To the Graduate Council:

I am submitting herewith a thesis written by Clark S. Fletcher entitled "A Geochemical Study of the Effects Coal Mining Has Had on the Piney Creek Watershed, Van Buren County, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

Don W. Byerly, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

A GEOCHEMICAL STUDY OF THE EFFECTS COAL MINING HAS HAD ON THE PINEY CREEK WATERSHED, VAN BUREN COUNTY, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

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ABSTRACT

The Piney Creek watershed has been disturbed by mining operations for many years. The mines, which are now inactive, still produce many potential pollutants which are common by-products of coal mining operations. This thesis deals with the effects which these inactive mines still have on Piney Creek and provides the base line values which can be used in later studies on Piney Creek. The study was primarily set up to compliment a reclamation program; however, with the recent prospects of renewed mining in the watershed, this study may take on added importance by serving to also monitor the effects of future mining activities.

In order to determine the present condition of Piney Creek a number of different entities were studied. These included water chemistry, metals in the stream sediment, metals in filterable material from discharge waters at point sources of pollution, and two biologic inventories.

Water samples were analyzed for Fe, Mn, pH, sulfate and conductivity. Sampling was conducted by taking grab samples over a 23-month period at nine different sites.

Sediment analyses for metals were performed on samples from nine different sites. Each site was sampled five times and the sediment collected was analyzed for iron, manganese,

zinc, lead, copper, and cobalt by atomic absorption spectrophotometry.

Suspended particulate material in water at three point sources of pollution were trapped and analyzed for iron, manganese, and zinc. This was done by field-filtering discharge water and analyzing the filtrate by atomic absorption spectrophotometry.

Two biologic parameters were studied at sites along Piney Creek with the aid of the Tennessee Wildlife Resources Agency and the Tennessee Division of Water Quality Control. The benthonic life was inventoried and the fish population was sampled at selected sites in Piney Creek.

Water chemistry analyses indicate that the water does show effects that can be related to the inactive mines. Analyses of the stream sediment show an increase in metals content in areas of mining. Studies of the suspended material at point sources indicate that a significant amount of metals are held in suspension as particulate material. Both biologic studies indicate a reduction in diversity of species present in areas which have mine drainage.

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CHAPTER I

INTRODUCTION

I. PURPOSE OF THE INVESTIGATION

Coal mining results in an abnormal exposure of coal and related strata to subaerial weathering. Thus, a number of mining-derived potential pollutants can become incorporated in the fluvial system which drains mined areas, and can create an ecological hazard. A great deal of research has been devoted to the environmental impact of active mining; however, vast areas of previously mined countryside still remain in a disturbed condition. These abandoned underground mines and orphan surface mines were active before reclamation laws were legislated. Mines of this type are and may continue to be sources of pollution for scores of years and hinder the progress of stream rehabilitation. Thus, an ecologically degraded fluvial system may remain depressed for a great many years due to coal mining activities, and some may never totally recover naturally.

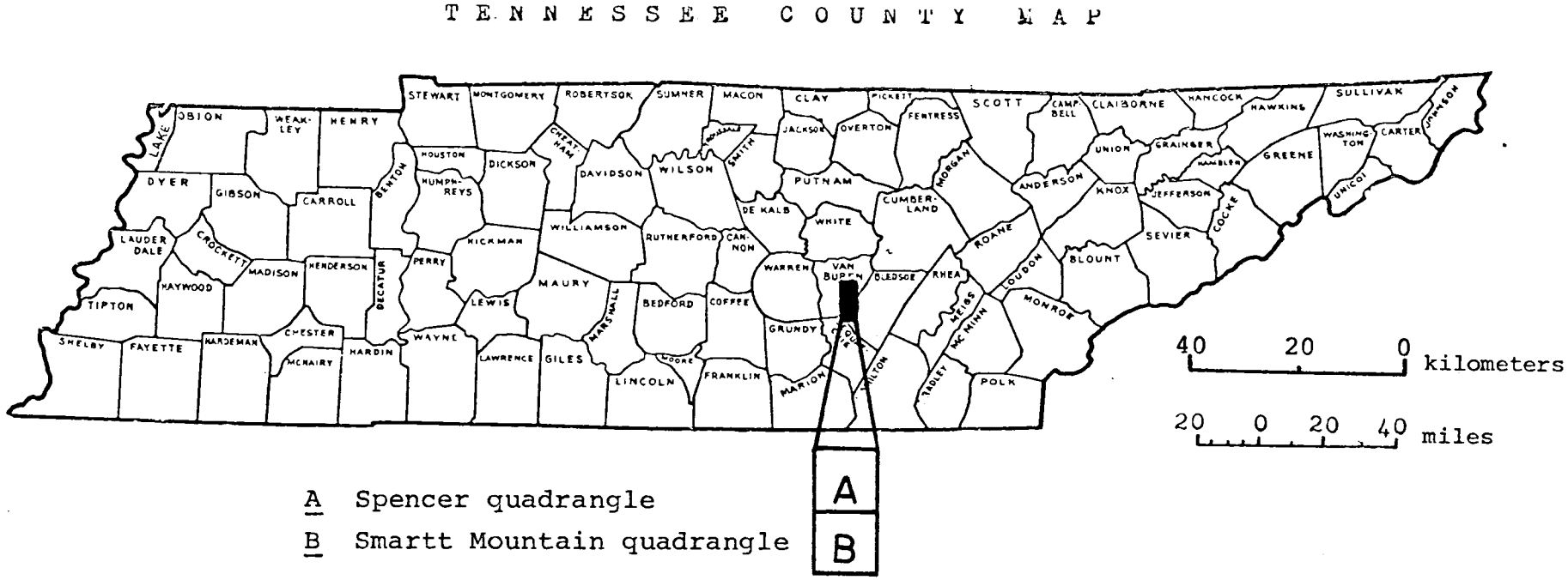
The purpose of this research was to establish the present condition of Piney Creek through the study of a number of environmental parameters which can later be used to measure the progress of the stream's rehabilitation. These parameters are metals in the stream sediment, water chemistry,

filtered particulate metals, and studies of fish and benthonic life. This array of base line studies should give an accurate account of the environmental condition of Piney Creek prior to reclamation attempts, and show the long-term effect of environmentally hazardous mining techniques.

II. LOCATION

Piney Creek is part of the Caney Fork fluvial system, which drains a portion of the Southern Cumberland Plateau. A dam on Caney Fork River forms Center Hill reservoir in De Kalb County, Tennessee. The Piney Creek watershed embraces some 22,000 acres in Van Buren County, Tennessee, and is located on the Smartt Mountain and Spencer 7 1/2 minute quadrangle maps (Figure 1). Piney Creek was chosen for this project because of its drainage into Fall Creek Falls State Park and the lack of active mining inside the watershed at the time of the project conception. The watershed was then protected from new mining activities by the establishment of a five-year mining moratorium by the Tennessee Department of Conservation, Division of Surface Mining. This area was also chosen for the study because of the presence of the combined environmental impact of abandoned underground and orphan surface mines.

Piney Creek first comes in contact with mine discharge approximately 3 3/4 miles (6 kilometers) downstream from its



A Spencer quadrangle

B Smartt Mountain quadrangle

Figure 1. Location of the Spencer and Smartt Mountain quadrangles.

origin at Hitchcox Mountain. Mine effluent continues to enter the stream as it flows northward some 11 more miles (17.7 kilometers) to the boundary of Fall Creek Falls State Park. The last evident influence from mining is at the confluence of the Rockhead underground mine discharge into Piney Creek, approximately 1 3/4 miles (2.8 kilometers) west and upstream from Fall Creek Falls State Park.

III. GEOLOGIC SETTING

Stratigraphic Location

The Cumberland Plateau of Tennessee is a long, narrow arch between the coal basins of the central Appalachians to the north and the Black Warrior structural basin to the south. The portion of the plateau south of Interstate 40 is designated the Southern Cumberland Plateau. The plateau is bordered by a linear escarpment on the east, and the Highland Rim on the west and northwest (Milici, 1974).

The plateau is composed of a thick sequence of Pennsylvanian age strata consisting mostly of sandstones and shales which protect the less resistant underlying Mississippian carbonates. The more resistant sandstones act as cap rocks, and due to the near horizontal attitude, give a flat-topped, tableland character to the area.

Bedrock exposed within the Piney Creek watershed consists of the Crab Orchard Mountain Group of early

Pennsylvanian age (Figure 2). The most frequently exposed units in the watershed include the Whitwell Shale, the Newton Sandstone, and the Sewanee Conglomerate. Occasional exposures of the Vandever Formation occur in the higher elevations. The unit of principal economic importance is the Whitwell Shale. It consists of interbedded shales, siltstones, and sandstones, all of which are very pyritic and/or carbonaceous in part. In this watershed the Whitwell Shale also contains two mineable coal seams, the Richland and the Sewanee. Above the Whitwell Shale is the Newton Sandstone which is generally a fine-grained locally micaceous sandstone with high-angle crossbedding. Below the Whitwell Shale is the Sewanee Conglomerate which is composed of medium- to very thick-bedded sandstone, conglomeratic sandstone and conglomerate.

The Sewanee seam which occurs in the upper Whitwell Shale is the major seam of mining interest in the Smartt Mountain quadrangle (Eframian, 1976). The seam is covered with from 20 to 40 feet (6.1 to 12.2 meters) of carbonaceous shale with occasional lenses of pyritic sandstone which is capable of generating severe acid problems. The seam is generally 12 to 60 inches (30.5 to 152.4 centimeters) thick, but is structurally thickened to as much as 12 feet (3.7 meters) in local areas outside the watershed. Laterally the quality of the coal varies significantly. The BTU range is

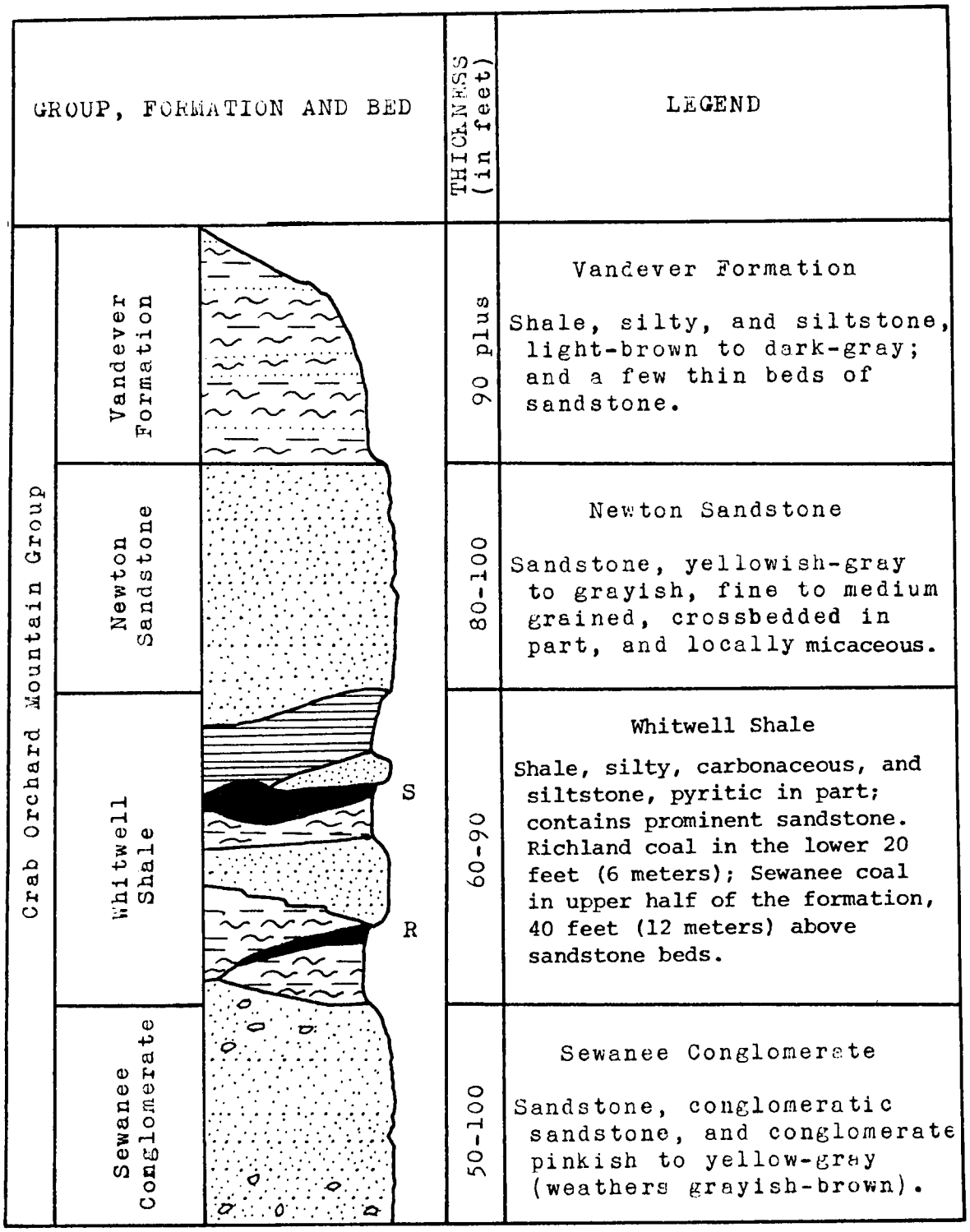


Figure 2. Geologic column of the Crab Orchard Mountain group in the Piney Creek watershed. [Taken from the Geologic map of the Spencer Quadrangle, Tennessee, after Robert C. Milici (1969).]

from 13,000 to 15,000, and sulfur ranges from .4% to 1.4% inside the Piney Creek watershed (Milici, 1969A and Eframian, 1976).

The Richland seam, located stratigraphically near the base of the Whitwell Shale, is the most frequently mined seam in the Spencer quadrangle (Milici, 1969B). Like the Sewanee seam the Richland seam also changes laterally with considerable variation in both thickness and quality. Its average observed thickness ranges from 0 to 55 inches (140 centimeters), but it may be locally thickened due to structural deformation. The sulfur content of the Richland seam is much higher than that of the Sewanee, ranging from 2.5% to greater than 4% (Eframian, 1976).

The existence of a sandstone unit immediately above the Richland seam (Figure 2) in some areas made underground mining practical by providing roof support. The major underground mining complex is located in the Richland seam in the area of the abandoned mining community of Phiferes in the northern portion of the watershed (Plate 1). This area is the source of most of the acid mine drainage generated from underground mines inside the Piney Creek watershed.

Environment of Deposition

Ferm, Milici, and Eason (1972) interpreted the stratigraphy of the southern plateau as a product of a system of prograding littoral environments, proceeding

generally from north to south. As a result, an interrelated system of tidal-delta, lagoon, marsh, and tidal-channel environments developed. The interbedded sands, shales, siltstones, and coals of the Crab Orchard Mountain Group were deposited in this type of coastal-marine environment.

Ferm, Milici, and Eason (1972) stated that the Newton Sandstone, which consists mostly of fine- to medium-grained sandstone containing crossbedded units, was deposited in a tidal-delta environment; that the Whitwell Shale, composed mostly of siltstone, shales, and a number of coal seams, is a result of barrier-back lagoonal and marsh deposition; and that the Sewanee Conglomerate, with its high-angle cross-bedding and massive channel-fill sands, can be interpreted as a subtidal portion of a reworked barrier system.

In a prograding system of littoral environments, like the one proposed by Ferm, Milici, and Eason (1972), large amounts of organic material generally accumulate in the lagoonal and marsh areas. In the case of the Whitwell Shale these deposits were preserved and make up the various coal seams and carbonaceous shales present in the area. Variation in the composition of the coals at different localities may be attributed to local differences in the depositional environment.

IV. RECLAMATION

One phase of the Piney Creek Project consisted of a reclamation program. The purpose of this program was to establish a basic vegetation cover on the surface mines and to reduce or eliminate any underground mine acid drainage which was considered to be within the project limits.

In the course of the project all of the 13 surface mines, such as the one shown in Figure 3, were planted with trees, shrubs, and/or grass. A total of approximately 230,000 trees and shrubs were planted on the 425 acres of disturbed land. Grass of various species was used in some areas. In planting grass, 2500 pounds of grass seed was used in conjunction with 13 tons of fertilizer and over 200 tons of agricultural lime.

The project also undertook the sealing of two underground mines, such as the one shown in Figure 4. Rockhead and Phiferes Number One underground mines (Plate 1) were sealed and both appear to be holding. The seals were a double bulkhead type seal, using crushed limestone as the major building component. Each seal was grouted with a cement mixture after construction.

The project completed many other tasks which are too numerous to be discussed in this thesis (Byerly, Eagle and Fletcher, 1974-1976). The majority of this work was completed through the use of manual labor. The work crews



Figure 3. Photograph showing a portion of surface mine number 6 before reclamation.



Figure 4. Photograph showing the adit of Rockhead underground mine and its discharge over a six inch V-notch weir.

were made up of boys from the Taft Youth Center, Pikeville, Tennessee.

CHAPTER II

LITERATURE REVIEW

Due to our higher standard of living, the mining of natural resources has grown rapidly over the past 150 years. This growth in many cases has been coupled with deterioration of the natural equilibrium in many biological systems. Though the existence of this relationship is well known, it is not totally understood.

Coal mining disturbs the earth and unbalances natural systems. In general, most types of mining generate some type of water pollution which may be categorized as being either physical and/or chemical. Physical pollution includes increased sediment and results from rapid erosion of exposed spoil. Chemical pollution, the undesired increase in concentrations of dissolved materials, may be generated by both oxidation or leaching of previously unexposed minerals.

Stream sediment is derived from the weathering, erosion, and transport of the regolith and bedrock underlying the terrain adjacent to the stream. Mining exposes large amounts of bedrock material to subaerial weathering, resulting in increased erosion and greater sediment loads in the streams. Train (1973) and many other researchers have reported that siltation is one, if not the major type of stream pollution resulting from coal mining. Collier (1970) reported that

coal strip mining operations may increase sediment yield 1000 times. For this reason, this writer felt that in order to have an in-depth study of Piney Creek's physical condition, a sediment study would be warranted.

In the course of the Piney Creek Project, a study of the metal concentrations of Fe, Mn, Zn, Pb, Co, and Cu contained in the sediment was conducted. These metals were chosen because previous research in coal mined areas of the Cumberland Plateau showed these trace metals to be of principal interest (Schrader, 1975, and Upham, 1975).

Schrader (1975) stated that coarse fractions of sediment generally approximate their metal content with that of associated shales. Though direct weathering and transport of metals incorporated in the bedrock may occur, Magee, Hall, and Varga (1973) reported that many elements do increase in stream sediments due to mining. Included in those that increase are Fe, Mn, Zn, Pb, Co, and Cu. They also reported that many recorded trace element values for coals and associated strata may be incorrect due to natural leaching of the weathered samples used in the analyses.

Upham (1975) demonstrated that a significant amount of hydrous Fe and Mn oxide coating occurs in sediments of the 105-1000μ size fractions and smaller in sediments in coal mining-affected areas.

Siegel (1974) stated that once ions are liberated from solids by the various weathering processes and enter the hydrological system, they may react according to their ionic potential. This may result in areas of precipitation of metals some distance downstream from the point source. He further stated that Fe and Mn oxides tend to precipitate out of mine waters with increasing pH and Eh. The research of Upham (1975) indicated that some trace metals, such as Cu, may be trapped in the loose molecular structure of Fe and Mn oxides.

Iron, which is by far the most abundant metal in the stream sediment, commonly occurs as FeS_2 in coal and associated strata. Blatt, Middleton and Murray (1972) stated that in calm swamp waters O_2 concentration decreases, resulting in a reducing environment. Under such conditions, gray to black shales with a high percent of organic matter are formed. Also, in such an environment, ferrous iron combines with sulfur to form one of the mineralogical forms of FeS_2. The environment of deposition of some units of the Whitwell Shale was probably very similar to that described by Blatt, Middleton and Murray (1972). Connor and Shacklette (1975) determined that there was a broad range of Fe concentration (.45% to 10%) in Pennsylvanian shales of Kentucky. Milici (1969A) reported that in the Piney Creek area, the sulfur content in the Sewanee seam ranges from .5% to .88%, while

the Richland seam has 3.2% sulfur content in a mine immediately north of the watershed.

Acid generation associated with mining operations is closely tied to the FeS_2 contained in the coal and associated strata. A paper by the Ohio State University Research Foundation (1971) stated that the oxidation rate of the "pyritic system," which is any acid-producing situation associated with mining, is dependent on a number of physical, chemical, and microbiological factors. These factors include transport of mobile reactants, as well as the physical environment of the reaction.

Oxidation of pyritic materials associated with coal is described by the Ohio State University Research Foundation (1971) by the following equation:

Step 1 $\quad 2(FeS_2) + 7O_2 + 2H_2O \longrightarrow 4SO_4^{=} + 2Fe^{++} + 4H^{+}$

2 $\quad 4Fe^{++} + O_2 + 4H \longrightarrow 4Fe^{+++} + 2H_2O$

3 $\quad Fe^{+++} + 3H_2O \longrightarrow \underline{Fe(OH)}_3 + 3H^{+}$

In the above equation, one can see the importance of FeS_2 in acid production. Even though ferric hydroxide [$\underline{Fe(OH)}_3$] is not considered to be highly toxic to stream biologic systems, the acid which is generated during its production is highly toxic (Ohio State University Research Foundation, 1971). Under periods of stress such as high acidity, biologic diversity decreases as the tolerance

limits for given organisms is reached. Thus, the total number of species present is reduced. Hydrogen ion concentration, or pH, is important in the study of aquatic environments (Odum, 1959). The pH is very important in regulating respiration and enzyme systems within organisms, and a small difference is critical. Thus, one of the physiochemical limiting factors of mining-affected streams is pH. Acid generation also serves to make toxic metals more soluble and available to organisms in the fluvial system.

Water of low pH may be partly neutralized in nature by the degradation of illite clay to kaolinite clay. The following reaction is given by Grim (1968) to explain this occurrence:

$$2KAl_2(AlSi_3)O_{10}(OH)_2 + 5H_2O \longrightarrow 3Al_2Si_2O_5(OH)_4 + 2KOH$$

Grim goes on to state that illite clay is by far the most abundant clay mineral in argillaceous rocks. The presence of shales, which contain clay minerals, in the Piney Creek watershed may serve to neutralize some of the acid generated by oxidizing sulfides.

Another mechanism for reducing acid is the reaction of limestone with low pH waters. Pearson and McDonnell (1974) proposed the following reaction for limestone dissolution:

$$CaCO_3 + H^+ \longrightarrow Ca^{2+} + HCO_3^-$$

$$HCO_3^- + H^+ \longleftrightarrow H_2CO_3$$

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

Even though no limestone outcrops are present in the project area, Piney Creek encounters limestone inside Fall Creek Falls State Park as it descends into the upper Mississippian strata of the Pennington and Bangor Formations (Milici, 1969B). Limestone used for road gravel also provides a considerable amount of limestone to the drainage area.

Upham (1975) observed that manganese concentrations increase in stream sediment after coal mining. Even though manganese has a much lower affinity for oxygen than iron (Rankama and Sahama, 1950) resulting in slower oxidation rates, it is an important metal in stream sediment for base line studies. Manganese oxides (though very insoluble and immobile in natural waters) can be leached from spoil material as shown by Massey and Barnhisel (1972). They reported Mn concentrations of 1800 ppm in unfiltered interstitial solutions from surface mine spoil banks in Kentucky. This writer has observed Mn concentrations in excess of 9000 ppm in surface mine impoundments in the Piney Creek watershed. The lower pH of the water in the Piney Creek area, 3.9, as compared to higher than 4.5 in eastern Kentucky, may

possibly account for the higher Mn concentration. Posselt, Anderson, and Weber (1968) stated that Mn hydroxides probably occur in natural waters whenever a sufficient source for Mn is present.

Zinc, though not normally as abundant as Fe and Mn in coal mining-affected stream sediment, should be considered worthy of mention in base line studies. Connor and Shacklette (1975) reported that Zn concentrations in Pennsylvanian shales may range from 25 to 780 ppm. Massey and Barnhisel (1972) reported Zn concentrations of 145 ppm in solutions of mining-affected water in Kentucky. This shows the ability of zinc to be leached from spoil material and to be held in solution. The mobility of zinc is low and usually is absorbed by clay, Fe^{+++} oxides, and organic matter (Wedepohl, 1971).

Massey and Barnhisel (1972) reported that Zn concentrations were higher in mining spoil than in natural soils. Nigrini (1971) demonstrated that by increasing the pH of water, the concentrations of Cu, Pb, and Zn in the water can be decreased because of their capture by Fe and Mn oxide precipitates. This should result in increased concentration of zinc in the sediment.

Siegel (1974) stated that Pb is a good "pathfinder" element in many geochemical studies because of its ease of detection and its affinity for organic material. Rankama

and Sahama (1950) stated that upon weathering and transport lead can form a stable compound, $PbSO_4$. Lead is more likely to occur in the sulfate form in the Piney Creek watershed than as the bicarbonate, Pb, due to the lack of carbonate rocks.

Goldschmidt (1954) reported that concentrations up to 1000 ppm of Pb occur in some coal ash. Connor (1975) reported Pb concentrations of 10 to 100 ppm in Pennsylvanian shales. Upham (1975) stated that Pb concentrations in the sediment of his study area were probably affected by strip mining. However, Magee, Hall, and Varga (1973) noted an increase in Pb due to mining operations. Most of this increase may be caused by the Pb capture by Fe and Mn oxides, which are precipitated from mining-affected waters.

Connor and Schacklette (1975) reported that cobalt is a relatively rare element in the Pennsylvanian shales. Upham (1975) reported that Co has the ability to coprecipitate with Fe and Mn oxides, and Blatt (1972) stated that Co may be entrapped in Mn oxide minerals. Part of the reason for this may lie in the very similar ionic potential of Co^{++} (2.8) as compared to Mn^{++} and Fe^{++}, 2.5 and 2.7 respectively. Mason (1966) showed a very unique change in the redox potential of Fe^{++}, Co^{++}, and Mn^{++} with a change in pH. All three elements show a radical change in the redox potential between pH 4 through 8. In general, the oxidizing potential

for a reaction increases in a near linear fashion with the change of pH; however, Co^{++}, Mn^{++}, and Fe^{++} show a strong inflection from a linear path when plotting pH versus Eh, between pH 4 and 8.

Goldschmidt (1954) reported that copper can occur in high concentration in sulfide-bearing muds under reducing conditions. Siegel (1974) stated that Cu, much like Zn, is very easily oxidized in the presence of pyrite, which is a common mineral associated with the coal of the Piney Creek watershed. Massey (1972) found Cu concentrations to be greater in spoil banks than in unaffected soils.

Siegel (1974) stated that pH is one of the most important properties in water that influences the different chemical reactions. In general, the oxidizing potential for a reaction increases with a decrease in pH. In the oxidizing reaction of pyrite, the products $SO_4^{=}$, H^{+}, and Fe^{++} are formed. This reaction could theoretically proceed until all of the pyrite is consumed. The reaction is checked, or retarded, by the limitation of one or more of the components of the reaction. The Ohio State University Research Foundation (1971) stated that the limiting factor was generally either lack of sufficient O_2 diffusion or oxidation product buildup on the reaction surface.

CHAPTER III

METHODOLOGY

I. WATER SAMPLING

Monitoring the environmental impact of previous mining on the entire Piney Creek was of primary importance to this project. The watershed not only contains two different coal seams, but also exhibits various kinds of mining and degrees of reclamation all of which affect the environment. In order to adequately study this area, the watershed was subdivided into nine drainage areas. Each area was given a sample site number which would represent the area. Sites 1 through 3 are located in the Spencer quadrangle and sites 4 through 9 are located in the Smartt Mountain quadrangle (Plate 1).

Site number 6 was to act as a control. This location was chosen for a number of reasons. At the beginning of the monitoring period there was no known evidence of there ever having been mining activity inside the drainage basin of site number 6. This site also provided year-round flow, whereas points farther upstream were dry during certain months. Accessibility was also a major consideration in the location of all sample sites. The remaining eight sites were chosen to monitor selected drainage basins inside the watershed.

A brief description and location of the sample sites is given in Table 1.

This writer acknowledges the fact that from a purely technical standpoint the sites used were not ideal. However, this combination of sites is considered by this writer to include the most practical sample network for study.

The sample sites were all monitored for water chemistry over a 23-month period. Water chemistry monitoring was done by periodic grab sampling of the nine monitoring sites. This thesis contains information on pH, conductivity, iron and manganese content, and sulfate. All pH and conductivity determinations were done with electronic meters. Iron and manganese contents were determined by atomic absorption spectrophotometry, and sulfate was calculated by means of a colorimetric kit.

II. SEDIMENT SAMPLING

Sediment samples were taken from eight predetermined locations (monitoring sites 1 through 8) along Piney Creek and the portal of Rockhead underground mine (Plate 1). Each location was sampled five times over a 14-month period. Sampling was done by random scooping of bottom sediment in areas of accumulation. The sampling area consisted of approximately 50 square feet of stream bottom. Each sample was a composite of 5-15 random subsamples. The samples

TABLE 1

LOCATION OF SAMPLE SITES
ALONG PINEY CREEK

Site	Tennessee Coordinates	Description
1.	462,500'N 2,182,600'E	Between the dam and bridge at Youth Camp Number 2, Fall Creek Falls State Park. Area drained is 21.7 square miles.
2.	460,100'N 2,171,750'E	Three miles upstream from Number 1, where the logging road crosses Piney Creek. Area drained is 15.3 square miles.
3.	450,100'N 2,167,300'E	Three miles upstream from Number 2, just downstream from the bridge at Piney Church, on the south entrance road to Fall Creek Falls State Park. Area drained is 10.3 square miles.
4.	444,400'N 2,166,900'E	One mile upstream from Number 3, east of the pond, which is approximately 1/4 mile northwest of Walling Cemetery. Area drained is 6.7 square miles.
5.	444,100'N 2,166,500'E	Bouldin Branch tributary, west of the pond, which is approximately 1/4 mile northwest of Walling Cemetery. Area drained is 2.0 square miles.
6.	439,750'N 2,175,000'E	Approximately 1 mile upstream from Number 7, 50 yards upstream from where the road crosses Piney Creek on surface mine Number 6. Area drained is 3.1 square miles.
7.	443,600'N 2,171,500'E	Approximately 3/4 mile upstream from Number 5, upstream from the bridge that crosses Piney Creek. Area drained is 5.0 square miles.

TABLE 1 (CONTINUED)

Site	Tennessee Coordinates	Description
8.	445,500'N 2,170,250'E	The upstream side of the culvert which crosses the road and carries the effluent from Moffit's strip mine. Strip mine 1/4 mile southwest of Bench Mark MLB 240. Area drained is not available due to alterations of the drainage caused by mining.
9.	445,000'N 2,172,000'E	The downstream side of the culvert carrying the water from Smith's Cove. Area drained is not available due to alterations of the drainage caused by mining.

were then transported back to the laboratory for subsequent separation, dissolution, and analysis.

The separation process consisted of wet-sieving to remove all size fractions larger than 1 mm. The remaining sample, comprised of the less than 1 mm size particles, was dried. When the sample was completely dried, it was ground to enable it to pass through a 200 mesh sieve. The finely ground sample was then put into solution by the "Total Acid Dissolution" process (note Appendix). The metal content was then determined by atomic absorption spectrophotometry.

III. PARTICULATE MATERIAL SAMPLING

Suspended particulate material was sampled from a number of point sources of acid mine pollution in the Piney Creek watershed. Sampling was attempted at eight different locations inside the watershed; however, satisfactory results were only obtained for three sites. These locations were: (1) the pool on surface mine number 6 north (lower pool), (2) discharge from underground mine Rockhead, and (3) discharge from underground mine Phiferes Number One (from a leak about three feet from the main adit) (Plate 1).

Sampling was done by field filtering 1000 ml of water through a Millipore HAWG 04700 HA 0.45 μ filter paper. The paper and trapped material were transported back to the lab and dried. The paper and sample were then put into solution

by the "Acid Digestion Procedure" (note Appendix). Metal content was then determined by atomic absorption spectrophotometry.

CHAPTER IV

RESULTS AND DISCUSSION OF DATA

I. RESULTS OF WATER CHEMISTRY ANALYSES

This study was conducted over a 23-month period, which allowed for a number of samples to be taken and analyzed. The sampling for water chemistry analysis was done under a variety of weather and stream conditions. The number of samples taken helps to lessen the possibility of biasing the sampling by a nonrandom sample, or contamination through negligence. Any bias caused by sampling or contamination should be statistically diminished due to averaging with nonbias samples. The accuracy of the water chemistry data and the other data presented is substantiated by the general agreement of the results obtained.

Both field and laboratory pH's are reported. In Tables 3 through 11, Appendix, the pH is recorded for each of the seven main stream monitoring sites and the two mine drainage sites (sites 8 and 9). The mathematical average pH from Tables 3 through 11, Appendix, is shown graphically in Figure 5. The average in the main stream (sites 1 through 7) ranged from a high of 6.2 (lab and field) at site 6, to a low average of 4.8 (lab) at site 4.

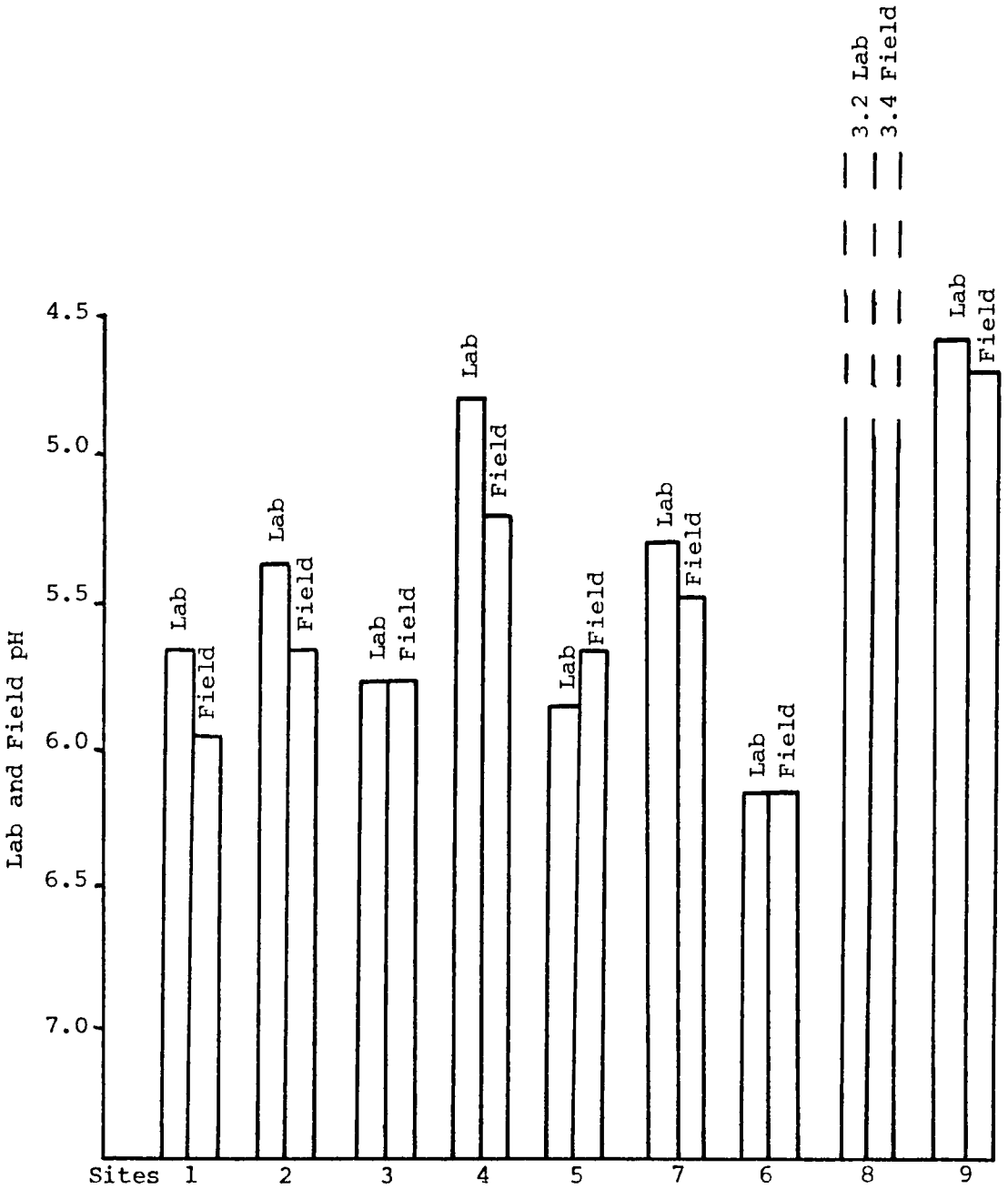


Figure 5. Average pH (Lab and Field) values from the water chemistry analyses at sites along Piney Creek.

All of the monitoring sites had an average pH lower than that of number 6, the control site, which indicates that coal mining indirectly lowers the surface water pH. This is further verified by the observed average pH of acid mine drainage at site 8 with its 3.2 lab and 3.4 field average. This drastic lowering of the water pH some 1.4 points in the main stream could have a significant effect on the organisms that may be present. The effect on the stream is compounded even more by the observed lows at the different sites (Tables 3 through 11, Appendix). Site 4, for example, has some pH readings in the lower four range and even the upper three's. This is far below the tolerance limits of many of the organisms common to waters of this area.

Iron concentration, which is reported by various authors to be closely tied to coal mining, was also studied in the Piney Creek watershed. The chemical analyses for iron can be seen in Tables 3 through 11, Appendix. Even though iron is one of the key elements liberated in pyrite oxidation, its average concentration is lower at site 6 (the control site) than at the other main stream sites affected by mine drainage in the Piney Creek watershed. A significant decrease in iron concentration is noted at all points downstream from site 6, except at site 8 (Figure 6). Site 8, as previously stated, is the discharge from a very detrimental mining complex. The very high iron content at the control

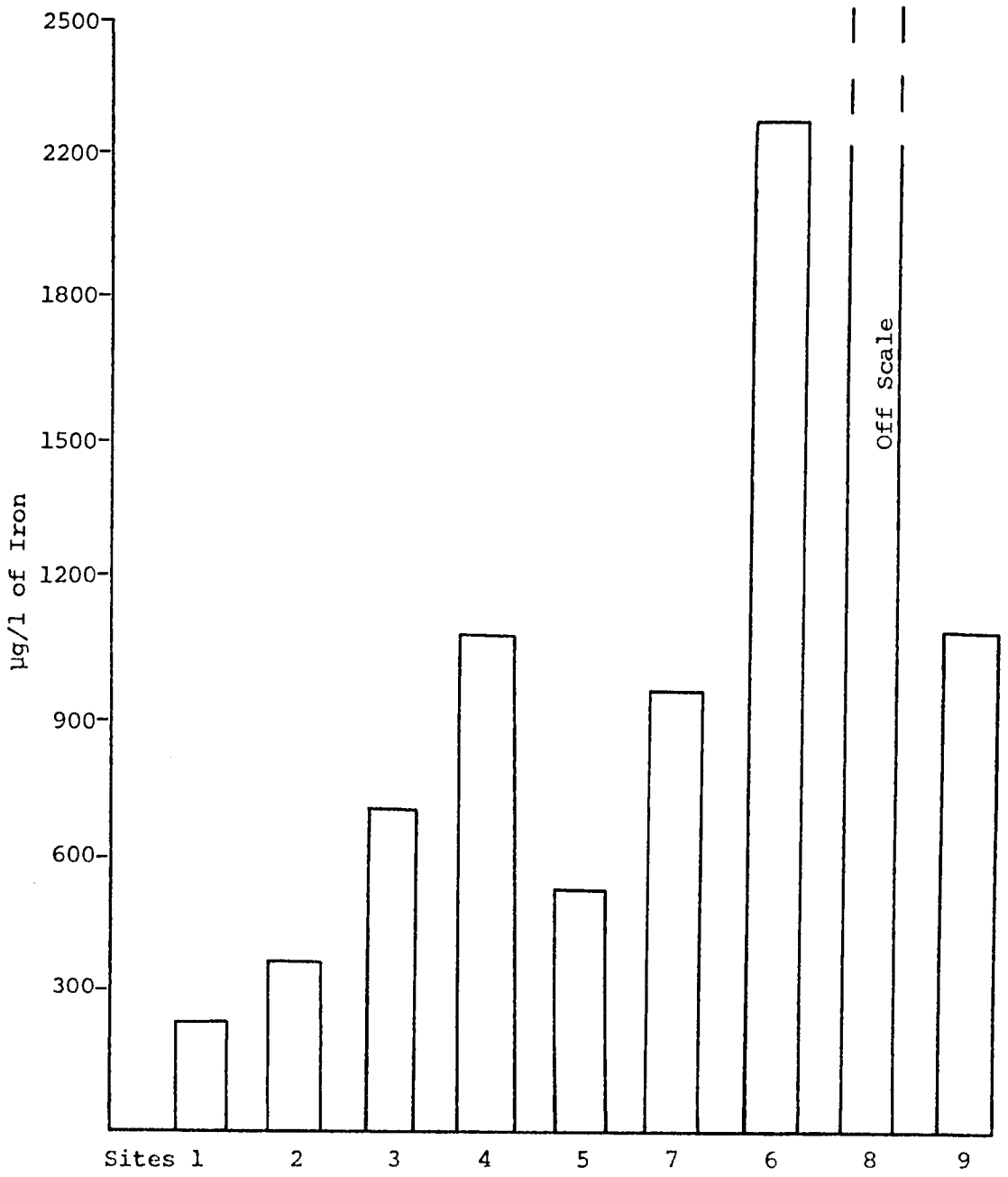


Figure 6. The average concentrations of iron in solution, from the water chemistry analyses at sites along Piney Creek.

site, number 6, may indicate a continuous input of highly iron contaminated water, which gives the unusually high iron content during periods of low flow. There is the possibility that mine water was being pumped into this portion of the watershed from one of the active mines immediately to the southwest of the watershed. However, this occurrence was never proven. Even though the control site (number 6) shows iron content greater than the lower sites, a general trend of increasing concentration of iron from sites 1 through 4 is present.

In studying the relationship of iron content versus flow (Tables 3 through 11, Appendix), it has been observed that with increased flow the iron content drops sharply. In Table 8, Appendix, the near cyclic rise and drop of iron concentration suggests a seasonal cycle for iron. In dry periods, generally June through September, the iron concentration increases sharply as flow decreases. This same seasonal trend can be seen on other water quality analyses tables for iron (Tables 3 through 11, Appendix). However, this observed seasonal cycle could be related to a number of other parameters which also change seasonally.

Manganese, like iron, was of particular interest to this project. The analyses for manganese for each sample site are shown in Tables 3 through 11, Appendix. The same seasonal variation can be seen for Mn as was observed for Fe. In

Figure 7, the increase of manganese from the control site (number 6) to site number 4 was slightly over an eleven-fold increase for the average concentration. The difference between site 6 and site 1, however, was only slight, 456 µg/l and 629 µg/l respectively. A continuous increase of manganese is shown from sites 1 through 4. There was a significant drop at site 5 on the Bouldin Branch tributary. Site 7, however, was only a few hundred µg/l below site 4, which was the site that had the highest average manganese concentration in the main stream. The extremely high concentrations shown at sites 8 and 9, as related to the other sites (Figure 7), give a strong indication that manganese in the surface water is definitely linked with mining.

A very significant relationship is observed when comparing the Fe:Mn ratio of the nine sampling sites (Tables 3 through 11, Appendix). In general, the Fe concentration is lower than that of Mn for all sites except number 6, the control site. This Mn over Fe change in ratio of elemental abundance occurs after the first encounter with mined areas which indicates a possible relationship between iron concentration reduction as compared with manganese. Water above mining activity has a higher iron content than water below mining activity. This phenomena may be controlled by iron's greater affinity for oxygen, which

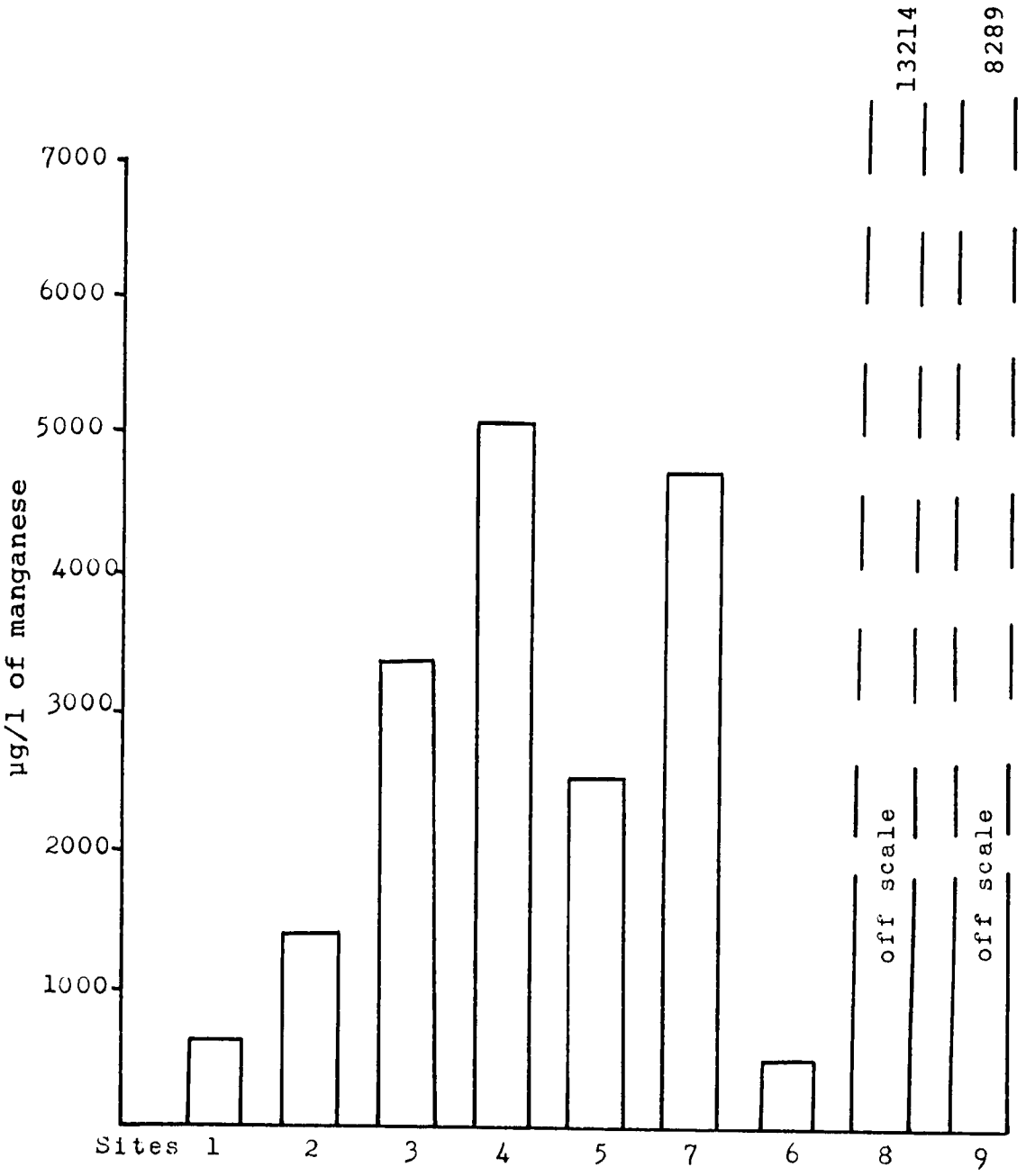


Figure 7. The average concentrations of manganese in solution, from the water chemistry analyses at sites along Piney Creek.

would cause iron to oxidize more rapidly than manganese to an oxidized, insoluble state which will precipitate out (Rankama and Sahama, 1950). This theory is supported by the sediment and suspended material studies to be discussed later (Tables 12 through 21, Appendix).

In comparing the Mn:Fe ratio from site 1 to site 3 (Tables 3 through 11, Appendix), the ratio increases from 2.5:1 at site 1 to 4.8:1 at site 3. The ratio of the remaining main stream monitoring sites is approximately 4.5-5.0:1. Site 9 has the highest ratio of Mn:Fe at 7.8:1. Site 8, which has the shortest distance from mine to sample site, had a 1.4:1 ratio.

Sulfate is also an important environmental parameter. Analyses for $SO_4^{=}$ are given in Tables 3 through 11, Appendix. The generally seasonal pattern of increased concentration with decreased flow appears to hold true for sulfate. Figure 8 indicates the radical difference in average $SO_4^{=}$ concentrations among the nine monitoring sites. There is a thirteen-fold increase in sulfate from site 6 to site 7, which is one mile downstream. The same continuous increase in concentration from sites 1 through 4 is exhibited for $SO_4^{=}$ as was shown for Fe and Mn in Figures 6 and 7 (pages 30 and 33).

Conductivity for the nine monitoring sites can be found in Tables 3 through 11, Appendix. This parameter demonstrated

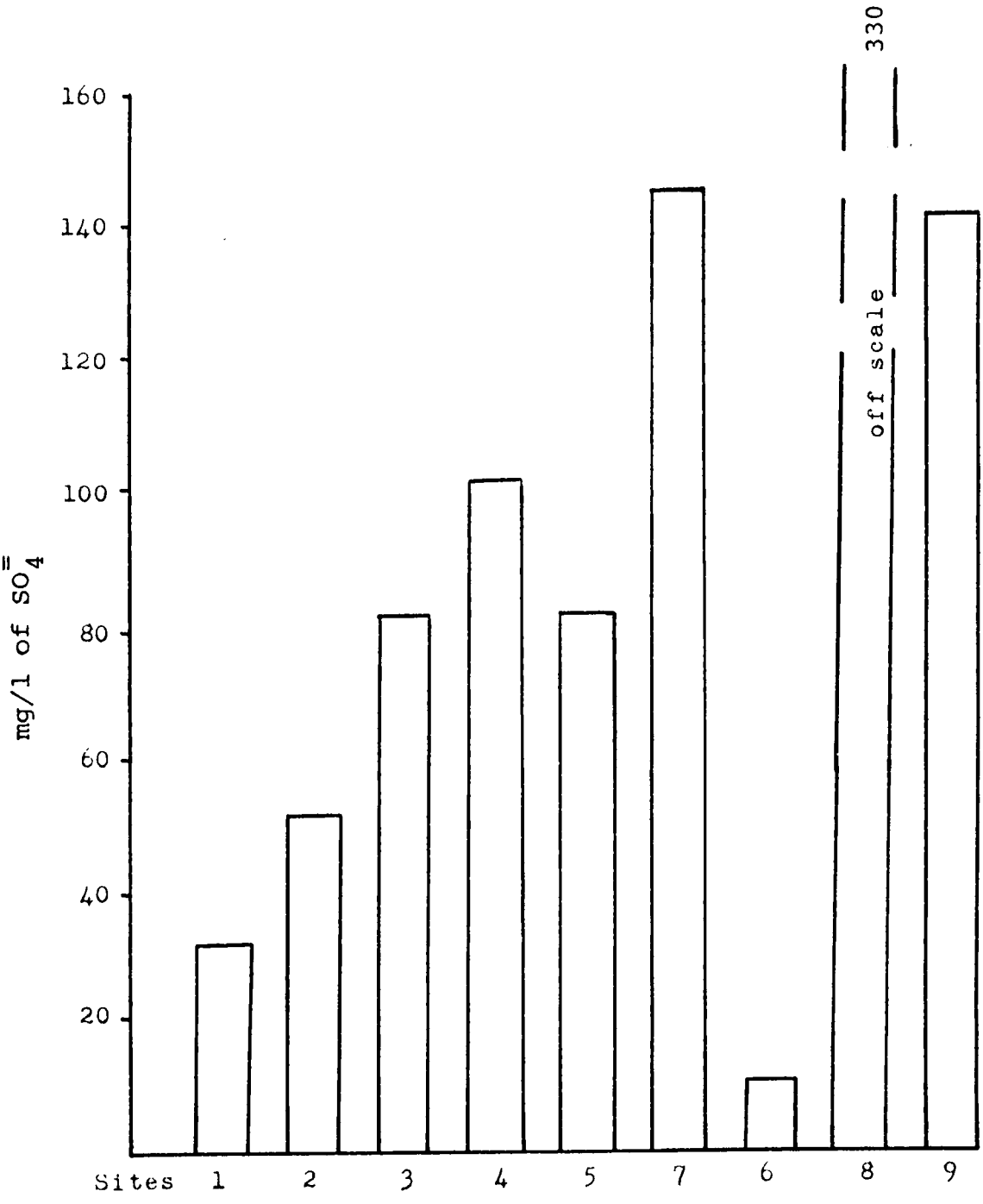


Figure 8. The average concentrations of sulfate in solution, from the water chemistry analyses at sites along Piney Creek.

a leveling-off between the middle monitoring points. Sites 3, 4, 5, and 7 had only a 7 micromho variation in the total average (Figure 9). The increase between site 1 and site 7, the highest monitoring site in the main stream, was slightly over 200%. The averages for sites 8 and 9 were, as usual, higher than the other sites with site 8 approximately two times greater than site 9.

II. RESULTS OF SEDIMENT ANALYSES

Bottom sediment samples were collected five times at eight stream locations (sites 1 through 8) previously discussed, and the Rockhead underground mine site. Two samples were taken for each site during the winter of 1975, and three samples were taken during the winter and spring of 1976.

One of the key elements analyzed for in this study was iron. It has been indicated that iron oxide increases sharply in stream sediment with the advent of mining. Related studies have shown the ability of iron oxide precipitates to trap and hold other metals in stream sediment (Schrader, 1975, and Upham, 1975). Iron was by far the most abundant metal present in the stream sediment. The sediment analyses for iron concentrations are given in Tables 12 through 20, Appendix. The average concentration of iron in the sediment shows a linear increase from sites 1 through 4

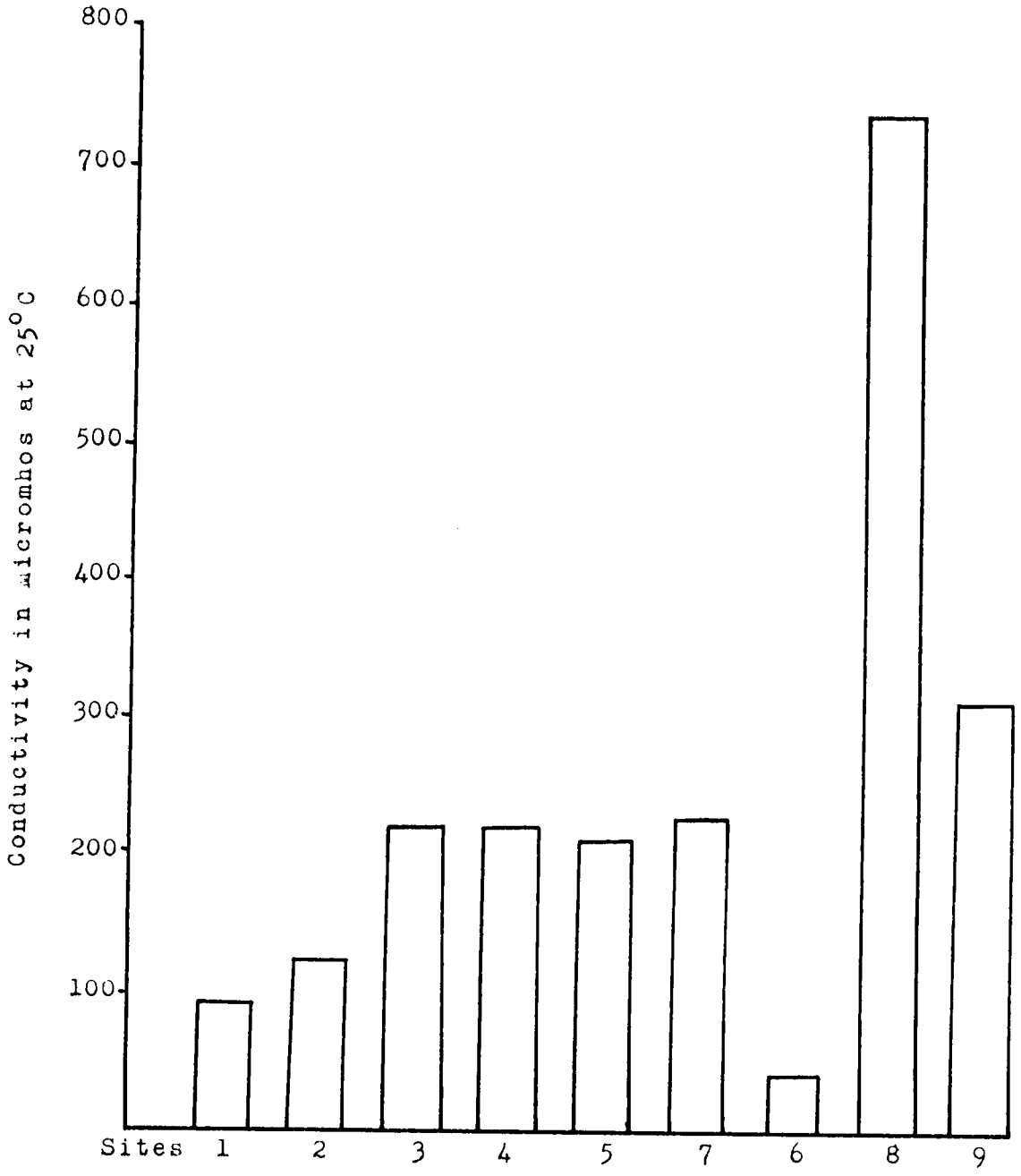
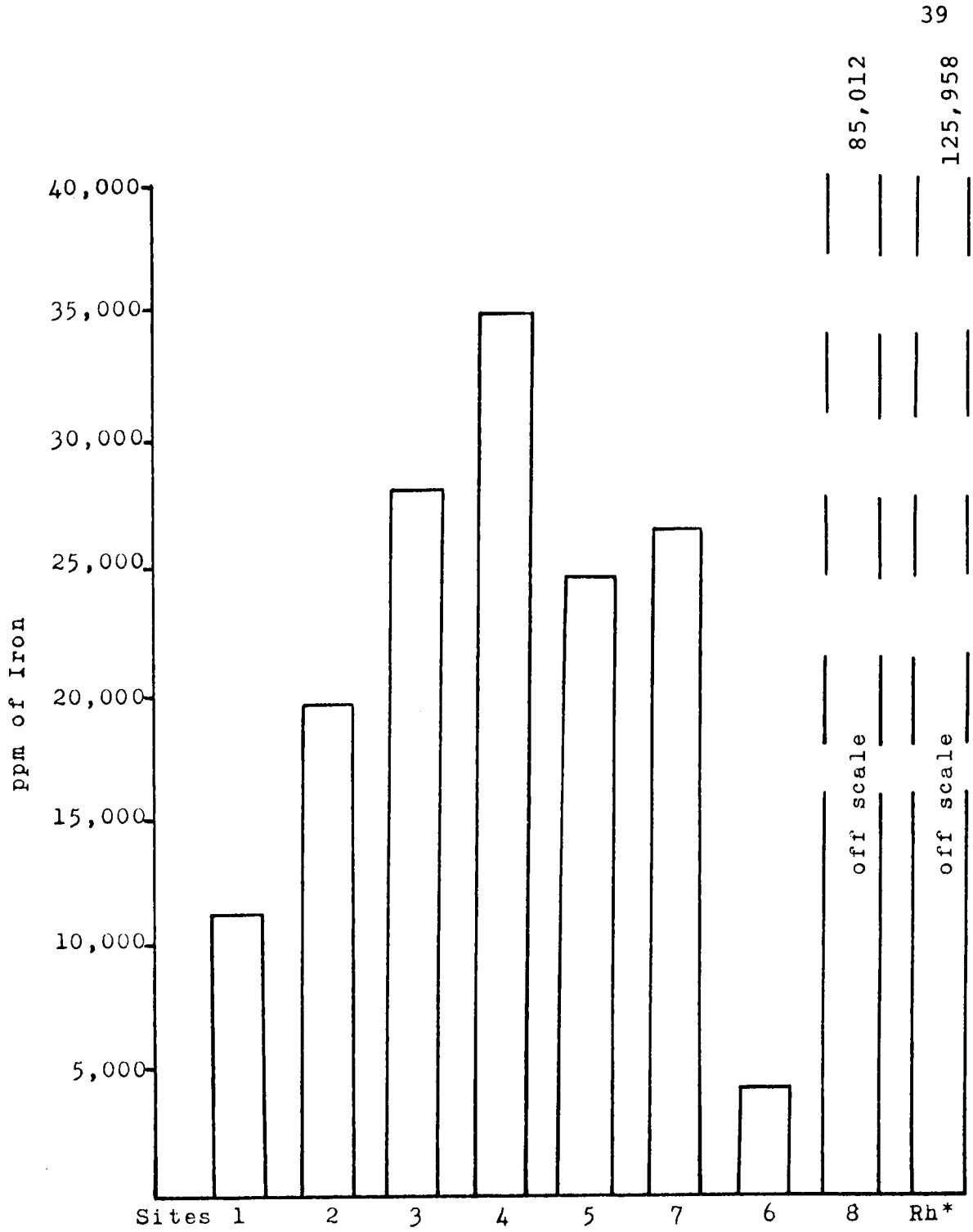


Figure 9. The average conductivity from the water chemistry analyses at sites along Piney Creek.

(Figure 10), much like increases shown in many of the water chemistry analyses. An increase of nearly 75% is shown for each successive site progressing upstream from 1 through 4. The concentration drops for sites 5 and 7 to concentration levels near the level recorded at site 3. As shown by Figure 10, site 6 has by far the least amount of iron in the sediment. The two sites at point sources of acid drainage, site 8 and Rockhead underground mine, show a very drastic increase in iron concentration. Rockhead had the highest concentration of iron, which was about 45% higher than the concentration at site 8 and 30 times greater than the concentration observed at site 6.

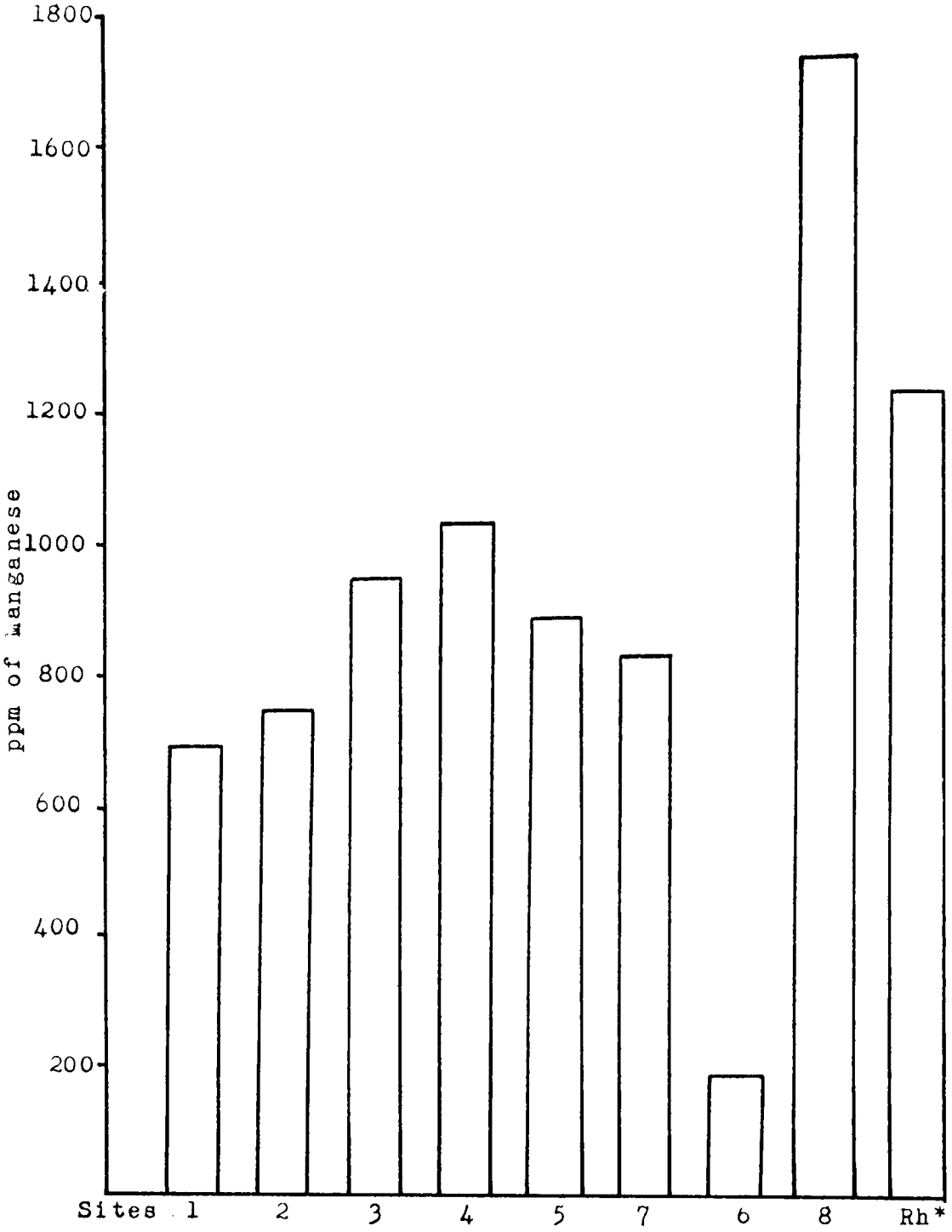
Manganese, like iron, increased by a near constant rate successively upstream from sites 1 through 4 in the sediment study (Figure 11). The increase, however, was not as great as the increase for iron. Manganese showed a 50% increase from site 1 to site 4, while iron had approximately a 200% increase. Site 6 had the lowest concentration, about 1/4 that of site 1, which was the second lowest site. Site 8 contained the highest concentration, some 40% higher in average concentration than Rockhead sediment, and 8 1/2 times greater than site 6.

Zinc analyses gave the most sporadic results when comparing average concentration (Figure 12). The general shape of the graph displayed by the other elements is not



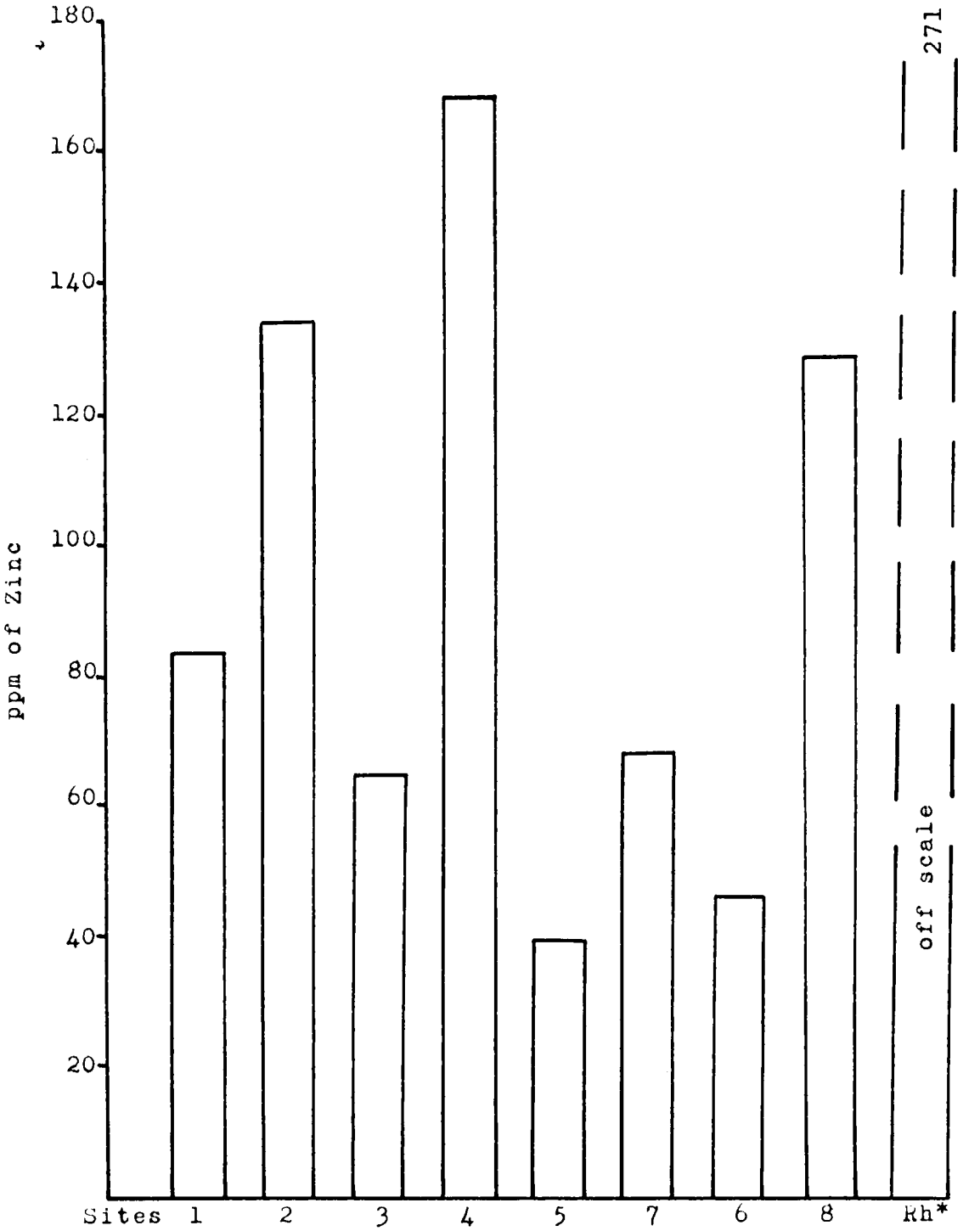
* Rh is a symbol for Rockhead underground mine.

Figure 10. Average concentrations of iron in the bottom sediment at sites in the Piney Creek watershed.



* Rh is a symbol for Rockhead underground mine.

Figure 11. Average concentrations of manganese in bottom sediment at sites in the Piney Creek watershed.



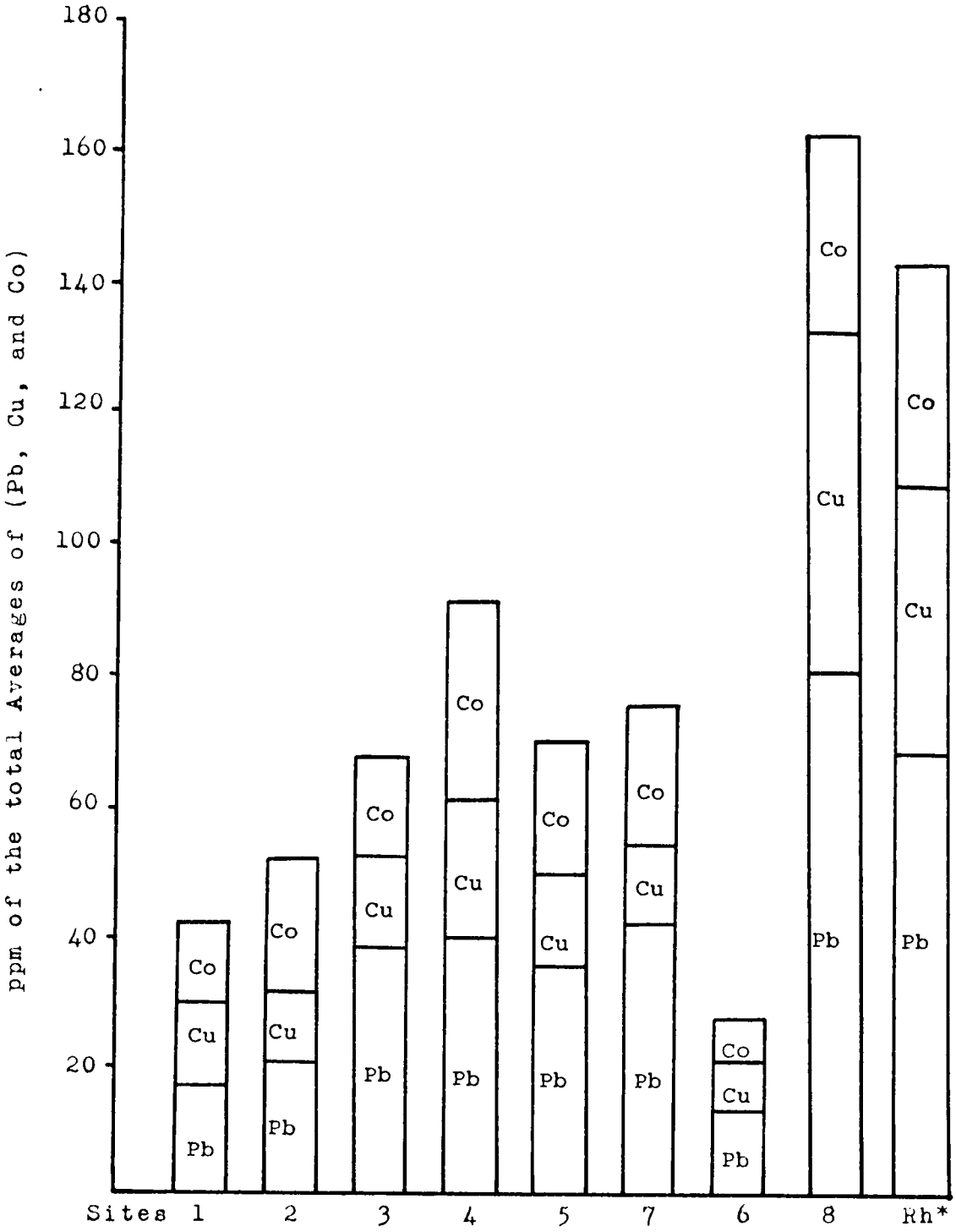
* Rh is a symbol for Rockhead underground mine.

Figure 12. Average concentrations of zinc in bottom sediment at sites in the Piney Creek watershed.

followed by zinc. Site 4 had the highest concentration of zinc for the main stream monitoring points and even outranked site number 8 in zinc concentration. Site number 3 was low compared to sites 1, 2, and 4. Site 5 had the lowest concentration of zinc, 15% lower than site 6. Rockhead sediment had the highest concentration of zinc which was over 100% higher than site 8.

A close study of Figure 12 reveals that the main differences between Zn and the other metal concentrations is the lower readings obtained at sites 3 and 5. The fact that site 8 ranked lower in Zn concentration than sites 2 and 4 and deviated from the pattern set by the other analyses may be caused by its location adjacent to a limestone gravel road.

The analyses for lead, copper and cobalt shown in Tables 12 through 20, Appendix, are displayed in a composite graph, Figure 13. This was done because of the very low concentration of lead, copper and cobalt in the sediment. These concentrations were near the detection limits of the atomic absorption unit and analyzing for an element near the detection limit of the unit lowers the reliability of any one reading. By making a composite graph, one reduces the statistical value of any one reading. This reduces the possibility of biasing a conclusion caused by mechanical or human error.



* Rh is a symbol for Rockhead underground mine.

Figure 13. Average total concentrations of the metals (Pb, Cu, and Co) in the bottom sediment at sites in the Piney Creek watershed.

In the composite graph for Pb, Cu, and Co (Figure 13), the established graph shape which increases from sites 1 through 4 is demonstrated. The concentration increases over 100% from sites 1 through 4. The usual drop at site 5 is present and site 7 is only slightly higher than site 5. Site number 6 had the lowest composite concentration of the three elements. Site 8 had the highest concentration of the three elements. Rockhead was only 12% lower than site 8 in elemental concentrations. The increase from site 6 to site 4 was nearly 150%.

III. RESULTS OF FILTERED MATERIAL ANALYSES

The samples for filtered suspended particulate solids were taken five times from the locations at surface mine number 6 and Rockhead underground mine. Samples from Phiferes Number One underground mine were only taken three times because the mine was sealed prior to sampling and a leak did not appear until April of 1976. Rockhead underground mine was subsequently sealed and the Phiferes leak has been sealed.

Analyses for metals in suspended particulate material (Table 21, Appendix) revealed, as would be expected, that iron was by far the most abundant metal. Iron was generally one order of magnitude more plentiful in all samples taken than manganese, the second most common metal found. Analyses

for iron in the filterable material are given in Table 21, Appendix. Figure 14 shows the relative average concentration of iron determined in this study. Phiferes Number One underground mine showed the most iron in the filtrate material. Phiferes water exhibited a 15% higher filterable iron content than water discharging from Rockhead underground mine, and was 50% higher than the suspended iron content in water from the pool on surface mine number 6.

Manganese analyses are given in Table 21, Appendix. The concentrations of manganese were much lower than that of iron; however, manganese concentrations were still an order of magnitude greater than zinc concentrations. The relative concentrations of manganese for the three sample sites are shown graphically in Figure 15. Phiferes Number One discharge water had the lowest suspended manganese concentration, and the highest iron concentration. Rockhead underground mine discharge waters were the most abundant in particulate manganese, 40% higher than Phiferes analyses. Pool water from the site at surface mine number 6 had concentrations of recoverable manganese between that of Rockhead and Phiferes Number One concentrations for recoverable manganese.

Zinc concentrations from filtered particulate material (Figure 16) seem to range higher for the underground mine sites than for the surface mine site. Zinc concentrations were highest at Rockhead underground mine. Phiferes Number

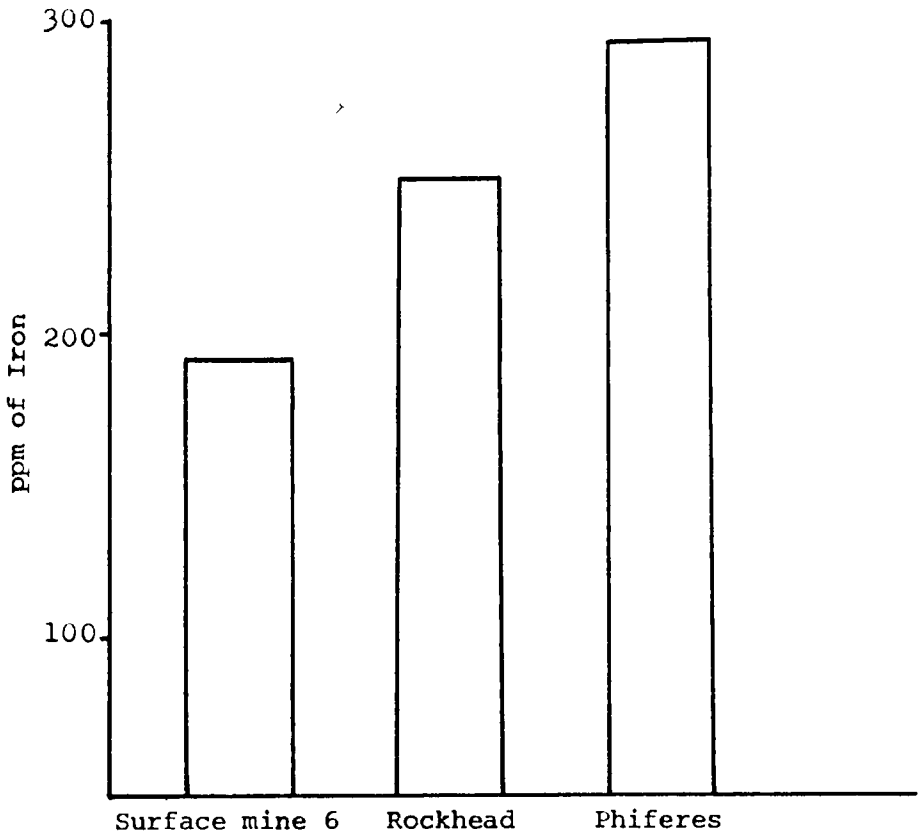


Figure 14. Average concentrations of iron in filtered material from three point sources of pollution in the Piney Creek watershed.

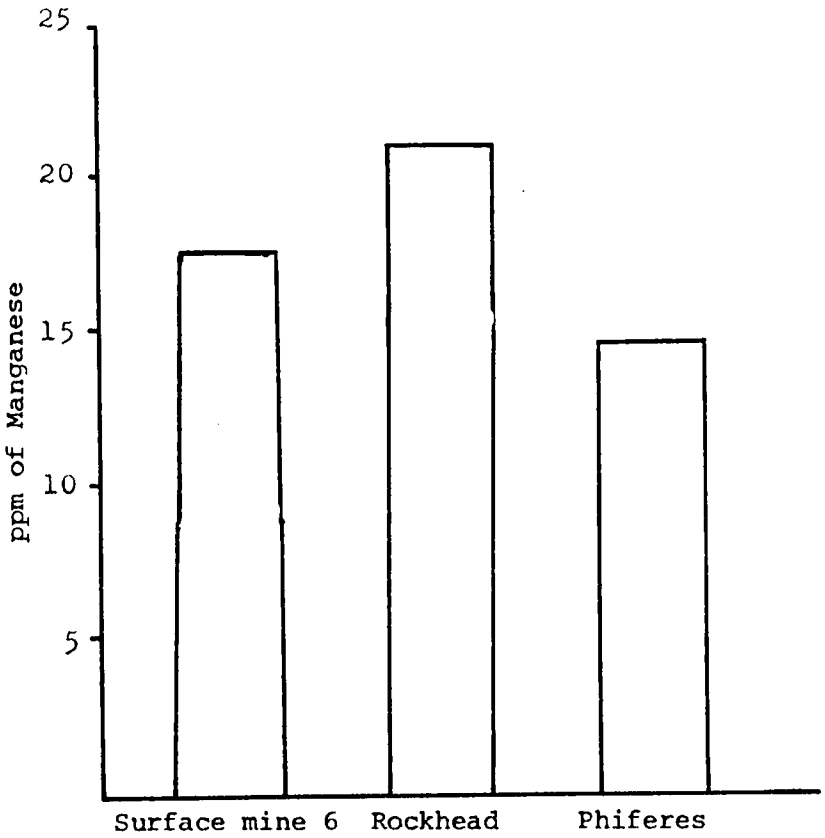


Figure 15. Average concentrations of manganese in filtered material from three point sources of pollution in the Piney Creek watershed.

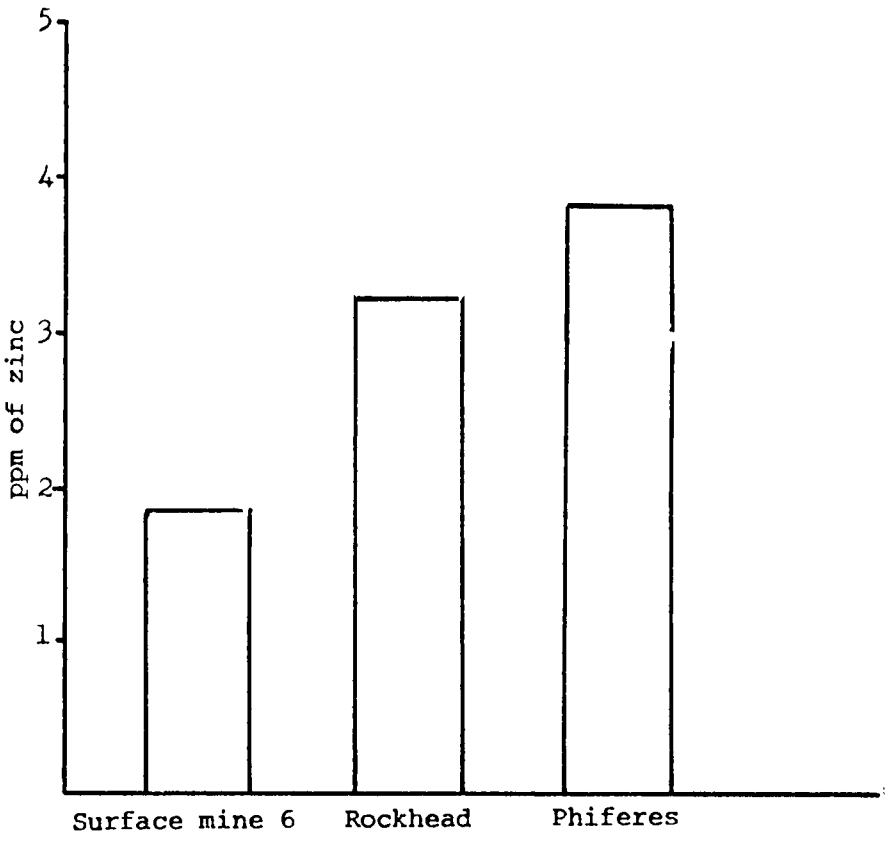


Figure 16. Average concentrations of zinc in filtered material from three point sources of pollution in the Piney Creek watershed.

One underground mine discharge waters had a zinc concentration for filterable material only 18% lower in average zinc concentration than that at Rockhead. The increase from the pool on surface mine number 6 to Rockhead underground mine was over 100%.

In studying Table 21, Appendix, there appears to be some correlation between pH and iron concentration. Samples taken at periods of lowest pH at the pool on surface mine number 6 and Rockhead underground mine discharge had the lowest concentrations of iron in the filtered material. Lower iron concentration with lower pH seems to be the general rule for the site at surface mine number 6. This generalization does not hold true for Phiferes Number One underground mine discharge waters.

CHAPTER V

SUMMARY AND CONCLUSIONS

The following observations were made in the water chemistry study. The pH, both lab and field, decreased for the sites along Piney Creek which were below control site 6. Water chemistry analyses for iron showed a decrease in iron concentrations for the sites below the control area. However, water analyzed from the direct discharge of an inactive mining complex, site 8, exhibited much higher concentrations than site 6. Manganese concentrations for sites inside the mined area were higher than control site 6. In Figure 17 a correlation in percent change from control site 6 is exhibited by manganese and sulfate. Sulfate, like manganese, displayed a definite increase in the disturbed areas. Conductivity also increased for the sites below the control area.

Sediment analyses for metals indicated an increase in concentrations at all sites below control site 6, with the exception of the zinc concentration at site 5 where a marked decrease was observed. Iron concentration exhibited the greatest percent increase over the control site average concentration (Figure 18). Manganese concentration also increased sharply over the concentrations observed at the control site.

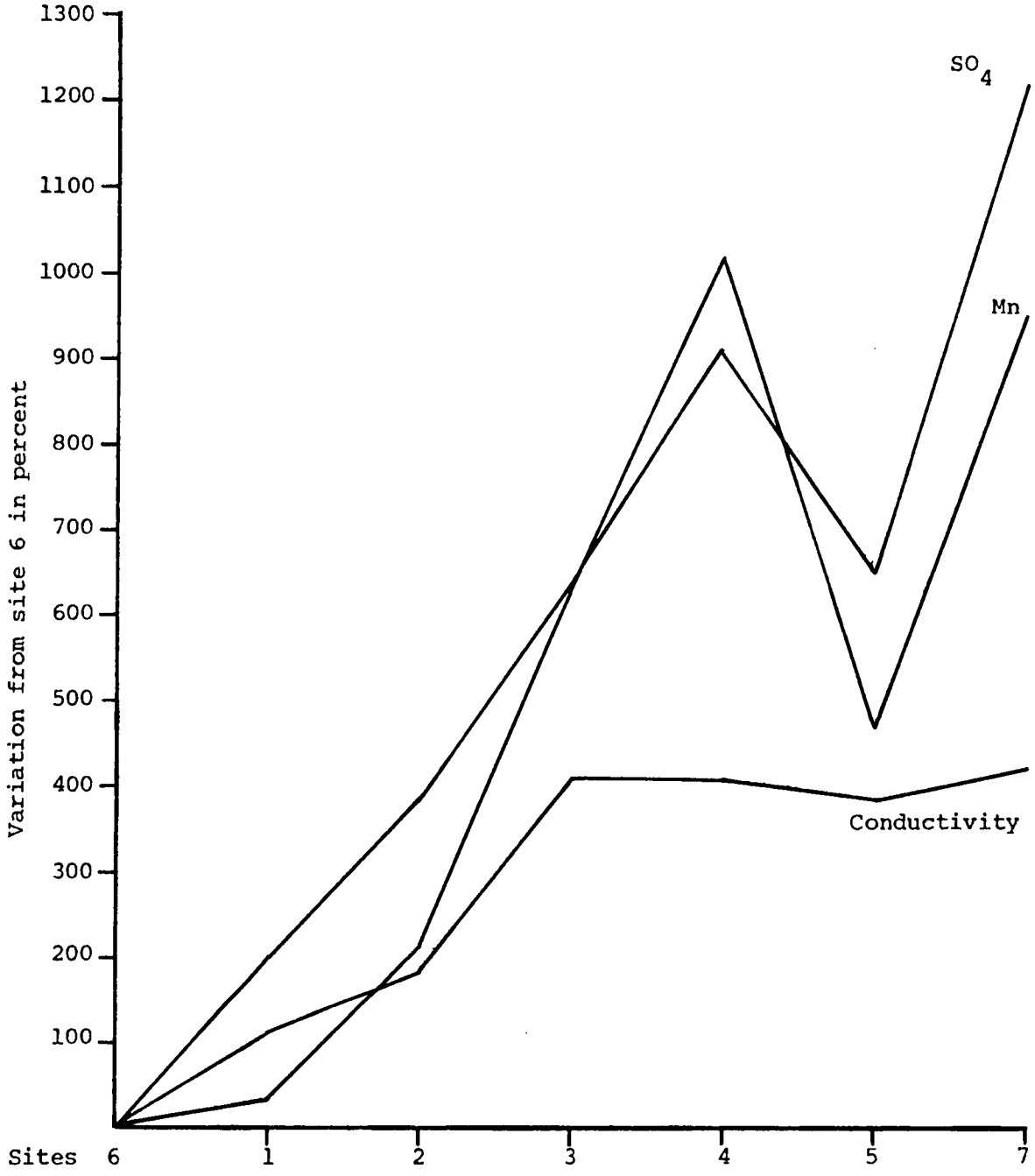


Figure 17. Percent variation from site 6 of Mn, $SO_4^{=}$, and conductivity, taken from the water chemistry analyses.

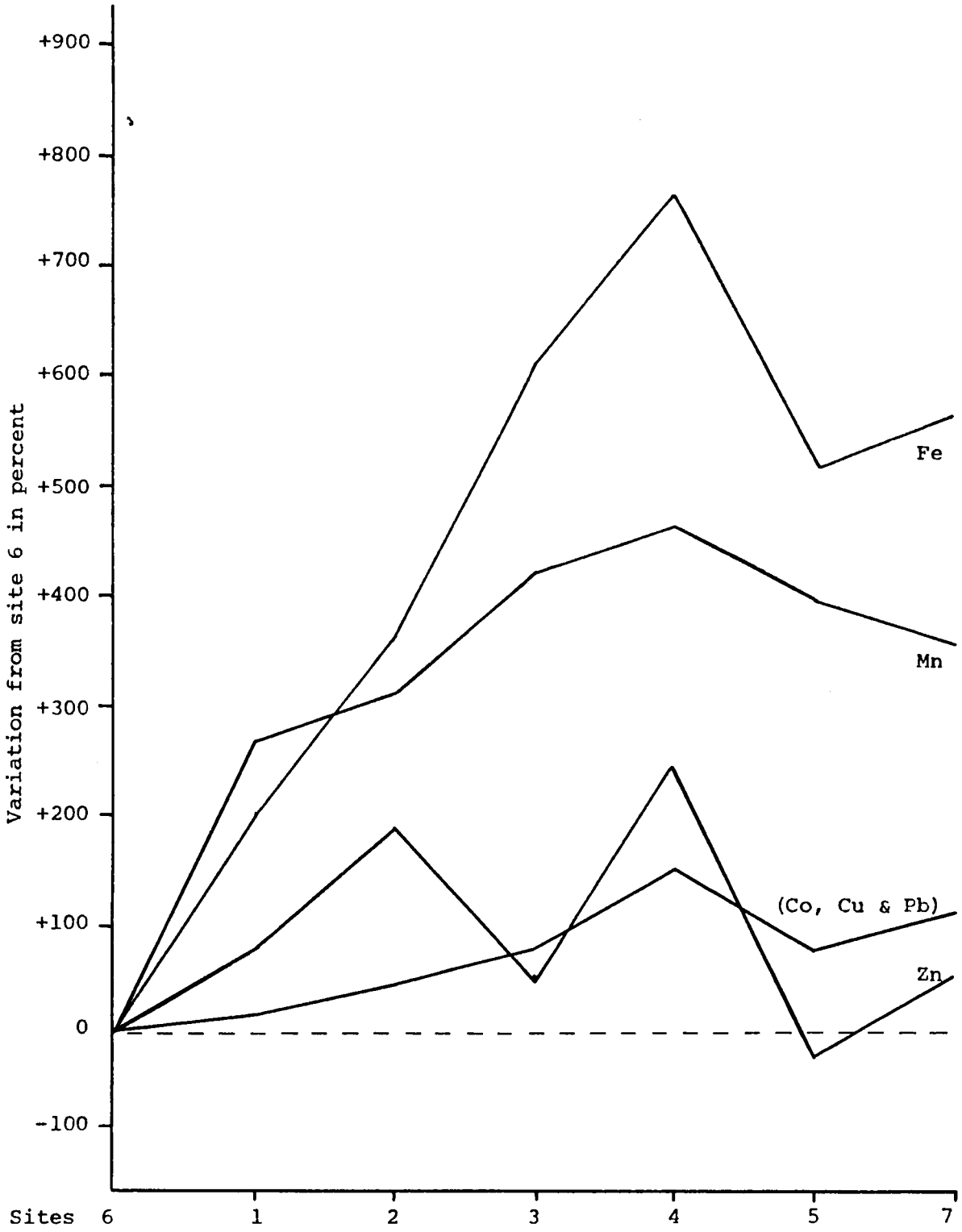


Figure 18. Percent variation from site 6 of Mn, Fe, Zn, and (Co, Cu and Pb) taken from the sediment analyses.

The results of the suspended material analyses verify the fact that iron, manganese, and zinc occur as particulate material in discharge water at point sources of acid mine drainage in the watershed. Iron is the most abundant metal, manganese is approximately one order of magnitude less abundant than iron, and the zinc concentration is approximately one order of magnitude below that of manganese.

This writer has observed that some species of beetles have adapted quite well in waters of less than pH 3.5. Sinclair (1975) reported dobsonflys Nigronia sp. collected from the Piney Creek watershed survived almost a week in bioassay tests at pH of 2.2. Though some very hardy species of aquatic life can adapt to extreme conditions, the general rule is that with more stressed conditions, the diversity of organisms is decreased.

The two biologic studies conducted by the Tennessee Division of Water Quality Control and Tennessee Wildlife Resources Agency on the benthonic life and fish population (note Appendix) suggest that in the areas below sample site 6, organisms were being subjected to some form of stress (Figures 19 and 20, Appendix). This conclusion results from an observed reduction in the number of different species present at sites below the control site (Sinclair, 1975).

The mean pH for Piney Creek was slightly above 6 at the control site, and was considered normal for this undisturbed environment by the Tennessee Division of Water Quality Control. At the other sites along Piney Creek the pH was generally lower than the established mean. This condition of depressed pH was most severe at site 4; however, some signs of recovery in pH values were observed at sites 1 through 3 in the lower reaches of Piney Creek. Recovery back to the level observed at site 6 was not achieved by the stream at any point inside the study area during this investigation.

Observations from water chemistry analyses showed iron to have a higher concentration at control site 6 than the sites inside the mining-affected area. The reason for this unexpected phenomenon is not totally understood. The answer may in part be attributed to iron precipitating to the bottom of the stream and becoming incorporated in the sediment in the lower segment of the stream. As previously stated, there was also the possibility of mine water being pumped into the watershed from active mines outside the watershed; however, this was not proven.

Sediment analyses revealed an impressive increase in iron content in the mined areas reaching a high of nearly 35,000 ppm of iron at site 4. However, the concentration decreases greatly downstream below site 4. Reduction to a

concentration level approximating the level found at the control site was not observed anywhere in the study area.

The results of the suspended material analyses verified the fact that iron was the most abundant metal in the suspended material found in point source discharge water in the watershed. This suggests that the more easily oxidized iron utilizes the available oxygen more rapidly than other metals and forms insoluble oxides. The iron oxides precipitate out near the source which leaves the unsightly "yellow boy" staining commonly associated with coal mining. This also helps explain the very sharp increase in iron in the stream sediment downstream from mining activity, and the rapid reduction in concentration as samples are collected away from the source.

Manganese in solution showed a definite increase in concentration at the sites inside the coal mining-affected area. Sediment manganese likewise increases sharply over the control site in the mining-affected areas. The suspended material study shows manganese to be a major metal in suspension as particulate material in point source water.

Water chemistry analyses indicate a rise in sulfate content for the sites inside the mine drainage area. The increase parallels very closely the percent increase of manganese (Figure 17, page 51).

Conductivity also increased from the control site to the mining-affected sites. The increase leveled off at values near the 200 micromho level, then decreased at the lower two sites. The decrease in conductivity, however, did not return to the level at the control site.

Sediment analyses for zinc reveal the only real deviation from the established pattern adhered to by the other parameters. In Figure 18, page 52, one can see the erratic percent change of zinc. Elevated concentrations are seen not only at site 4, but the lower two sites are also abnormally high. All three of these sites receive drainage from underground mines and surface mines in the Richland seam. This suggests two possibilities. The first is that zinc shows a closer association with the Richland coal seam than it does with the Sewanee coal seam. The second hypothesis is that zinc pollution is associated more with underground mining than surface mining operations. The suspended material study only served to substantiate the already-stated conclusions because both underground mines (Rockhead and Phiferes Number One) were located in the Richland coal seam. The pool on surface mine number 6 (Plate 1) is a product of mining the Sewanee coal seam. The results of the suspended material study show that zinc concentrations are much higher for the two underground mines in the Richland seam.

The combined concentrations of lead, copper, and cobalt also show an increase in the sediment at sites in the mining-affected areas. The pattern is much like that of the other parameters. A peak is shown at site number 4 with a linear decrease downstream (Figure 13, page 43).

It is conceivable that other causes might explain the lower quality of water and the higher metal contents in the sediment found at the sites inside the mining-affected areas as compared to the control site. However, the presence of these mines, the quality of the water being discharged from them, and the metal concentrations found in the sediment at locations near the mines strongly suggest to this writer that the mining activity of the past is the major cause of the degraded condition of Piney Creek. The fact that site 4 was generally the most adversely affected by the possible pollutants could possibly be attributed to the fact that its drainage area is the most intensely mined. Even though more mining is encountered downstream from site 4, one can see by referring to Plate 1 that the ratio of mined to unmined land diminishes. This dilution factor could in part account for the apparent reduction in the intensity of possible pollutants at the sites downstream.

This thesis is only the termination of one phase of the Piney Creek Project, and much of the monitoring will continue until 1979 or longer. This will be done in part to

ascertain the effectiveness of the reclamation phase of the project, and in part to better understand what effects future mining operations might have on Piney Creek.

I would suggest that for future study some effort be made to determine the reason for the seemingly high total iron concentrations in the water reported at the control site. The addition of one or more sites that could be used as controls would be helpful. One possible location would be where a tributary enters Piney Creek at the western portion of surface mine number 6. It might also prove useful to analyze some of the bedrock exposed within the watershed.

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APPENDIX

EXPLANATION OF THE QUALITY OF THE DATA TABLE

In Table 2 the quality of the standardizing solution is given in either ppm or percent. Those values given in ppm are the qualities stated by the manufacturers of that standard solution. Values given in percent for standardizing solutions are the measure of the greatest possible error in preparation of the solution used to standardize the departmental atomic absorption unit and were considered acceptable by Dr. Joseph H. Rule. The standardizing solutions are used to standardize the instruments prior to and during each analytical run.

In the water chemistry analyses the stated accuracy is the accuracy reported by the Tennessee Division of Water Quality Control by whom the analyses were performed.

Sensitivity given in this table refers to the sensitivity claimed by the manufacturers for the instruments used in the analyses.

The standard deviation given in this table refers to the analytical variation for multiple runs of the same sample.

TABLE 2

QUALITY OF DATA

	Standardizing Solution	Accuracy	Sensitivity	Standard Deviation
Water Chemistry Analyses				
pH	±0.01	±0.1	--	--
Fe	±0.1 ppm	±0.5 ppm	.005 ppm	--
Mn	±0.1 ppm	±0.5 ppm	.005 ppm	--
$SO_4^=$	± .5 ppm	±1.0 ppm	--	--
Conductivity	± .5*	±1.0*	--	--
Sediment Analyses				
Fe	± .1%	--	1.3 ppm	±12%
Mn	± .1%	--	.055 ppm	± 8%
Zn	± .1%	--	.65 ppm	± 9%
Co	± .1%	--	.65 ppm	± 5%
Cu	± .1%	--	.3 ppm	±13%
Pb	± .1%	--	.5 ppm	± 4%
Particulate Material Analyses				
Fe	± .1%	--	1.3 ppm	±11%
Mn	± .1%	--	.055 ppm	±12%
Zn	± .1%	--	.65 ppm	± 6%

TABLE 3

WATER QUALITY ANALYSES AT SITE NUMBER 1

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	5.8	5.8	200	410	16	55	22-
06/23/74	5.9	5.3	200	940	35	138	2.0-
07/21/74	6.7	5.7	1100	1290	10	154	.4-
08/19/74	6.6	6.7	400	530	29	75	.4-
09/22/74	6.4	7.0	300	200	19	62	.0***
10/28/74	5.5	5.5	200	720	70	170	.4-
11/17/74	5.0	6.3	100	1330	140	200	1.4+
12/19/74	5.6	5.7	100	750	36	80	6.5-
01/19/75	5.1	6.1	100	870	29	73	55-
02/14/75	5.1	6.5	50	890	33	78	38-
03/15/75	6.4	5.8	200	700	32	73	574-
05/04/75	5.3	5.8	50	440	29	60	17-
05/20/75	3.9	6.5	100	390	35	100	53-
06/22/75	5.7	--	200	600	58	120	14-
07/06/75	5.8	--	400	600	44	108	3.1-
07/21/75	6.2	7.0	500	560	7	80	.5-
08/04/75	6.4	7.0	500	420	24	59	.2-
09/08/75	5.9	6.5	300	420	16	48	.0***
10/14/75	5.0	5.4	100	550	3	92	45-
01/12/76	4.8	4.3	100	690	26	74	58+
05/02/76	5.6	4.6	100	470	34	89	--
06/27/76	6.4	6.7	200	370	26	92	--
09/28/76	6.3	--	100	320	12	26	--
Average	5.7	6.0	243	629	33	92	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 4

WATER QUALITY ANALYSES AT SITE NUMBER 2

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
04/20/74	5.0	6.2	200	950	23	72	16-
06/23/74	4.5	4.7	260	1400	45	108	1.5-
07/21/74	4.8	4.9	900	1300	14	260	.3-
08/19/74	6.0	6.5	600	860	39	89	.3-
09/22/74	5.9	6.7	300	740	134	99	.0***
10/28/74	5.1	5.2	300	2540	140	244	.3-
11/17/74	4.7	6.1	200	4270	160	290	1.0+
12/19/74	4.9	6.2	50	1560	47	110	4.5-
01/19/75	5.0	6.2	300	1180	34	86	38-
02/14/75	4.9	5.0	100	1410	43	102	26-
03/15/75	5.6	5.2	200	1030	38	78	398-
05/04/75	5.1	4.8	50	1070	44	82	12-
05/20/75	5.6	5.0	100	750	32	80	38-
06/22/75	5.7	--	300	870	70	135	10-
07/06/75	5.6	--	400	740	58	125	2.2-
07/21/75	6.1	6.9	600	810	13	105	.4-
08/04/75	6.1	6.1	300	1090	44	85	.2-
09/08/75	6.0	6.6	1000	4750	17	62	.0***
10/14/75	5.2	5.5	50	1050	43	114	31-
01/12/76	5.4	5.3	50	1300	37	101	41+
05/02/76	5.1	4.8	100	1290	42	128	--
06/27/76	6.5	5.3	200	540	40	122	--
09/28/76	6.9	--	1800	720	52	185	--
Average	5.4	5.7	363	1401	53	124	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 5

WATER QUALITY ANALYSES AT SITE NUMBER 3

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^=$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	5.1	6.0	400	1890	33	106	11-
06/23/74	5.2	5.7	1200	4400	70	148	10-
07/21/74	6.4	6.2	1700	4180	35	870	.2-
08/19/74	6.6	6.4	1600	5670	125	290	.2-
09/22/74	6.6	6.7	1300	5520	125	355	.0***
10/28/74	5.6	6.0	600	9060	218	360	.2-
11/17/74	5.2	4.5	200	6660	190	332	.4+
12/19/74	5.0	4.8	100	2570	70	145	2.8-
01/19/75	5.8	6.5	700	1640	45	110	24-
02/14/75	5.0	4.7	200	2130	55	137	16-
03/15/75	5.3	5.0	300	1540	56	115	261-
05/04/75	5.2	4.9	200	2400	64	118	7.9-
05/20/75	5.7	6.4	100	1370	40	90	25-
06/22/75	6.1	--	800	2760	86	180	6.3-
07/06/75	6.3	--	1000	3600	120	240	1.4-
07/21/75	6.7	6.7	1700	3450	27	230	.2-
08/04/75	6.9	6.8	1900	3030	90	185	.1-
09/08/75	6.6	6.8	600	850	60	170	.0***
10/14/75	5.6	5.5	100	2560	64	158	19-
01/12/76	5.3	5.0	300	1530	44	112	28+
05/02/76	5.0	4.9	100	2480	41	169	--
06/27/76	6.5	5.8	400	3050	66	177	--
09/28/76	6.3	--	200	4160	135	350	--
Average	5.8	5.8	683	3326	81	224	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 6

WATER QUALITY ANALYSES AT SITE NUMBER 4

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	4.8	6.0	900	2380	38	120	6.7-
06/23/74	3.8	4.7	1500	6900	103	118	.6-
07/21/74	5.0	5.8	3500	3390	19	265	.1-
08/19/74	5.8	6.1	1800	10400	215	6	.1-
09/22/74	5.1	6.8	1100	9180	250	465	.0***
10/28/74	4.1	4.4	3400	12360	270	435	.1-
11/17/74	4.1	3.6	400	9300	220	400	.2+
12/19/74	4.4	4.0	600	3780	60	165	2.1-
01/19/75	4.8	6.1	900	1730	56	1200	17-
02/14/75	4.6	4.3	500	2750	70	160	12-
03/15/75	5.0	4.6	200	2010	90	155	158-
05/04/75	4.8	4.6	400	2330	64	110	5.4-
05/20/75	4.9	6.4	300	1570	44	80	16-
06/22/75	5.0	--	700	3650	88	210	4.3-
07/06/75	4.6	--	2200	6640	185	340	.9-
07/21/75	5.7	6.2	1300	7160	35	340	.2-
08/04/75	6.4	6.7	1800	8460	225	355	.08-
09/08/75	--	--	--	--	--	--	.0***
10/14/75	4.4	4.8	100	2240	74	181	14-
01/12/76	4.8	4.2	100	1920	44	119	18+
05/02/76	4.8	4.8	200	2650	40	156	--
06/27/76	5.0	4.4	600	4860	130	240	--
09/28/76	4.4	--	1400	5640	130	350	--
Average	4.8	5.2	1086	5059	111	222	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 7

WATER QUALITY ANALYSES AT SITE NUMBER 5

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	5.3	6.5	200	2030	70	142	2.1-
06/23/74	6.2	6.0	400	3030	68	330	.2-
07/21/74	5.6	5.9	2000	2890	14	245	.04-
08/19/74	7.0	6.7	1700	3-4-	100	220	.04-
09/22/74	6.2	6.8	800	2690	100	260	.0***
10/28/74	5.4	5.3	1600	4930	150	232	.03-
11/17/74	5.5	5.3	500	4320	180	340	.14+
12/19/74	5.4	4.6	100	2510	110	188	.5-
01/19/75	4.7	6.2	700	1040	43	109	4.7-
02/14/75	5.1	4.7	200	1940	80	170	3.1-
03/15/75	4.7	5.6	400	2790	74	150	42-
05/04/75	5.5	5.1	200	2060	80	144	1.5-
05/20/75	5.6	5.4	200	1790	64	140	4.6-
06/22/75	6.6	--	200	2140	90	210	1.2-
07/06/75	6.7	--	500	1670	90	230	.3-
07/21/75	7.1	7.0	400	1640	23	235	.05-
08/04/75	7.1	6.9	400	2530	85	190	.02-
09/08/75	--	--	--	--	--	--	.0***
10/14/75	4.6	4.7	400	2200	74	179	33-
01/12/76	5.2	4.5	200	1760	64	157	5.7+
05/02/76	5.3	4.8	200	2000	40	188	--
06/27/76	7.2	6.4	200	2440	50	193	--
09/28/76	6.9	--	100	3540	150	415	--
Average	5.9	5.7	527	2499	82	212	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 8

WATER QUALITY ANALYSES AT SITE NUMBER 6

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	--	--	--	--	--	--	3.1-
06/23/74	5.8	6.3	1400	70	2	15	.3-
07/21/74	6.1	6.4	3900	1800	12	63	.07-
08/19/74	6.5	6.5	12600	2300	3	18	.06-
09/22/74	6.5	6.9	17500	2560	20	120	.0***
10/28/74	6.5	6.3	3800	620	11	48	.06-
11/17/74	6.1	6.5	500	30	9	39	.2+
12/19/74	6.1	4.5	100	5	2	20	1.0-
01/19/75	6.0	6.5	300	30	5	24	7.8-
02/14/75	6.2	5.8	100	5	6	17	5.5-
03/15/75	6.0	5.9	200	20	5	80	67-
05/04/75	5.9	5.6	400	10	5	17	2.5-
05/20/75	6.1	5.7	200	5	--	15	7.3-
06/22/75	6.6	--	800	70	4	28	3.0-
07/06/75	6.4	--	1000	150	8	42	.4-
07/21/75	6.5	6.8	2000	440	3	52	.08-
08/04/75	7.1	6.9	1300	830	26	75	.03-
09/08/75	5.9	6.2	600	1000	90	150	.0***
10/14/75	5.7	6.1	400	30	7	28	5.9-
01/12/76	5.9	6.2	30	5	4	25	8.3+
05/02/76	6.1	6.4	400	30	4	16	--
06/27/76	6.9	6.4	600	1	2	20	--
09/28/76	6.2	--	800	30	11	55	--
Average	6.2	6.2	2224	456	11	44	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 9

WATER QUALITY ANALYSES AT SITE NUMBER 7

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$
05/20/74	--	--	--	--	--	--	4.1-
06/23/74	--	--	--	--	--	--	.4-
07/21/74	--	--	--	--	--	--	.09-
08/19/74	6.4	6.0	800	9000	215	11	.08-
09/22/74	5.9	6.7	1700	9140	300	485	.0***
10/28/74	4.5	4.5	2500	11550	270	490	.09-
11/17/74	3.8	3.7	3000	7740	200	360	.4+
12/19/74	4.6	6.5	800	2590	62	137	1.5-
01/19/75	4.8	6.0	1800	1460	36	89	13-
02/14/75	4.8	4.7	400	1880	43	110	8.9-
03/15/75	4.8	4.5	400	1320	38	77	114-
05/04/75	5.5	5.1	600	1480	39	79	4-
05/20/75	5.4	5.2	400	1060	32	68	12-
06/22/75	6.2	--	700	3120	88	200	3.3-
07/06/75	5.0	--	1000	8100	230	379	.7-
07/21/75	5.4	6.3	200	9330	45	430	.1-
08/04/75	6.5	6.6	200	6360	700	350	.06+
09/08/75	6.3	6.7	200	4100	210	350	.0***
10/14/75	5.5	5.1	600	2180	56	134	9.8-
01/12/76	5.1	5.5	600	1250	30	87	13.4+
05/02/76	5.2	4.6	500	1780	39	105	--
06/27/76	5.6	5.4	700	3350	90	183	--
09/28/76	3.9	--	1700	8730	180	460	--
Average	5.3	5.5	940	4776	145	229	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 10

WATER QUALITY ANALYSES AT SITE NUMBER 8

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	--	--	--	--	--	--	--
06/23/74	--	--	--	--	--	--	--
07/21/74	--	--	--	--	--	--	--
08/19/74	--	--	--	--	--	--	--
09/22/74	--	--	--	--	--	--	--
10/28/74	2.9	3.4	15000	27000	550	910	--
11/17/74	2.9	2.8	28200	19000	800	1120	--
12/19/74	3.1	2.9	3300	13500	310	700	--
01/19/75	3.7	5.0	6400	4130	125	260	--
02/14/75	3.4	3.5	12300	7230	210	455	--
03/15/75	3.8	3.8	1200	4400	140	265	--
05/04/75	3.2	3.2	5000	9570	280	475	--
05/20/75	3.6	3.5	2500	4720	120	280	--
06/22/75	3.0	--	10000	12700	310	800	--
07/06/75	3.0	--	12500	20550	450	1065	--
07/21/75	3.0	3.0	17000	24400	116	1200	--
08/04/75	2.9	3.0	15500	2460	800	1100	--
09/08/75	2.8	3.0	18000	25000	400	1150	--
10/14/75	3.0	3.2	2900	13950	300	700	--
01/12/76	3.5	3.7	3100	5760	145	370	--
05/02/76	3.3	3.3	6400	14480	310	889	--
06/27/76	3.2	3.3	2200	14650	340	793	--
09/28/76	3.3	--	7500	14350	240	700	--
Average	3.2	3.4	9380	13214	330	735	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

***The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 11

WATER QUALITY ANALYSES AT SITE NUMBER 9

Date	Lab pH	Field pH	Fe µg/l	Mn µg/l	$SO_4^{=}$ mg/l	Cond.*	Flow $Ft^3/sec.$**
05/20/74	--	--	--	--	--	--	--
06/23/74	--	--	--	--	--	--	--
07/21/74	--	--	--	--	--	--	--
08/19/74	--	--	--	--	--	--	--
09/22/74	--	--	--	--	--	--	--
10/28/74	--	--	--	--	--	--	--
11/17/74	3.8	3.5	300	15750	280	460	--
12/19/74	4.8	4.8	200	4420	60	160	--
01/19/75	5.3	5.3	200	2500	52	120	--
02/14/75	4.5	4.4	100	4770	80	208	--
03/15/75	5.2	4.8	300	2650	64	125	--
05/04/75	4.4	4.2	200	6020	130	210	--
05/20/75	5.8	5.6	100	2120	48	105	--
06/22/75	4.1	--	1500	10290	248	400	--
07/06/75	3.6	--	3500	18600	340	658	--
07/21/75	3.5	3.5	7400	18700	66	650	--
08/04/75	6.4	6.3	1800	10500	230	345	--
09/08/75	--	--	--	--	--	--	--
10/14/75	3.8	4.3	100	8790	175	327	--
01/12/76	5.2	5.5	200	2450	46	131	--
05/02/76	4.5	4.6	200	5760	104	256	--
06/27/76	4.0	4.4	800	11700	180	345	--
09/28/76	4.9	--	300	7600	150	375	--
Average	4.6	4.7	1075	8289	141	305	--

*Conductivity is given in micromhos at 25° C.

**The + and - following the flow readings indicate the rising or falling of the discharge rate at that site over a three-day period.

**The continuous daily-streamflow computer model indicated a period of no-flow.

TABLE 12

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 1

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	12440	680	88	15	8	14
02/08/75	10507	690	80	20	10	8
01/11/76	11680	670	84	17	7	10
02/15/76	Lost to contamination					
04/25/76	13130	720	81	11	21	24
Average	11950	690	83	16	12	14

TABLE 13

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 2

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	18340	720	140	22	10	18
02/08/75	17490	740	130	20	8	25
01/11/76	17500	740	150	24	10	20
02/15/76	17600	750	130	20	10	15
04/25/76	22570	750	120	14	22	28
Average	18700	740	134	20	12	21

TABLE 14

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 3

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	28500	940	65	41	18	22
02/08/75	27480	950	70	35	20	12
01/11/76	28400	950	60	40	15	20
02/15/76	27900	950	75	40	10	15
04/25/76	28100	930	55	30	8	10
Average	28076	944	65	37	14	16

TABLE 15

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 4

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	36240	1140	180	45	22	42
02/08/75	34710	980	150	38	18	35
01/11/76	35400	990	180	45	20	40
02/15/76	34700	1100	140	40	15	35
04/25/76	33130	890	190	25	17	20
Average	34836	1020	168	39	18	34

TABLE 16

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 5

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	26420	890	60	35	15	24
02/08/75	24790	940	20	40	12	31
01/11/76	23980	910	40	30	10	25
02/15/76	24550	880	45	35	15	20
04/25/76	23120	810	30	23	18	14
Average	24572	886	39	33	14	23

TABLE 17

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 6

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	4200	150	45	20	10	8
02/08/75	3800	100	58	17	8	14
01/11/76	4300	200	40	10	13	10
02/15/76	3500	200	35	12	17	8
04/25/76	4100	250	50	10	15	10
Average	3980	180	46	14	13	10

TABLE 18

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 7

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	27420	840	60	44	14	18
02/08/75	24500	750	75	38	10	26
01/11/76	27520	820	75	40	15	25
02/15/76	26980	850	70	42	18	20
04/25/76	25920	860	65	40	10	22
Average	26468	824	69	41	13	22

TABLE 19

SUMMARY OF METAL ANALYSES OF THE STREAM SEDIMENT AT SITE NUMBER 8

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	85570	1843	140	86	55	41
02/08/75	84680	1552	110	70	64	25
01/11/76	85640	1792	150	85	52	35
02/15/76	84220	1687	120	76	43	28
04/25/76	84970	1810	120	82	48	19
Average	85012	1737	128	80	52	30

TABLE 20

SUMMARY OF METAL ANALYSES OF THE SEDIMENT AT ROCKHEAD (UNDERGROUND MINE)

Date	Fe ppm	Mn ppm	Zn ppm	Pb ppm	Cu ppm	Co ppm
01/18/75	126,430	1252	280	76	58	37
02/08/75	127,150	1248	265	65	50	25
01/11/76	132,150	1246	310	70	42	38
02/15/76	128,420	1351	290	68	28	35
04/25/76	105,640	1022	210	60	29	30
Average	123,958	1224	271	68	41	33

TABLE 21

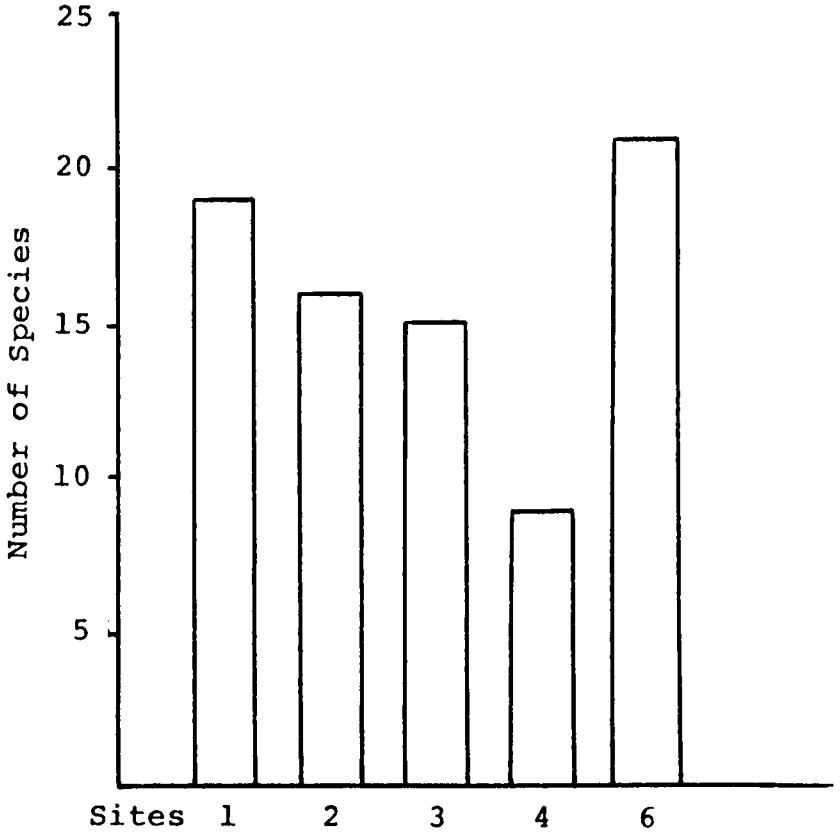
SUMMARY OF METAL ANALYSES OF FILTERED SUSPENDED SOLIDS

Date	Fe ppm	Mn ppm	Zn ppm	pH	Flow $Ft^3/min.$
Impoundment on Surface Mine Number 6					
02/24/76	205	14.2	1.8	3.4	1.8
03/24/76	175	23.2	2.5	3.0	1.3
04/10/76	190	14.0	2.2	3.3	.6
04/17/76	180	13.4	1.4	3.2	1.9
04/25/76	195	24.1	.9	3.2	1.7
Average	189	17.8	1.8	3.2	1.5
Rockhead Underground Mine					
01/24/76	249	16.8	2.2	3.4	3.9
03/24/76	196	19.3	3.1	3.0	3.8
04/10/76	216	23.4	3.1	3.4	2.4
04/17/76	294	26.4	3.5	3.4	1.8
04/25/76	286	20.9	3.1	3.3	2.7
Average	248	20.9	3.1	3.3	2.7
Phiferes Number One Underground Mine					
04/10/76	310	28.3	4.3	3.0	--
04/17/76	285	19.0	3.8	3.0	--
04/25/76	260	27.4	3.3	3.0	--
Average	285	14.9	3.8	3.0	--

BIOLOGICAL STUDIES

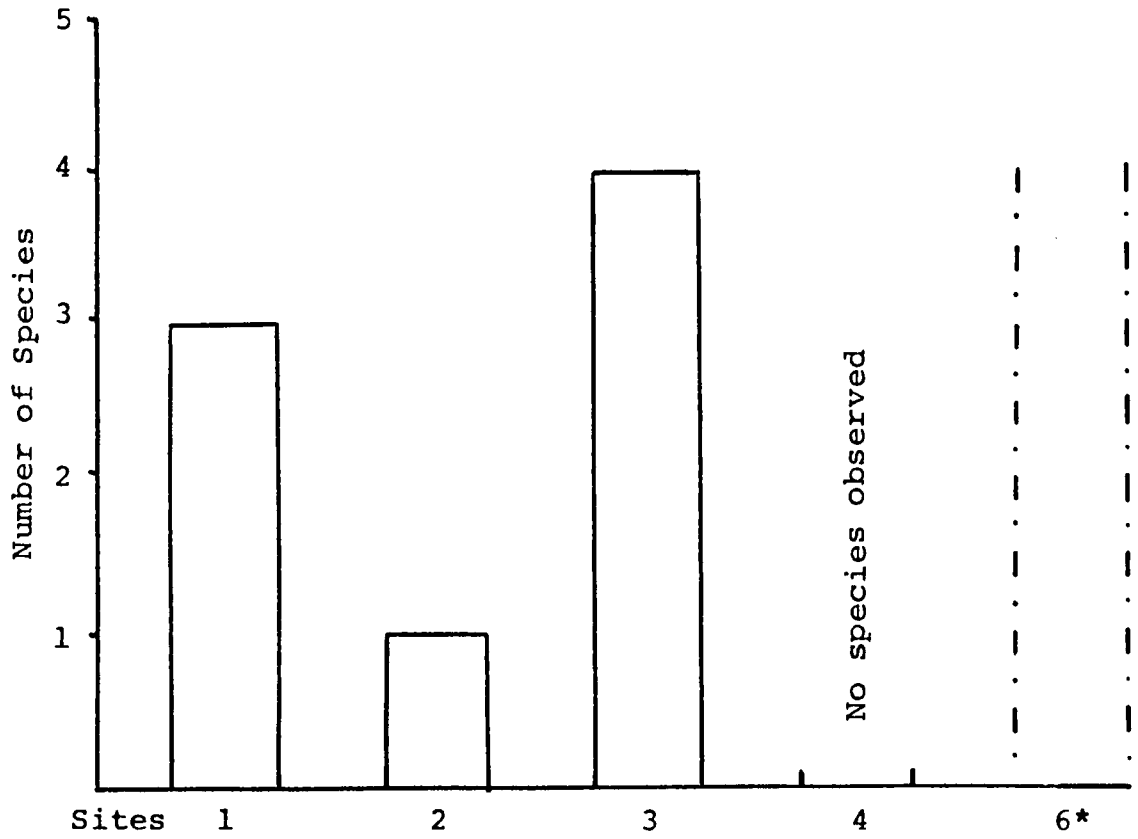
Two biological studies were conducted with the aid of the Tennessee Division of Water Quality Control and Tennessee Wildlife Resources. The results of these two studies are given in a generalized form in Figures 19 and 20.

The benthonic life was inventoried along selected sites on Piney Creek by a team from the Tennessee Division of Water Quality Control, under the supervision of Ralph Sinclair. The results are shown in Figure 19, and indicate a decrease in diversity as you move upstream from site 1 to site 4. Site number 6 has the greatest diversity of all sites. A different study on fish population was conducted with the aid of the Tennessee Wildlife Resources Agency, under the direction of Anders Myhr. The general results of this study are shown in Figure 20. The same conclusion can be drawn from this study as was drawn from the benthonic study. The condition of stress increases upstream from site 1 causing a reduction in the number of different species present at the upstream sites (Sinclair, 1975).



Data for this graph was collected by Ralph Sinclair, Division of Water Quality Control (1975).

Figure 19. Graph showing the biologic diversity of the benthonic life at five of the monitoring sites along Piney Creek.



*A qualitative study was not conducted at site 6. Micropterus salmoides (large-mouth bass) have been observed at site 6 by this author. Micropterus salmoids are one of the most susceptible species to low water quality which are common to this area. One can consequently assume that site 6 is at least as diverse as site 3, which was the only other site where Micropterous salmoides were observed.

Figure 20. Graph showing the biologic diversity of the fish population at five of the monitoring sites along Piney Creek.

ACID DIGESTION PROCEDURE
(PARTICULATE MATERIAL)

Step	Process
1.	Place filter paper and sample in a 50 ml teflon beaker. Add 10 ml of concentrated hydrochloric acid. Cover beaker and place in a sandbath at 130° for two hours.
2.	Remove samples from heat and allow them to cool slightly. Add 10 ml of concentrated HNO_3 acid. Allow sample to sit overnight.
3.	Heat sample in sandbath until it boils gently. Cover the beaker for two hours.
4.	Remove lid and expel digestion gases at a gentle boil until nearly dry.
5.	Add 5 ml of concentrated hydrochloric acid and allow to boil covered for 15 minutes and remove lid.
6.	Add 5 ml of deionized water and bring to a gentle boil, until volume is reduced by approximately one-half.
7.	Transfer solution to a 10 ml flask and bring to volume, with deionized water. In transferring, use deionized water to rinse the beaker and use the rinse water to bring to volume, 10 ml.

In this procedure blank samples were analyzed and the results showed that the process had no significant effect on the atomic absorption spectrophotometry reading for any of the metals analyzed for.

TOTAL ACID DISSOLUTION PROCEDURE
(SEDIMENT ANALYSES)

Step	Process
1.	Weigh 0.31 ± 0.01 g of finely ground sample into a 50 ml teflon beaker. Accuracy should be to the nearest 0.1 mg.
2.	Add 5 ml of concentrated nitric acid, HNO_3, and allow the sample to sit overnight.
3.	Heat sample in a sandbath at 130° C. Cover beaker for the first hour, then allow to evaporate to near-dryness. Permit the sample to cool slightly. At this point the samples should be placed under a hood.
4.	Add 10 ml of 48% hydrofluoric acid, HF, and 2 ml of concentrated perchloric acid, $HClO_4$.
5.	Cover beaker and boil sample for four hours. Heat should be 200-225° C. Remove sandbath from heat and allow to sit overnight.
6.	Return sandbath and samples to heat and raise temperature to 225° and hold until sample dissolves (appears clear and gelatinous).
7.	Reduce heat until sample boils slowly, and remove lid and permit solution to evaporate to near-dryness.
8.	Add 5 ml of 1 N hydrochloric acid, HCl, and continue heating for one hour with the lid on the beaker.

Step	Process
9.	Add 5 ml of deionized water and continue boiling gently for 15 minutes.
10.	Transfer solution to a 25 ml volumetric flask and bring to volume with deionized water. In transferring, use deionized water to rinse the beaker and use rinse water to bring to volume.

In this procedure blank samples were analyzed and the results showed that the process had no significant effect on the atomic absorption spectrophotometry reading for any of the metals analyzed for.

TENNESSEE COORDINATE SYSTEM

The Tennessee Coordinate System is a map location system which uses a base reference point from which other points are related. The base point for the Tennessee Coordinate System is at the intersection of 86° 00' W longitude, and 34° 40' N latitude, near Scottsboro, Alabama. This point was assigned the values of 7,000,000 feet east and 100,000 feet north. The coordinate location (in feet) of any point in Tennessee may be expressed with reference to its distance east or west and north of the base reference point.

VITA

Clark S. Fletcher was born in Mountain Home, Arkansas, on April 1, 1951. He received his elementary and secondary education in the public school system of Baxter County. He graduated from Mountain Home High School in May 1969. In September 1969, he entered Arkansas Polytechnic College, Russellville, Arkansas. He graduated with a Bachelor of Science degree in geology May 19, 1973.

He then entered the Graduate School of the University of Tennessee, Knoxville, Tennessee, in September 1973, where he served as a graduate assistant for the first nine months of his enrollment. He then received a research assistantship for the remainder of his enrollment. He received a Master of Science degree, with a major in geology, in June 1977.

He was wed to Janice L. Hargrave of Mountain Home, Arkansas, in October 1976.

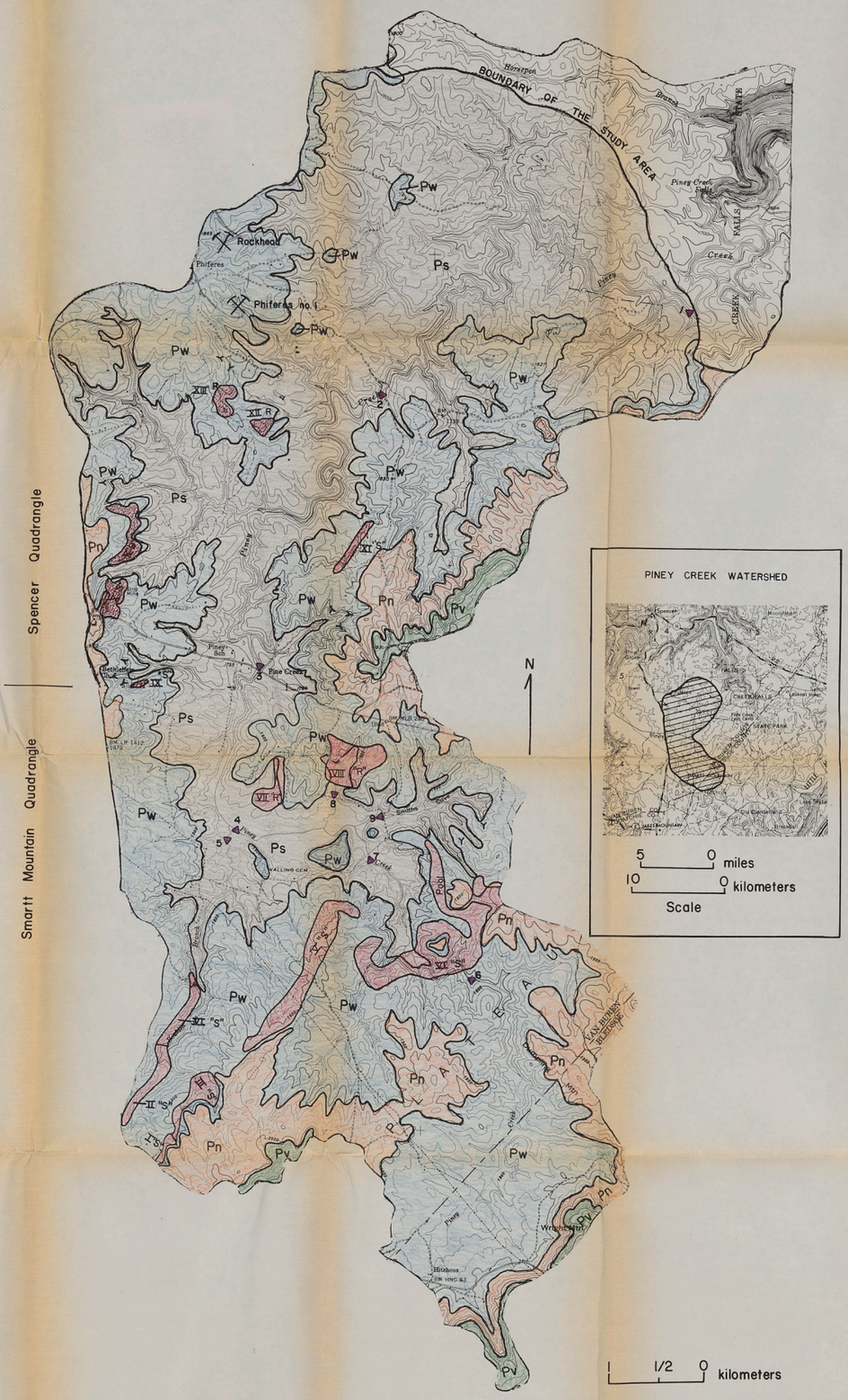


Plate 1

GEOLOGIC MAP OF THE PINEY CREEK WATERSHED

- Surface Mine (I–XIII)
- Major Underground Mine
- Minor Underground Mine
- Sample Site (1–9)
- "R" Richland Coal Seam
- "S" Sewanee Coal Seam

Contour interval 20 feet

- Pv Vandever Formation
- Pn Newton Sandstone
- Pw Whitwell Shale
- Ps Sewanee Conglomerate

Geology of the Spencer quadrangle after Milici 1969.

Smartt Mountain quadrangle geology was mapped by this writer.