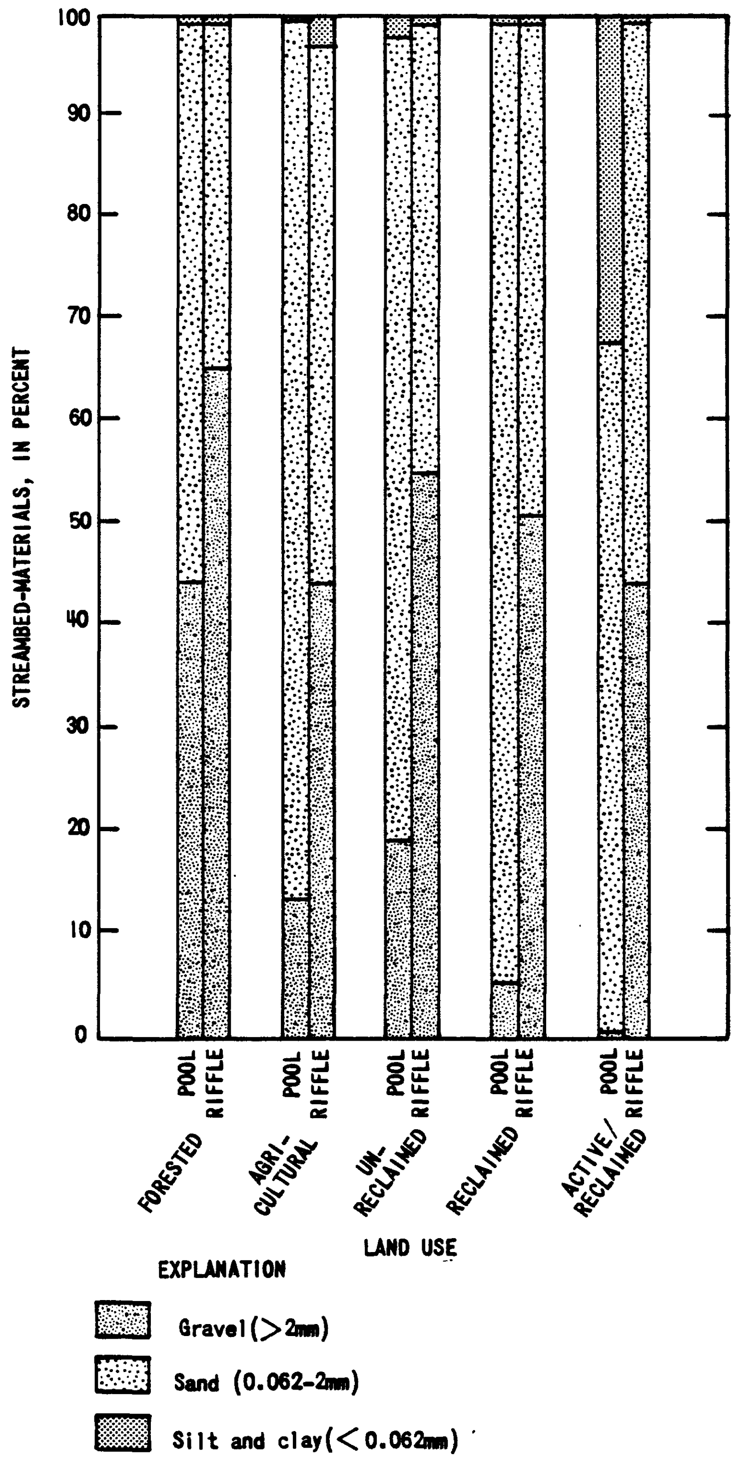

Figure 10.-- Average distribution of streambed-material sizes for selected land-use areas, southwestern Indiana, October-November 1979.

Biological Analyses

Benthic Invertebrates

Means, medians, and ranges of number of benthic invertebrates per square meter of stream bottom is shown in figure 11. The ranges in total numbers of organisms are large, but the average number of organisms was greater at agricultural sites than at the other land-use sites. The active/reclaimed-mine site had the fewest benthic invertebrates, probably because of the effects of mining on water quality and the instability of the benthic habitat caused by the large number of silt- and clay-size particles on the streambed materials and the constant shifting of the streambed materials. At this site, more organisms were collected with multiplate samples than with a Surber net. The organisms seem to prefer the stable habitat offered by the multiplates rather than the unstable stream substrates. Multiplate samplers and stream substrates were colonized equally at agricultural sites, but at the other land-use sites the natural subtrates were apparently a more suitable habitat for the benthic invertebrate communities.

To eliminate the effect of drainage area on the invertebrate population, the author divided the number of organisms per square meter by the drainage area of the sampling site. The results are in number of organisms per square meter of substrate per square kilometer of drainage area. The means, medians, and ranges of the results are shown in figure 12. Although drainage area seems to be related to the number of benthic invertebrates in this study, the major factor is land use. Forested sites had the most organisms per unit area, and the active/reclaimed-mine site had the fewest organisms.

A pattern similar to the one described in the preceding paragraph is obtained when invertebrate biomass is expressed in milligrams of invertebrate biomass per square meter per square mile. The decreasing order of average biomass concentrations by land use was as follows: forested, agricultural, unreclaimed mines, reclaimed mine, and active/reclaimed mine, respectively.

Invertebrate diversities were calculated with the Brillouin, Shannon, and Simpson equations. Because similar results were obtained by the three equations, only the Shannon Index is discussed in this report. Means, medians, and ranges of indices for each of the land uses are presented in figure 13. A diversity of less than 1.0 indicates poor water quality, from 1.0 to 3.0 indicates moderate water quality, and greater than 3.0 indicates good water quality (Wilhm and Dorris, 1968). These data show a pattern similar to that shown by total numbers and biomass in that the average invertebrate diversities for forested and agricultural land uses were higher than the diversities for the land-use areas affected by mining.

Some organisms are more sensitive to the water quality of streams affected by coal mining than others. Roback and Richardson (1969) found that the invertebrate orders Odonata (dragonflies and damselflies), Ephemeroptera (mayflies),

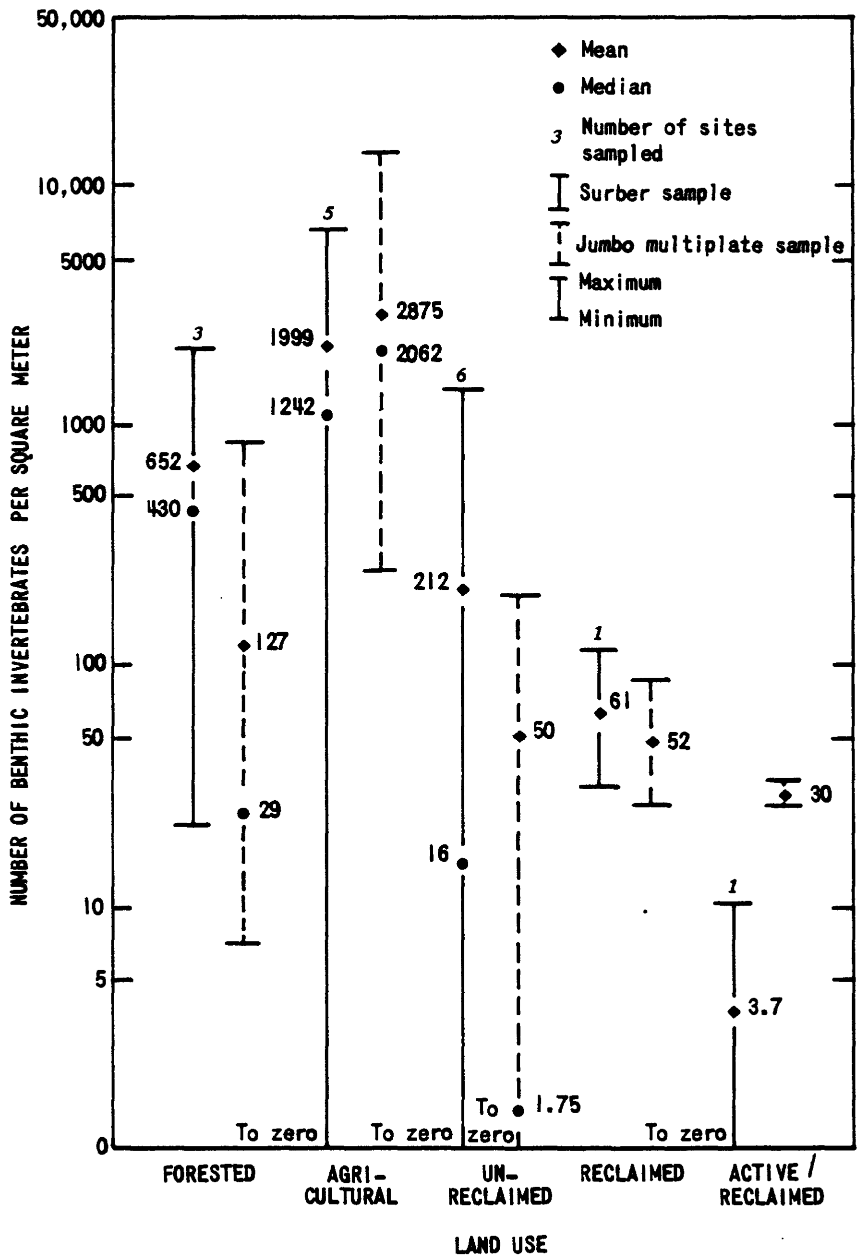

Figure 11.-- Number of benthic invertebrates per square meter of streambed materials from selected land-use areas, southwestern Indiana, October-November 1979.

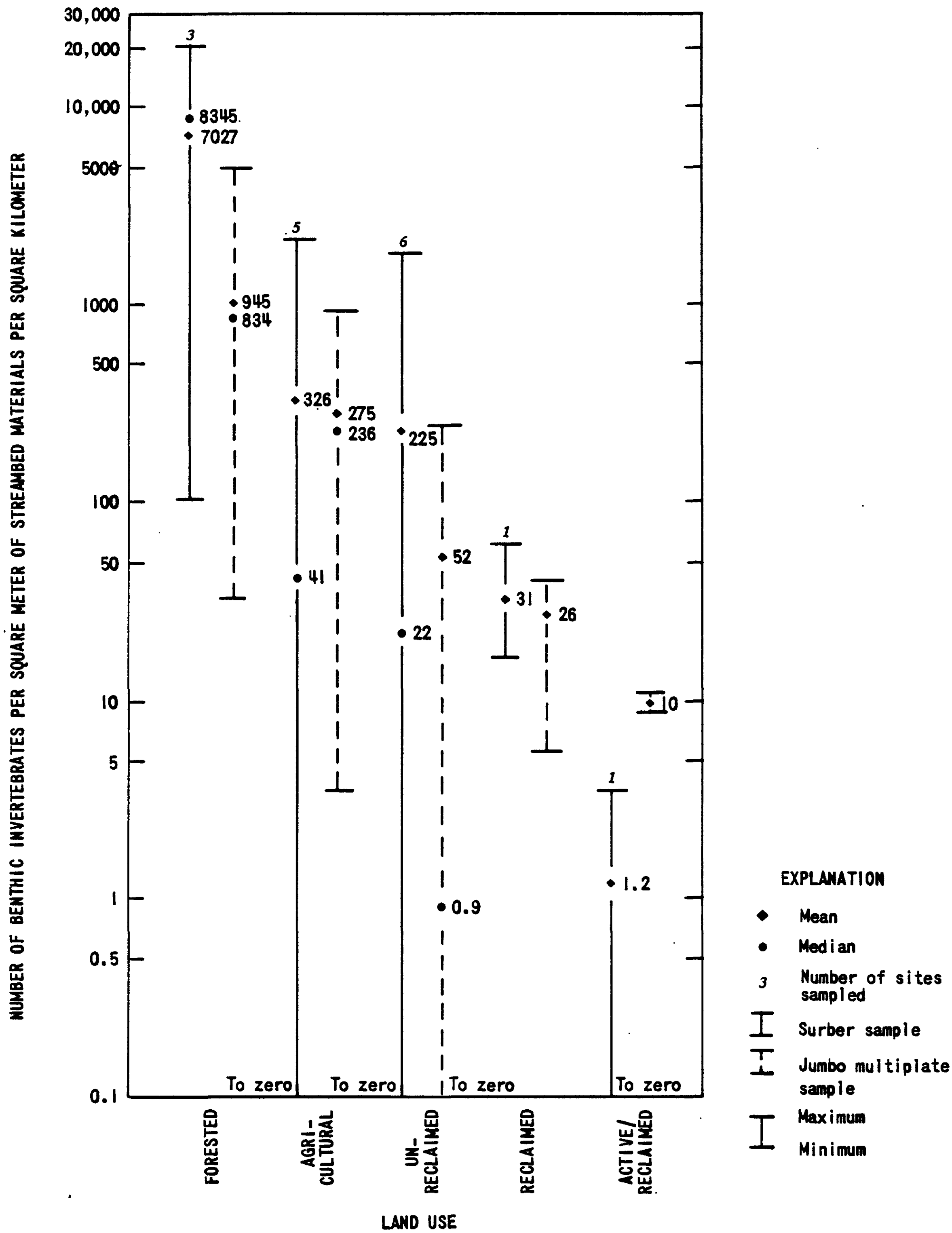

Figure 12.-- Number of benthic invertebrates per square meter of streambed materials per square kilometer from selected land-use areas, southwestern Indiana, October-November 1979.

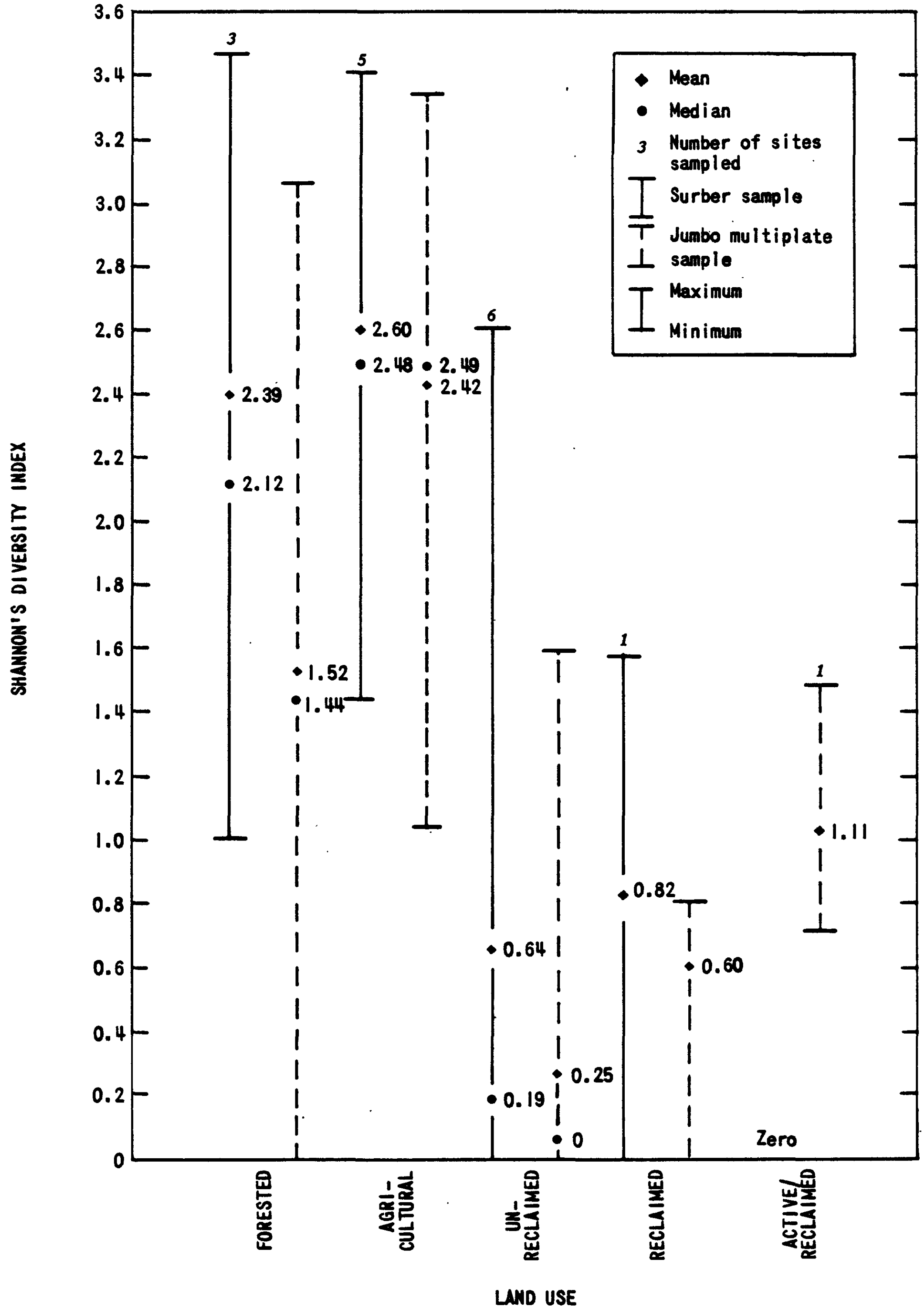

Figure 13.-- Benthic-invertebrate diversity for selected land-use areas, southwestern Indiana, October-November 1979.

and Plecoptera (stoneflies) are eliminated by mine drainage. The orders Tricoptera (caddisflies), Megaloptera (alderflies, dobson flies, and fishflies), and Diptera (flies, mosquitoes, and midges) are reduced in number, but several genera, including Sialis and Chironomus, are the most tolerant of environmental conditions resulting from mining. Parsons (1968) found the caddisfly Cheumatopsyche to be resistant to mine drainage, and Platts and others (1979) suggested that some species of caddisflies and midges are resistant to mine drainage.

The types of invertebrates varied with land use. The organisms by genera and the number of observations per land use are listed in table 2. Many more types of organisms were identified at sites in forested and agricultural lands than at sites affected by various stages of mining. Organisms in the orders Plecoptera and Ephemeroptera were absent from samples collected at sites affected by mining. Only a few genera were identified at some of the mined land-use sites, and no organisms were identified in the samples from three unreclaimed-mine sites. The caddisflies Cheumatopsyche and Hydropsyche and the chironomids Chironomous and Cricotopus were the dominant organisms at sites affected by mining. Studies by Platts and others (1979), Herricks and Cairns (1972), and Parsons (1968) indicated that these organisms are more tolerant of acid mine drainage than other invertebrates.

The percentages of occurrence of the major-organism groups are shown in figure 14. The percentages indicate well-mixed communities, including mayflies and stoneflies, on the natural substrates (Surber samples) at forested and agricultural sites. At unreclaimed-mine sites, caddisflies were dominant, and mayflies and stoneflies were absent. At the reclaimed-mine site, dipterans were dominant, and the number of caddisflies was much less than at the unreclaimed-mine sites. At the active/reclaimed-mine site, only dipterans were found in the samples. Some types of organisms preferred the habitat offered by the artificial substrates and were able to colonize artificial substrates but not natural substrates. The large percentage of snails and clams at the reclaimed-mine site and caddisflies at the active/reclaimed-mine site that were collected with the multiplate sampler are examples of this. Other organisms, such as mayflies, stoneflies, worms, and leeches, preferred stream substrates to the artificial substrates and did not colonize the multiplate samplers. The general trends shown by both types of sampling are similar however, because they both indicate that the diversity of organisms is greatest at forested and agricultural land-use sites and is least at sites that have been affected by mining. The least-diverse invertebrate community was at the active/reclaimed-mine site, which supported only one organism group naturally and only one additional group artificially.

The benthic invertebrate data indicate that several factors affect the invertebrate communities of streams in southwestern Indiana. Size of drainage area seems to be related to the number of organisms present. The streambed-material size and, therefore, the availability of suitable, stable habitats also seems to be related to the numbers as well as the diversity of the community. Land use affects the water quality as well as the size distribution of the streambed materials, which in turn affects the types and numbers of invertebrates. Intense rainstorms also affect the water quality and the stability of the streambed materials.

Table 2.--Benthic invertebrates identified during the study

[5/2=number of samples in which the organism was identified/number of times organism was dominant; data collected by U.S. Geological Survey; 20a...27, sampling-site numbers; n, number of samplings for each land use]

Organisms			Land use															
			Forested			Agricultural					Unreclaimed mine						Re-claimed mine	Active/ re-claimed mine
			20a n=5	275c n=6	301a n=6	20 n=6	32 n=3	77 n=6	98 n=6	243a n=6	409 n=4	422 n=5	456 n=5	401 n=3	112a n=3	455 n=3	417 n=6	27 n=5
Plecoptera—	Chloroperlidae—	Alloperla	—	1	2	1	—	—	—	—	—	—	—	—	—	—	—	—
	Perlodidae—	Isoperla	1	1	3/1	1	—	1	—	—	—	—	—	—	—	—	—	—
	Taeniopterygidae—	Taenionema	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		Taeniopteryx	—	1	—	5/2	1	—	1	—	—	—	—	—	—	—	—	—
Ephemeroptera—	Baetidae—	Pseudocloeons	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Baetis	—	—	4	2	1	1	2	—	—	—	—	—	—	—	—	—
	Baetiscidae—	Ephemerella	—	4/3	3	—	—	1	2	—	—	—	—	—	—	—	—	—
		Leptophlebia	—	—	4/1	—	—	2/1	4/1	—	—	—	—	—	—	—	—	—
		Paraleptophlebia	—	1	2/2	—	—	2	2	—	—	—	—	—	—	—	—	—
	Caenidae—	Caenis	—	—	—	1	—	2	—	—	—	—	—	—	—	—	—	—
	Heptageniidae—	Anepeorus	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Stenacron	—	—	—	2	—	4/1	5/1	1	—	—	—	—	—	—	—	—
		Stenonema	—	—	4/1	6/1	—	4/1	3	1	—	—	—	—	—	—	—	—
	Potamanthidae—	Potamanthus	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
	Siphlonuridae—	Isonychia	—	—	—	4/1	1	1	—	—	—	—	—	—	—	—	—	—
	Tricorythidae—	Tricorythodes	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—
Tricoptera—	Hydropsychidae—	Chaumatopsyche	1	1/1	2/2	5/2	2/1	3	6/2	1	4/3	4/3	—	—	—	—	2	2/1
		Diplectrona	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Hydropeyche	1	—	—	4	1	2	—	—	2/1	2/1	—	—	—	—	—	—
		Symphitopeyche	—	—	—	3	2	—	—	—	—	—	—	—	—	—	—	—
	Hydroptilidae—	Ochrotrichia	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
	Glossosomatidae—	Glossoeoma	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
	Philopotamidae—	Chimarra	—	1	2/1	—	—	—	—	—	—	2	—	—	—	—	—	—
	Polycentropodidae—	Cyrnellus	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
		Polycentropus	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—
Diptera—	Chironomidae—	Chironominae:																
		Chironomus	1	—	—	5/1	1	3	5	4	—	—	2/1	—	—	—	—	—
		Cladotanytarsu	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cryptochironomus	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—
		Endochironomus	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Glyptotendipes	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
		Limnochironomus	—	—	1	1	1	—	1	2	—	—	—	—	—	—	—	—
		Micropsectra	—	—	1	2	1	1	1	—	—	—	—	—	—	—	—	—
	Chironomidae—	Microtendipes	—	1	2	4	2	—	4/1	—	—	—	—	—	—	—	—	—
		Parachironomus	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Phaenopsectra	—	1	—	2/1	—	3	—	—	—	—	—	—	—	—	—	—
		Polypendilum	—	2	—	5/1	2	4/2	3	3	—	—	—	—	—	—	—	—
		Rheotanytarsus	—	—	1	4	2	3/2	2/1	1	—	—	—	—	—	—	—	—
		Robackia	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—
		Stenochironomus	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Stictochironomus	3	—	1	—	—	—	4/2	—	1/1	—	—	—	—	—	—	—
		Tanytarsus	2	—	4/1	4/2	2	3/2	3/1	1	—	—	—	—	—	—	—	—

Table 2.--Benthic invertebrates identified during the study--Continued

Organisms			Land use															
			Forested			Agricultural					Unreclaimed mine						Re-claimed mine	Active/re-claimed mine
			20s n=5	275c n=6	301a n=6	20 n=6	32 n=3	77 n=6	98 n=6	243a n=6	409 n=4	422 n=5	456 n=5	401 n=3	112a n=3	455 n=3	417 n=6	27 n=5
Diptera—	Chironomidae—	Orthodadiinae	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Brillia	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
		Cardiocladius	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
		Conchapelopia	—	1	2	4	—	3	2/1	3	—	—	—	—	—	—	—	—
		Corynoneura	1	1	2/1	1	—	3	2	1	—	—	—	—	—	—	—	—
		Cricotopus	—	2	3	6/4	2/2	5/2	3/1	4	2	4/1	—	—	—	—	—	1
		Diplocladius	—	—	—	—	—	1	2	—	—	—	—	—	—	—	—	—
		Eukiefferella	1	—	2	1	1	—	—	—	—	—	—	—	—	—	—	—
		Orthochadius	—	1	—	1	—	1	—	—	—	1	—	—	—	—	—	—
		Psectrocladius	—	—	3/2	1/1	—	2	—	—	—	1	—	—	—	—	—	—
		Thieueman-niella	—	—	2	3/2	2	3/2	2/1	—	—	—	—	—	—	—	—	—
		Trichocladius	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
		Trissocladius	1	1	—	1	2	3	3/1	—	—	—	—	—	—	—	—	—
		Podonominae																
		Labrundinia	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Tanypodinae																
		Ablabesmyia	—	—	2	—	—	1	—	—	—	—	—	—	—	—	—	1
		Coelotanypus	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
	Empididae—	Hemeradromia	—	—	4	3	1	—	—	—	—	1	—	—	—	—	—	—
	Heleidae—	Palpomyia	—	1	1	1	—	—	1	—	—	—	1	—	—	—	—	—
	Simuliidae—	Prosimulium	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
		Simulium	1	—	—	5	2	4	1	1	—	—	—	—	—	—	4/1	1
	Tabanidae—	Tabanus	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
	Tipulidae—	Dicranota	1	—	3	2	—	—	—	—	—	—	—	—	—	—	—	—
		Hexatoma	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Limnophila	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
		Ormoaia	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Pilaria	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		Tipula	3/2	1	3	1	—	—	1	1	3	1	—	—	—	—	—	—
		Conchapelopia	—	1	2	4	—	3	2/1	3	—	—	—	—	—	—	—	—
		Corynoneura	1	1	2/1	1	—	3	2	1	—	—	—	—	—	—	—	—
		Cricotopus	—	2	3	6/4	2/2	5/2	3/1	4	2	4/1	—	—	—	—	—	1
		Diplocladius	—	—	—	—	—	1	2	—	—	—	—	—	—	—	—	—
		Eukiefferella	1	—	2	1	1	—	—	—	—	—	—	—	—	—	—	—
		Orthochadius	—	1	—	1	—	1	—	—	—	1	—	—	—	—	—	—
		Psectrocladius	—	—	3/2	1/1	—	2	—	—	—	1	—	—	—	—	—	—
		Thieueman-niella	—	—	2	3/2	2	3/2	2/1	—	—	—	—	—	—	—	—	—
		Trichocledius	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—
		Trissocladius	1	1	—	1	2	3	3/1	—	—	—	—	—	—	—	—	—
		Podonominae																
		Labrundinia	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Tanypodinae																
		Ablabesmyia	—	—	2	—	—	1	—	—	—	—	—	—	—	—	—	1
		Coelotanypus	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—
	Empididae—	Hemeradromia	—	—	4	3	1	—	—	—	—	1	—	—	—	—	—	—
	Heleidae—	Palpomyia	—	1	1	1	—	—	1	—	—	—	1	—	—	—	—	—
	Simuliidae—	Prosimulium	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
		Simulium	1	—	—	5	2	4	1	1	—	—	—	—	—	—	4/1	1
	Tabanidae—	Tabanus	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
	Tipulidae—	Dicranota	1	—	3	2	—	—	—	—	—	—	—	—	—	—	—	—
		Hexatoma	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Limnophila	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
		Ormosia	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
		Pilaria	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		Tipula	3/2	1	3	1	—	—	1	1	3	1	—	—	—	—	—	—
Coleoptera—	Elmidae—	Macronychus	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Optioservus	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—

Table 2.--Benthic invertebrates identified during the study--Continued

Organisms			Land use: Forested 20a n=5	Forested 275c n=6	Forested 301a n=6	Agricultural 20 n=6	Agricultural 32 n=3	Agricultural 77 n=6	Agricultural 98 n=6	Agricultural 243a n=6	Unreclaimed mine 409 n=4	Unreclaimed mine 422 n=5	Unreclaimed mine 456 n=5	Unreclaimed mine 401 n=3	Unreclaimed mine 112a n=3	Unreclaimed mine 455 n=3	Reclaimed mine 417 n=6	Active/re-claimed mine 27 n=5
Coleoptera—	Elmidae—	Macronychus	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
		Optioservus	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—
		Stanelmis	—	1	—	2	—	—	—	1	—	—	—	—	—	—	—	—
Odonata—	Calopterygidae—	Calopteryx	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—
	Coenagriidae—	Argia	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—
	Cordulegastridae—	Cordulegaster	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gastropoda—	Lymnaeidae—	Lymnaea	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
	Physidae—	Physa	—	1	—	—	—	—	1	6/3	—	1	—	—	—	—	4/2	—
	Planorbidae—	Helisoma	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—
Pelecypoda—	Corbiculidae—	Corbicula	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—
	Sphaeriidae—	Sphaerium	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—	—
Amphipoda—	Gammaridae—	Crangonyx	—	2	—	—	—	—	2	1	—	—	—	—	—	—	—	—
	Talitridae—	Hyalella	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
Isopoda—	Asellidae—	Asellus	—	3	—	—	—	—	—	6/6	—	1	—	—	—	—	—	—
		Livceus	—	1	—	—	—	—	2	—	—	1	—	—	—	—	—	—
Decapoda—	Cambarinae—	Orconectes	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—
Hemiptera—	Veliidae—	Microvelia	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Megaloptera—	Corydalidae—	Corydalus	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—
	Sialidae—	Sialis	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Annelida—	Oligochaeta—	Enchytraeidae:	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
		Artocha	—	1	5	1	2/2	—	4	5/4	—	—	—	—	—	—	1	—
	Hirudinea—	Glossiphoniidae: Helobdella	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—

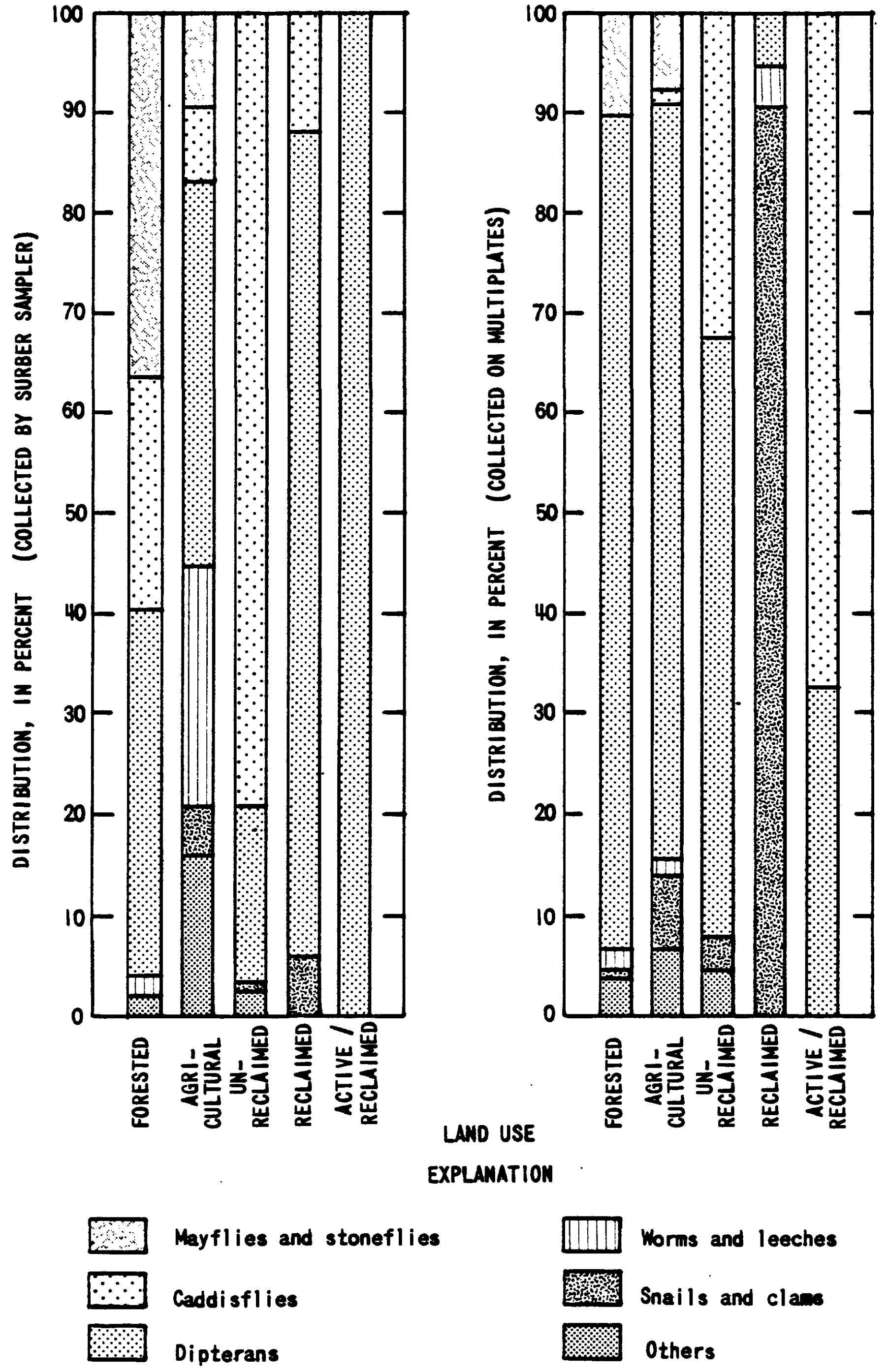

Figure 14.-- Benthic invertebrate distribution for selected land-use areas, southwestern Indiana, October-November 1979.

Periphytic Algae

Means, medians, and ranges of periphytic algae counts are shown in figure 15. The data are variable but the averages are similar, except ones at the unreclaimed-mine sites and the reclaimed-mine site. Those averages are lower because two unreclaimed-mine sites had no organisms, and the reclaimed-mine site had one unusually productive sample that raised the mean. Because of the large variability in the data and the lack of any clear trends, no clear conclusion can be drawn. Also, the variable periphyton-biomass data shown in figure 16 lacks a trend. Likewise, the variable community-diversity indices shown in figure 17 indicate that the average diversity of organisms at all of the land-use sites differed by less than one unit. The periphyton species listed in table 3 are similar for all land-use areas. Three differences between the land-use areas are: (1) Two of the unreclaimed-mine sites did not support any periphytic algae; (These were the same sites that did not support invertebrates); (2) green algae were present only at agricultural and forested sites and were absent from all the mined land-use sites, and (3) blue-green algae were present at only two of the unreclaimed-mine sites and were absent from the other land-use sites.

Means, medians, and ranges of chlorophylls a and b for each land-use area are presented in figure 18. The absence of chlorophyll b at the sites affected by mining is further evidence of the absence of green algae. The absence of algae at the two unreclaimed-mine sites is apparently caused by limiting-water-quality factors, but the absence of green algae and the presence of blue-green algae at mined land-use sites can not be explained with the available data.

Studies by Joseph (1953), Hendrey (1976), Hall and others (1980), and Muller (1980) indicated that the periphyton counts and biomass generally increase with a decrease in pH. Several diatoms and the euglenoid *Euglena* were found to be particularly tolerant. Hall and others (1980) reported a decrease in community diversity as sensitive organisms were replaced by more tolerant species. In general, all the studies indicated that pH affected the periphyton community less than the benthic invertebrate community and that the periphyton populations usually increased, owing to mining activity and the resulting change in water quality. The preceding authors and the author of this report collected periphyton samples with an artificial substrate. Hoehn and Sizemore (1977) found that natural periphyton communities are decreased or eliminated by the synergistic effect of pH, iron, zinc, copper, and cadmium but, more importantly, by the elimination of habitat when streambed materials were covered or coated by settleable solids that had been flushed into the stream and by precipitation of iron. The increase in concentrations of suspended solids during periods of disturbance also would affect the light available for algal growth. Therefore, even though many algal species can tolerate the chemical environment of areas affected by mining, the physical environment may make life impossible on natural substrates. This information suggests that if periphyton is to be used as an indicator of environmental changes in a stream affected by the mining of coal, samples will need to be collected from natural substrates rather than from artificial substrates.

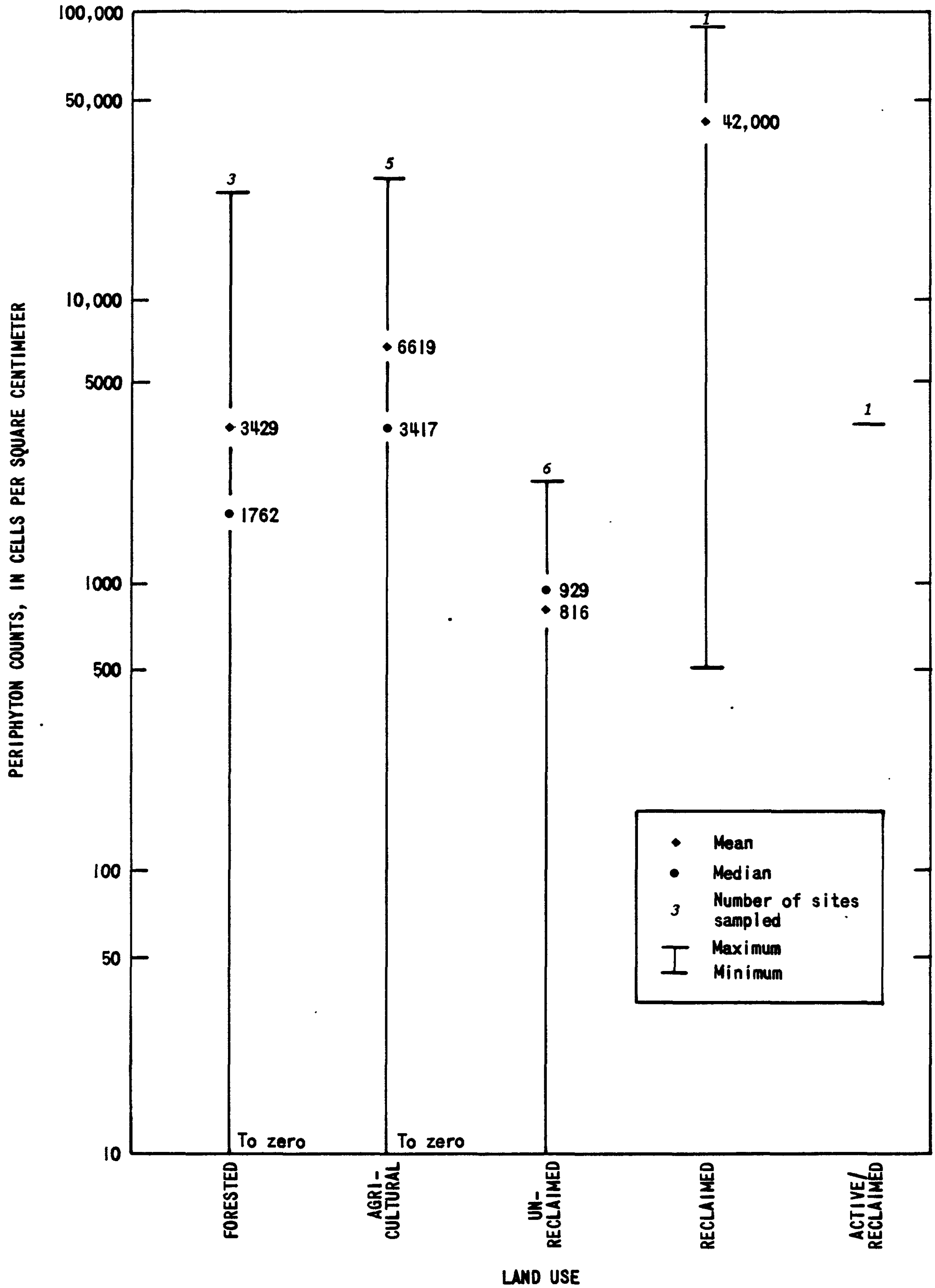

Figure 15.-- Numbers of periphytic algae for selected land-use areas, southwestern Indiana, October-November 1979.

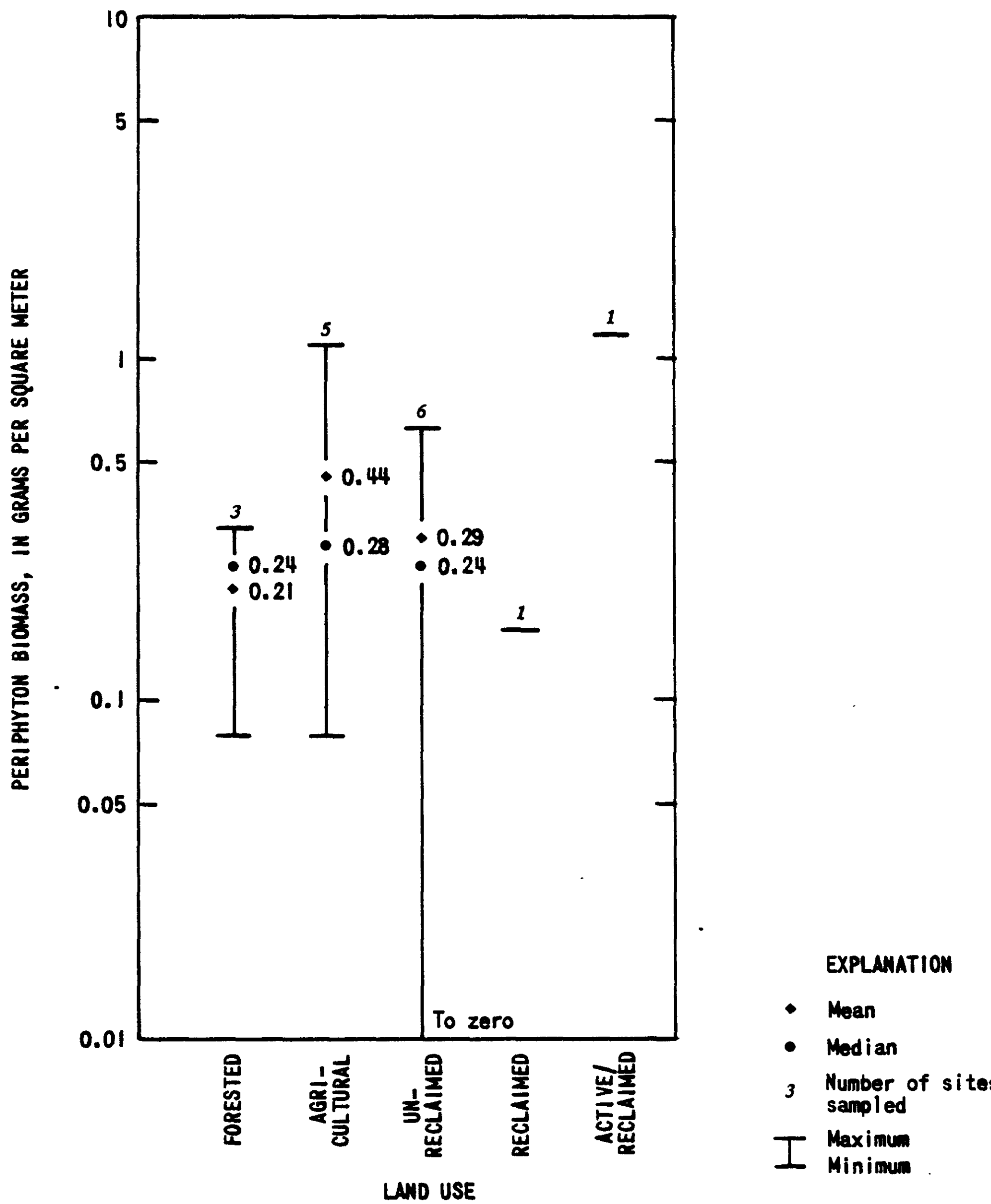

Figure 16.— Periphyton biomass for selected land-use areas, southwestern Indiana, October-November 1979.

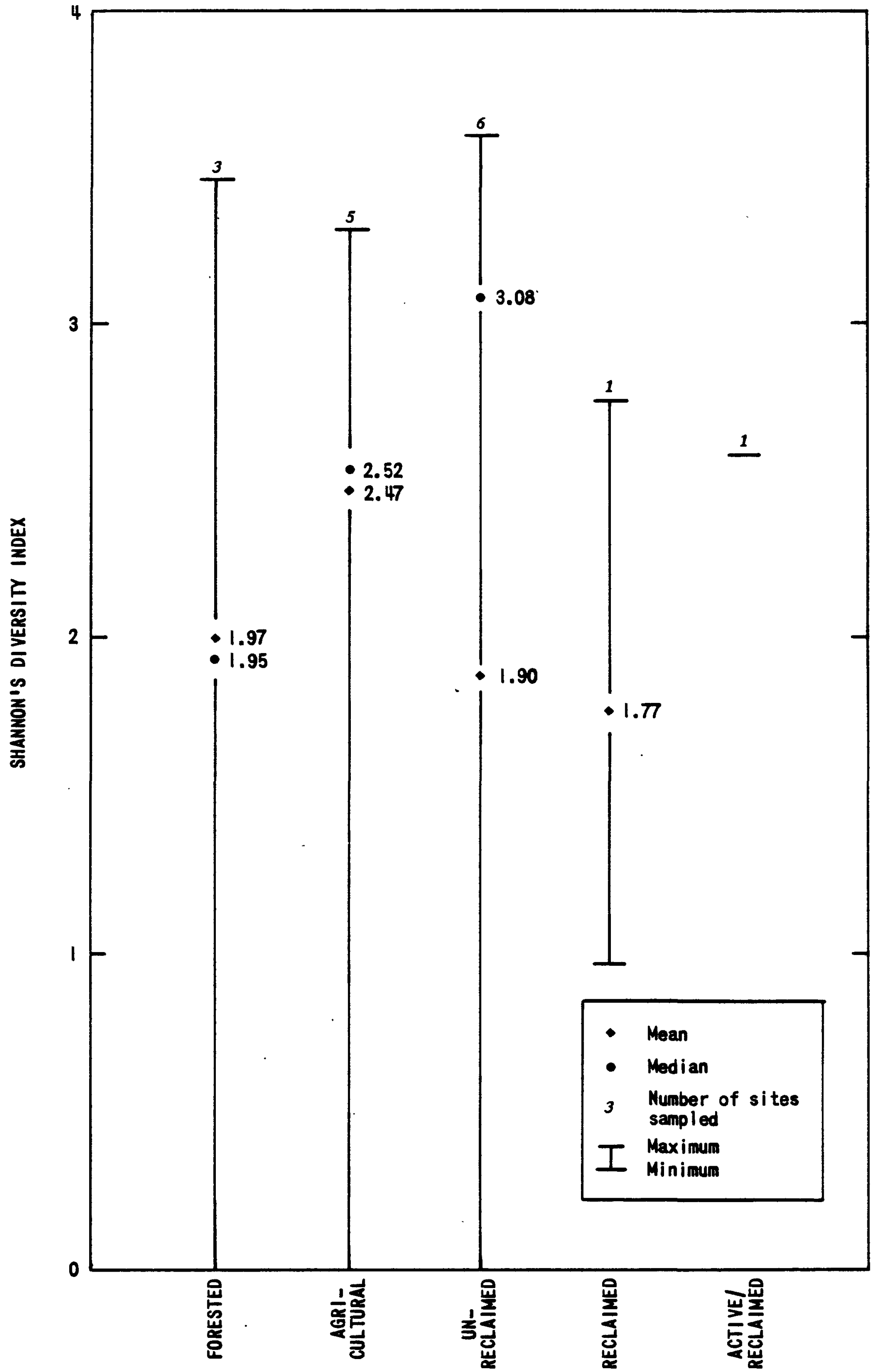

Figure 17.-- Periphyton diversity for selected land-use areas, southwestern Indiana, October-November 1979.

Table 3.--Periphytic algae identified during the study

[Number of samples in which the organism was identified/number of times organism was dominant; data collected by U.S. Geological Survey; 20a...27, sampling-site numbers; n, number of samplings for each land use]

	Land use															
	Forested			Agricultural					Unreclaimed mine						Re-claimed mine	Active/ re-claimed mine
Organisms	20a n=1	275c n=3	301a n=3	20 n=3	32 n=0	77 n=3	98 n=3	243a n=2	409 n=2	422 n=2	456 n=1	401 n=2	112a n=2	455 n=2	417 n=2	27 n=1
BACILLARIOPHYTA-Achnanthes clevei	—	—	—	1	—	—	1	1	—	1/1	—	—	—	—	—	—
Achnanthes lanceolata	1	—	2/1	—	—	1	3	—	—	1	—	1	—	—	1/1	—
Achnanthes minutissima	—	—	2/1	2	—	—	3	—	—	—	—	1	—	—	3	—
Amphipleura specie	—	—	1	—	—	—	2	—	1	1	—	1	—	—	2	—
Amphiprora specie	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—
Asterionella formosa	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Caloneis ventricoea	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Caloneis specie	—	—	2	—	—	—	1	—	—	—	—	—	—	—	—	—
Cocconeis disculus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Cocconeis pediculus	—	—	2	—	—	—	—	—	—	—	—	1	—	—	—	—
Cocconais placentula	—	1	3/1	3	—	2	3/1	2	1	2	—	—	—	—	2	—
Cocconeis specie	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cyclotella menaghiniana	—	—	2/1	1	—	1	—	—	—	—	—	—	—	—	—	—
Cyclotella ocellata	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
Cyclotella stelligera	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Cyclotella specie	—	—	—	2	—	1	—	1	—	—	—	—	—	—	1	—
Cymatopleura solea	—	—	1	2	—	2	—	—	1	1	—	—	—	—	—	—
Cymbella cistula	1	—	1	—	—	2	1	—	—	—	—	—	—	—	1	—
Cymbella cuspidata	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cymbella minuta	—	—	1	1	—	1	1	—	1	1	—	—	—	—	—	1
Cymbella sinuata	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Cymbella specie	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—
Diploneis margine-striata	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Diploneis ovalis	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Diploneis pseudovelis	—	—	—	—	—	—	—	—	1	2	—	—	—	—	1/1	—
Eunotia specie	—	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Fragilaria construens	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Gomphonema acuminatum	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Gomphonema dichotomum	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 3.--Periphytic algae identified during the study--Continued

Organisms	Land use															
	Forested			Agricultural					Unreclaimed mine						Re-claimed mine	Active/re-claimed mine
	20a n=1	275c n=3	301a n=3	20 n=3	32 n=0	77 n=3	98 n=3	243a n=2	409 n=2	422 n=2	456 n=1	401 n=2	112a n=2	455 n=2	417 n=2	27 n=1
BACILLARIOPHYTA-Gomphonema parrulum	—	—	—	1	—	—	2	—	—	—	—	—	—	—	1	—
Gomphonema truncatum	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Gomphonema specie	—	—	1	1	—	1	1	1	2	—	—	1	—	—	2	—
Gyrosigma spencerii	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Gyrosigma specie	1	—	2	2	—	2	3	1	1	2	—	—	—	—	—	1
Hantzschia amphioxys	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Melosira varians	1	—	3	2	—	2	1	—	—	—	—	—	—	—	—	1
Meridion circulare	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Navicula bacillum	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Navicula capitata	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Navicula exiqua	1	—	1	—	—	2	1	—	1	—	—	—	—	—	—	—
Navicula graciloides	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Navicula heufleri	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Navicula minima	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Navicula pseudoreinhardii	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Navicula pupula	—	—	—	—	—	1	—	2	1	—	—	—	—	—	1	—
Navicula radiosa	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—
Navicula salinarum	—	1/1	3	3/3	—	3/3	2/1	—	—	1/1	—	1	—	—	2	1
Navicula simplax	1/1	—	2/1	3/3	—	3/2	3/1	2	2/1	2/2	—	—	—	—	2	1/1
Navicula tripunctata	—	—	2	2	—	—	—	—	—	2	—	—	—	—	—	—
Navicula specia no. 1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Navicula specie no. 2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Navicula specie no. 3	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Navicula specie no. 4	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—
Navicula spacie no. 5	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Navicula specia no. 6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Navicula spacie no. 7	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Navicula specie no. 8	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Navicula viridula	—	—	—	2	—	1	2	—	1	—	—	—	—	—	—	—
Nadium specie	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Nitzschia acicularis	1	—	2	3	—	3	3	2	1	2	—	1	—	—	2	—
Nitzschia acuta	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
Nitzschia amphibia	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Nitzschia apiculata	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
Nitzschia communis	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Nitzschia dissipata	—	—	1	2	—	2	—	2/2	—	1	—	—	—	—	1	—
Nitzschia filiformis	—	—	—	2	—	1	1	—	1	2	—	—	—	—	1	—
Nitzschia linearis	—	1/1	3/1	3	—	2	—	2	1	—	—	—	—	—	—	1/1

Table 3.--Periphytic algae identified during the study--Continued

Organisms		Land use: Forested 20a n=1	Forested 275c n=3	Forested 301a n=3	Agricultural 20 n=3	Agricultural 32 n=0	Agricultural 77 n=3	Agricultural 98 n=3	Agricultural 243a n=2	Unreclaimed mine 409 n=2	Unreclaimed mine 422 n=2	Unreclaimed mine 456 n=1	Unreclaimed mine 401 n=2	Unreclaimed mine 112a n=2	Unreclaimed mine 455 n=2	Reclaimed mine 417 n=2	Active/reclaimed mine 27 n=1
BACILLARIOPHYTA—	Nitzschia obtuse	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
	Nitzschia palea	—	1/1	3/1	2	—	3	3/3	—	1/1	2	—	1/1	—	—	3	—
	Nitzschia sigmoidea	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—
	Nitzschia sublinearis	1/1	—	1/1	2	—	3	2	1	1	2	—	1	—	—	2	—
	Nitzschia specie no. 1	—	2/1	—	3	—	2	2/1	2/1	2/1	2	—	1	—	—	3	1
	Nitzschia specia no. 2	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
	Nitzschia specie no. 3	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
	Nitzschia specie no. 4	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
	Nitzschia specie no. 5	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
	Nitzschia tryblionella	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	1
	Nitzschia vermicularis	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
	Pinnularia specie	1	—	—	—	—	1	—	—	—	1	—	—	—	—	1	—
	Pleurosigma specie	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—
	Rhoicosphenia curvata	—	—	1	2	—	1	2	—	1	—	—	1	—	—	—	—
	Stauroneis specie	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
	Surirella angustata	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
	Surirella ovata	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
	Surirella specie	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—
	Synedra amphicephala	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
	Synedra radians	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
	Synedra tenera	—	—	—	—	—	—	—	—	1/1	—	—	—	—	—	2/2	—
	Synedre ulna	1	—	2/1	1	—	2	1	1	2	—	—	—	—	—	3	—
	Synedra specie	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—
	Tabellaria flocculosa	—	1	—	—	—	2	—	—	2	—	—	—	—	—	—	1
	Hannaea arcua	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
CHLOROPHYTA—	Closterium species	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
	Crucigenia tetrapedia	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—
	Gloeocystis specie	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
	Mougeotia specie	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
	Oedogonium specie	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
	Scenedesmus abundens	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—
	Ulothrix specie	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
CYANOPHYTA—	Oscillatoria specie	—	—	—	—	—	—	—	—	1	—	—	1/1	—	—	—	—
EUGLENOPHYTA—	Euglena specie	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1/1
CRYPTOPHYTA—	Chrocmonas specie	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
MISCELLANEOUS—	Fungi imperfeci	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
	Ciliates	—	—	—	1	—	1/1	1	—	—	—	—	—	—	—	—	—
	Flagellates	—	—	—	1	—	—	—	1/1	—	—	—	—	—	—	—	—

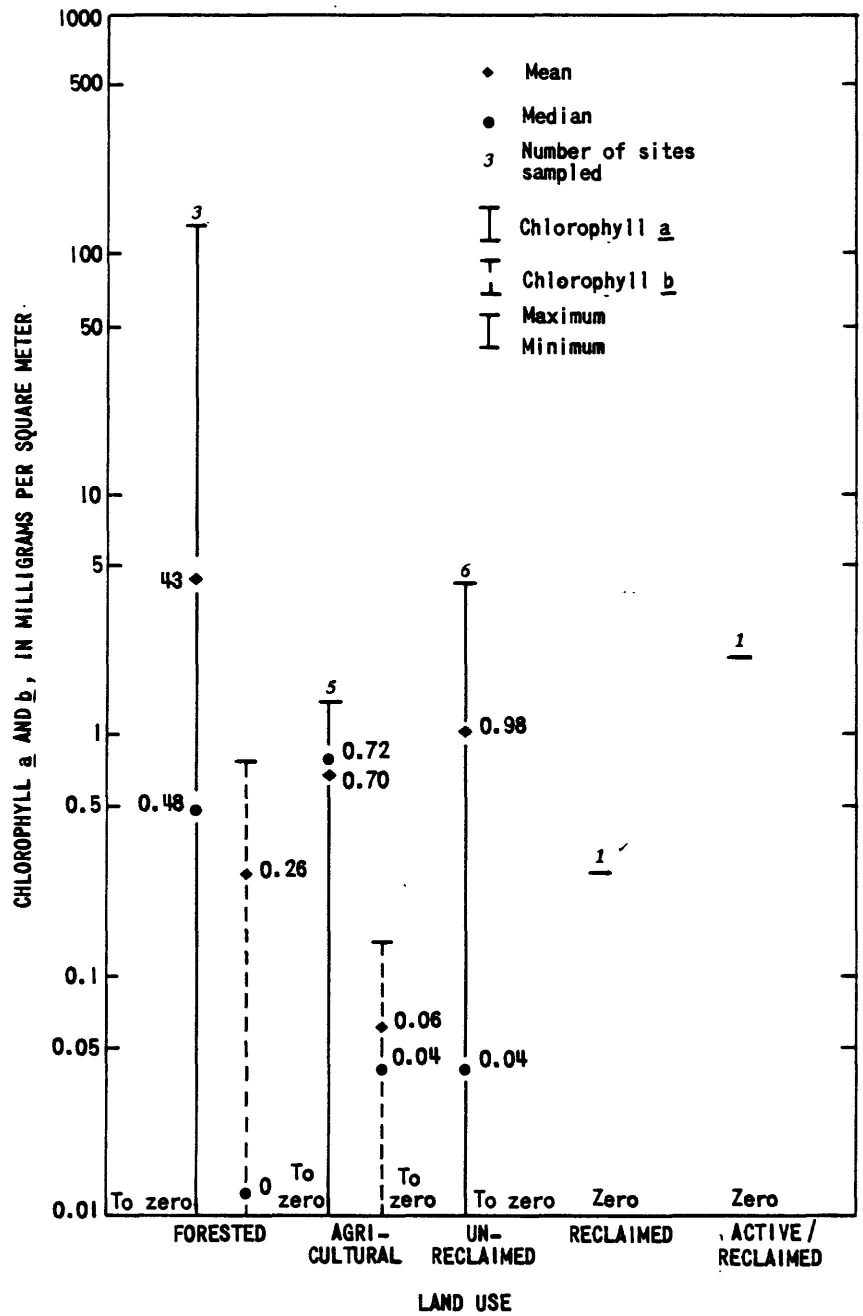

Figure 18.— Chlorophyll a and b in periphyton from selected land-use areas, southwestern Indiana, October-November 1979.

SUMMARY

This report discusses benthic-invertebrate and periphytic-algal communities in streams draining watersheds of five homogeneous land uses (forested, agricultural, unreclaimed mine, reclaimed mine, and active/reclaimed mine) and relates the biological communities to the physical and chemical characteristics of the streams.

The effect of runoff from mining areas, especially unreclaimed areas, was worse on water quality than that of runoff from forested or agricultural land-use areas. When the data for mined land-use sites are compared to the data for the forested and agricultural land-use sites, several relations are noted: (1) pH and alkalinity are lower at unreclaimed-mine sites; (2) specific conductance and concentrations of dissolved solids and hardness are higher at unreclaimed-mine sites; (3) concentrations of major ions, such as magnesium, calcium, sodium plus potassium, and especially sulfate, are higher at unreclaimed-mine sites; (4) concentrations of the metals iron, manganese, aluminum, zinc, copper, and nickel, in water, and aluminum, iron, and manganese, on streambed materials, are higher at unreclaimed-mine sites; (5) during intense rainstorms, runoff causes a substantial decrease in pH and alkalinity and a substantial increase in concentrations of suspended solids and total iron, aluminum, and manganese at an unreclaimed-mine site; (6) nitrite plus nitrate concentrations are highest at the active/reclaimed-mine site and the reclaimed-mine site; and (7) more silt- and clay-size streambed materials (>30 percent) are present at the active/reclaimed-mine site and more gravel-sized particles are present at the forested sites, which indicates that a better benthic habitat is available to organisms at forested sites than at other land-use sites.

Types and concentrations of periphytic algae were generally similar for all land uses. Many algal species can tolerate the chemical consistency of water draining areas affected by mining but probably are eliminated by the physical conditions of the benthic habitat. Therefore, in any further study of periphytic algae in coal areas, samples of both natural and artificial substrates would be needed.

Benthic invertebrate communities were adversely affected by the physical and chemical quality of the streams draining mined areas. Decreases in number and diversity of the invertebrate communities in the mined areas were greater than in forested and agricultural land-use areas. Samples from several of the unreclaimed mine sites contained no organisms. At unreclaimed-mine sites where organisms were captured, few groups were represented. The caddisflies *Cheumatopsyche* and *Hydrosyche* and chironomids *Chironomus* and *Crisotopus* seem to be tolerant of the stream's physical and chemical conditions resulting from mining. Mayflies and stoneflies that were common or even dominant in samples from forested and agricultural land-use sites were absent from all the sites affected by mining.

Several factors seem to affect the numbers and the types of benthic invertebrates that inhabit streams affected by mining. One of the major factors is pH. Many organisms are immediately sensitive to a decrease in pH, particularly the sharp decreases associated with runoff from unreclaimed mine sites during rainstorms. Also associated with a decrease in pH are the higher concentrations of metals such as iron, manganese, aluminum, zinc, nickel, and copper at unreclaimed-mine sites than at other land-use sites. Metal toxicity is dependent on the availability of the dissolved metal to the affected organisms. The pH and high concentrations of metals are often considered by several authors to have synergistic effects on the biological communities because it is difficult to separate the individual pH and metals toxicities in a natural setting. Another factor is the size of the streambed materials, which determines the type of habitat available to benthic organisms and the stability of the habitat. Large substrates offer a more diverse and stable habitat than small substrates. Streams that were affected by mining contained less gravel- and more sand-, silt- and clay-sized streambed materials than the streams in agricultural or forested areas. Still another factor is drainage area. The drainage upstream from a disturbed site affects the availability of invertebrates to the drift. A large upstream drainage area can provide a larger number of drift organisms for recolonizing a disturbed stream reach than a small upstream drainage area. In Indiana, much of the land disturbed by mining is in the headwaters of streams, which means that few or no organisms may be available to recolonize the affected streams after elimination of organisms by physical disturbance or chemical toxicity. Thus, the mined areas were affected by low pH (particularly during rainstorms), high concentrations of several metals, poor benthic habitat (characterized by small streambed materials and instability of the stream bottoms), and small drainage areas.

The data from this reconnaissance indicate that the number and the type of benthic invertebrates are related to land disturbance associated with land use. Forested areas are least disturbed, and mined areas are most disturbed. However, a better understanding of the factors listed in the preceding paragraph, and any other factors related to the biological community structure of the various land uses, is needed before any direct relationships can be drawn between degree of land disturbance and degree of disturbance of the biological communities.

REFERENCES

Archibald, R. E. M., 1972, Diversity in some South African diatom associations and its relation to water quality: Water Research, v. 6, p. 1229-1238.

Buchanan, T. J., and Somers, W. P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A8, 65 p.

Chapman, Gary, 1978, Toxicological considerations of heavy metals in the aquatic environment, <u>in</u> Toxic materials in the aquatic environment: Seminar Conducted by Water Resources Research Institute, Oregon State University, Corvallis, Oregon, July 1978, Proceedings, p. 69-77.

Greeson, P. E., Ehlke, T. A., Irwin, G. A., Lium, B. W., and Slack, K. V., 1977, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A4, 332 p.

Guy, H. P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Guy, H. P. and Norman, V. W., 1970, Field methods for the measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 59 p.

Hall, R. J., Likens, G. E., Fiance, S. B. and Hendrey, G. R., 1980, Experimental acidification of a stream in the Hubbard Brook Experimental Forest, New Hampshire: Ecology, v. 61, no. 4, p. 976-989.

Hendrey, G. R., 1976, Effects of pH on the growth of periphytic algae in artificial stream channels: SNSF, Project IR 25/76, 50 p.

Herricks, E. E., and Cairns, John, Jr., 1972, The recovery of stream macrobenthic communities from the effects of acid-mine drainage: Coal Mine Drainage Research Symposium, 4th, Mellon Institute, Pittsburg, Pa., April 1972, Proceedings, p. 370-398.

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

Hynes, H. B. N., 1972, The ecology of running waters: Toronto, University of Toronto Press, 555 p.

Joseph, J. M., 1953, Microbiological study of acid mine waters: Preliminary report: The Ohio Journal of Science, v. 53, no. 2, p. 123-127.

Kimmel, W. G., and Hales, D. C., 1973, Acute toxicity of low pH to aquatic insects, in Fish and food organisms in acid mine waters of Pennsylvania: Environmental Protection Agency, Office of Research and Monitoring, EPA-R3-73-032, p. 125-158.

Lium, B. W., 1974, Some biological aspects of pools and riffles in gravel bed streams in Western United States: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 379-384.

Muller, P., 1980, Effects of artificial acidification on the growth of periphyton: Canadian Journal of Fish and Aquatic Science, v. 37, no. 3, p. 355-363.

Parsons, J. D., 1968, The effects of acid strip-mine effluent on the ecology of a stream: Archiv Hydrobiologie, v. 65, no. 1, p. 25-50.

______ 1976, Effects of acid-mine wastes on aquatic ecosystems: Proceedings of the International Symposium on Acid Precipitation and the Forest Ecosystem, 1st, Columbus, Ohio, May 12-15, 1975, p. 571-591.

______ 1977, Effects of acid-mine wastes on aquatic ecosystems: Water, Air, and Soil Pollution, v. 7, p. 333-354.

Platts, W. S., Martin, S. B., and Primbs, E. R. J., 1979, Water quality in an Idaho stream degraded by acid mine waters: U.S. Forest Service, General Technical Report INT-67, 19 p.

Roback, S. S., and Richardson, J. W., 1969, The effects of acid mine drainage on aquatic insects: Proceedings of the Academy of Natural Science of Philadelphia, v. 121, p. 81-89.

Simpson, E. H., 1949, Measurement of diversity: Nature, v. 163, p. 688.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdman, 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.

Wilber, W. G., Crawford, C. G., Renn, D. E., Ragone, S. E., and Wangsness, D. J., 1980, Preliminary assessment of the factors affecting water quality in the coal-mining region, southwestern Indiana, March to October 1979: Indiana Water Resources Association Symposium, Water Resources and Land-Use Management in Indiana, Marshall, Ind., June 12-14, 1980, Proceedings, p. 215-234.

Wilhm, J. L., and Dorris, T. C., 1968, Biological parameters of water quality: Bioscience, v. 18, p. 447-481.