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The Influence of Coal Surface Mining on the Aquatic Environment of the Cumberland Plateau

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THE INFLUENCE OF COAL SURFACE MINING ON THE AQUATIC ENVIRONMENT OF THE CUMBERLAND PLATEAU

by

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ABSTRACT

Ten small watersheds in east Tennessee were studied during a 4-year period from 1975 to 1979 in order to provide background data for the development and demonstration of regional mathematical models for predicting the impacts of coal surface mining on the aquatic environment. Study streams were located in area- and contour-mined areas and were chosen to reflect varying degrees of mining impacts on the hydrology, water quality, and aquatic ecology of streams draining the Cumberland Plateau.

Analysis of the geological data from watershed core samples revealed that there was sufficient alkalinity and neutralization potential within the plateau rock strata to neutralize acidity produced from surface mining. This was confirmed by higher pH and alkalinity of water draining both the contour- and area-mined sites. However, leaching tests conducted on rock samples from area- and contour-mined watersheds revealed that pH of leachate would continue dropping and acidity would continue being produced beyond the mine-wash test duration, indicating that, in the field, acidity could eventually increase in waters draining mined sites as the rock strata was leached free of neturalizing agents.

Analysis of other water quality parameters did not reveal any significant metal contamination in the mined areas. Although most metal concentrations were higher in the mine-impacted streams, they were well below safe drinking water standards established by the U.S. Environmental Protection Agency. Suspended and dissolved solids concentrations were found to be significantly higher at mined sites than at unmined sites, although most suspended solids concentrations were below the 70 mg/l effluent limit requirement. Although suspended and dissolved concentrations were relatively low on days samples were collected, significant sedimentation was evident at mined sites, probably due to runoff from storms and heavy rainfall events.

Significant problems were encountered with the collection and analysis of hydrologic data. The placement of automatic recording equipment at remote, difficult to access study sites made frequent checking and servicing impossible. Consequently, malfunctions resulted in long periods of missing or questionable streamflow records. Problems were also encountered with rainfall data, as a result of instrument malfunctions (missing data) or unrepresentative catches. The effects of coal mining on streamflow, therefore, were difficult to evaluate.

All six contour-mined sites were sampled for benthic invertebrates using surber, drift, artificial substrate and kick net sampling techniques. A total of 163 identifiable taxa were collected of which 52 and 55 percent were found at reference sites. However, only 49 taxa (30 percent) were

common to each reference site. Collectors were the most numerous group of organisms collected, representing between 28 and 51 percent of the taxa collected at each site. Collectors were also slightly more numerous at the mined sites than at reference sites. Dipterans were the most numerous order followed by ephemeropterans and tricopterans.

Besides taxonomic differences, significant differences were observed among sites in species composition and numbers. Differences were attributed primarily to heavy siltation and sedimentation resulting from mining activity, which changed or reduced available habitat organisms. Those that were least resistant to increased sedimentation were ephemeroptera, plecoptera, and trichoptera. Dipterans were found to be most resistant to the siltation and sedimentation effects of mining.

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LIST OF ABBREVIATIONS AND SYMBOLS

Art Sub	-- artificial substrate
CC	-- Crooked Creek
CEC	-- cation exchange capacity
cm	-- centimeter
CORR	-- SAS correlation program
ENP	-- excess neutralization potential
EPA	-- Environmental Protection Agency
ft	-- foot
g	-- gram
LB	-- Long Branch
LY	-- Lynn Branch
m^2	-- square meter
m^3	-- cubic meter
meq	-- milliequivalents
mg	-- milligrams
ml	-- milliliter
mm	-- millimeter
msl	-- mean sea level
ORP, Eh	-- oxidation reduction potential
p	-- probability
PACID	-- partial acidity
ppm	-- parts per million
r	-- correlation coefficient
S	-- sulfur
SAS	-- Statistical Analysis System
sq mi	-- square mile
SMCRA	-- Strip Mine Control and Reclamation Act of 1977
TVA	-- Tennessee Valley Authority
UPGMA	-- unweighted pair-group arithmetic average
USGS	-- U.S. Geological Survey
UT	-- Unnamed Tributary
$\bar{d}$	-- species diversity index
µmoles	-- micromoles
µg	-- micrograms
Chemical symbols	-- standard symbols for elements and chemical compounds discussed are used throughout text

CHAPTER I.

INTRODUCTION

Coal has been a valuable energy resource of the Cumberland Plateau of eastern Tennessee since the early nineteenth century. Readily accessible outcroppings along the streams and rivers and the close proximity to growing urban markets, such as Nashville and Knoxville, only served to intensify mining activities throughout the region.

The southern Appalachian region, of which the Cumberland Plateau is a part, presently contains approximately 16 percent of the total U.S. coal reserves on a tonnage basis or 20 percent on a uniform Btu-adjusted basis (Murray, 1978). Increased demand for domestic energy sources will intensify pressures on the coal resources of the region, as well as the environment as a whole. Thus, a cost-effect and expeditious procedure for predicting the impact of proposed mining activities on the aquatic resource is necessary as the demand for coal increases and environmental regulations become more stringent.

This report contains the results of several investigations of streams draining into the Big South Fork of the Cumberland River in eastern Tennessee. The purpose of these investigations, conducted between 1975 and 1979, was to provide data for the development and demonstration of regional mathematical models for predicting the impacts of coal surface mining on the aquatic resource. These models offer the best methodology for quantitatively assessing the environmental consequences of surface mining provided there is a sufficient knowledge of the hydrological, geochemical, and biological forces which distinguish each coal mining region. With this knowledge, mine site characteristics can be integrated with mining and reclamation techniques and the consequences of future mining activities can, therefore, be accurately predicted.

An overview of the model components, study areas, and preliminary water quality and biological data was presented by Cox, et al. (1979). A report summarizing the findings and final modeling methodologies is presented by Betson et al. (1981). A more detailed examination of the geology, water quality, hydrology, and biology of the study sites and a discussion of the possible effects of area and contour mining in the upper eastern Tennessee portion of the Cumberland Plateau are presented in the following chapters. A description of the watershed characteristics, stratigraphic sequences of the underlying rock strata, historical and recent water quality data, and cross-sectional profiles of study watersheds are presented in chapter II. A discussion of the geological sources of potentially toxic chemical elements, as well as the results of the geochemical analysis of the overburden and coal for each site, is presented in chapter III. Chapter IV presents the results of the water quality analysis, while chapters V and VI present results of the hydrologic and benthic analysis of study streams.

CHAPTER II.

STUDY AREAS

Cox, et al. (1979) previously described both the area-mined sites in Fentress County and the contour-mined sites in Scott and Anderson Counties. All sites are located on the coal-bearing portion of the Cumberland Plateau in upper east Tennessee (figure 1, table 1). The stratigraphy in this region is Pennsylvanian in origin and is dominated by easily weathered sandstones, shales, and conglomerates (figure 2). Present geochemical interpretation of water analysis has confirmed earlier observations (Shoup, 1944) of the poor buffering action of natural waters draining this area of the plateau as indicated by the low pH and alkalinity of the reference (control) streams. Glenn (1925) presents an excellent historical, geological, and economic account of the study areas, and the counties in which they lie, in his description of the northern Tennessee coal fields. A more recent geological interpretation of this region, as well as a description of the updated stratigraphic nomenclature, is presented by Wilson, et al. (1956).

A. GENERAL GEOLOGY OF AREA-MINED SITES

The area-mined sites are situated on the coal-bearing portion of Fentress County. The general plateau surface in this region is gently rolling with streams sinking their courses below to depths ranging from small grooves to profound gorges. Typically, the headwater parts of the streams have not yet cut deeply beneath the plateau surface, but their lower courses have cut precipitous gorges 60 to 120 meters deep, such as the gorge along Clear Fork and the deeper gorge on lower White Oak Creek (Glenn, 1925).

The rocks of the area-mined sites are all of sedimentary origin and consist of varying quantities of conglomerates, sandstones, shales, and coal. This group of Pennsylvanian age rocks, previously referred to as the Lee Formation, is currently referred to as the Gizzard Group and the Crab Orchard Mountain Group. These groups are the oldest of the Pennsylvanian age rocks and are situated directly above Mississippian age limestones. The study streams drain the sandstones and shales of the Rockcastle conglomerate, a part of the Crab Orchard Mountain Group. The Nemo coal seam is the predominant coal of this conglomerate and is actively mined in the region. Figure 3 is a cross-sectional profile of Crooked Creek illustrating the major coal seams and formations through which it flows.

B. GENERAL GEOLOGY OF CONTOUR-MINED SITES

The contour-mined sites are located in Scott and Anderson Counties on the eastern edge of the Cumberland Plateau. The topography of

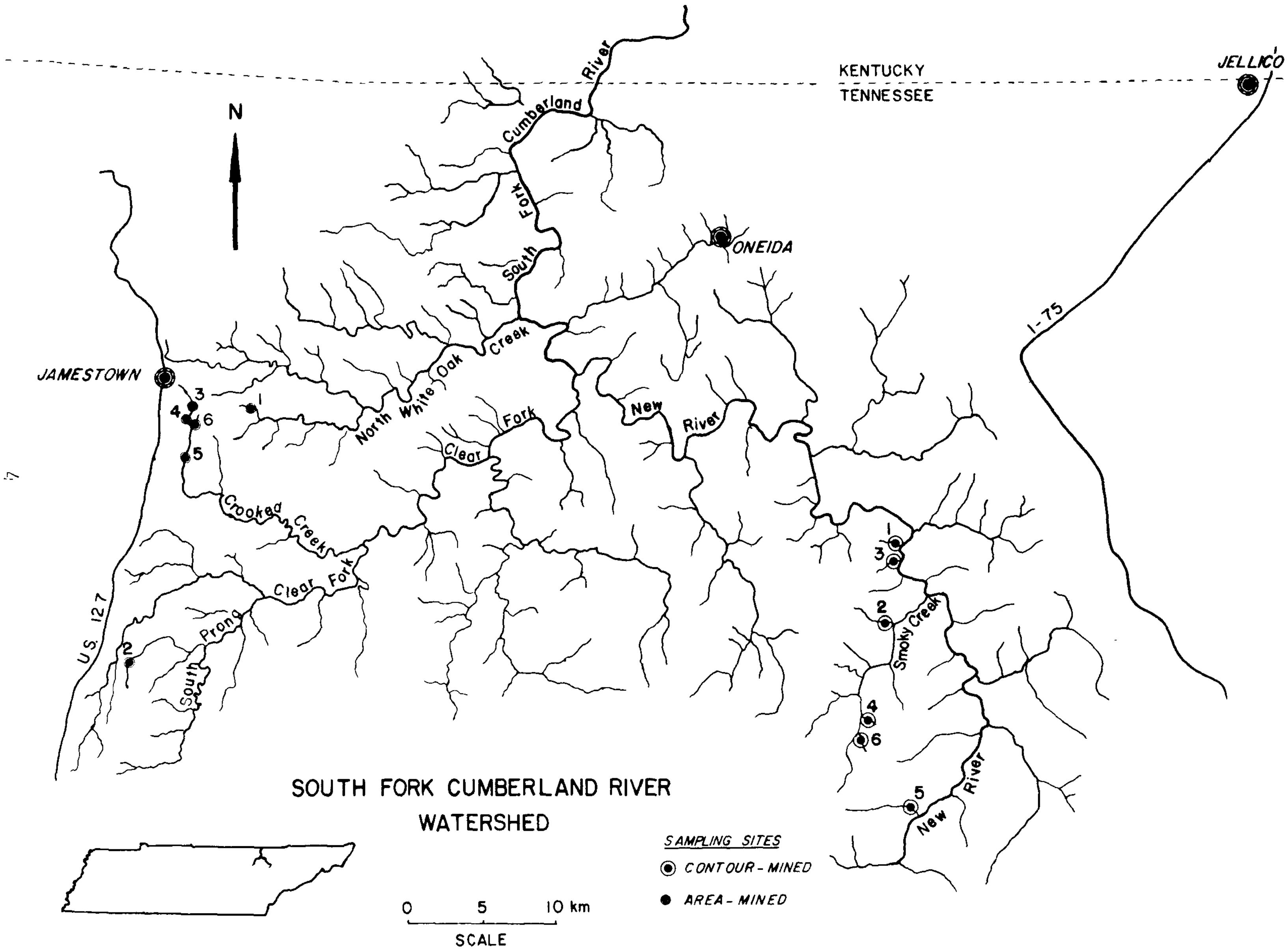

Figure 1. Location of Area and Contour-mined Sites in Upper East Tennessee

TABLE 1. WATERSHED CHARACTERISTICS OF STUDY STREAMS WITH PRIMARY LAND USE CHARACTERISTICS. WATERSHED AREAS ARE DETERMINED FROM THE AREA UPSTREAM OF EACH SAMPLING SITE LAND USE DATA ARE ACCURATE AS OF JANUARY 1979

	Study stream	Code	Watershed area (ha)	Land use (%) Mined	Rural-residential	Forested
			Area-Mined Sites			
1.	Lynn Branch	LY 0.4	103	0	11	89
2.	Long Branch	LB 4.0	280	0	11	89
3.	Crooked Creek	CC 18.5	180	0	69	31
4.	Crooked Creek	CC 16.7	725	13	56	31
5.	Crooked Creek	CC 15.9	950	13	55	32
6.	Unnamed Tributary	UT 0.01	52	43	52	5
			Contour-Mined Sites			
1.	Lowe Branch	LOW	238	0	0	100
2.	Bowling Branch	BOW	764	0	0	100
3.	Anderson Branch	AND	210	7.5	0	92.5
4.	Bills Branch	BIL	174	9.0	0	91.0
5.	Indian Branch	IND	1119	18.9	0	81.1
6.	Green Branch	GRE	357	24.1	0	75.9

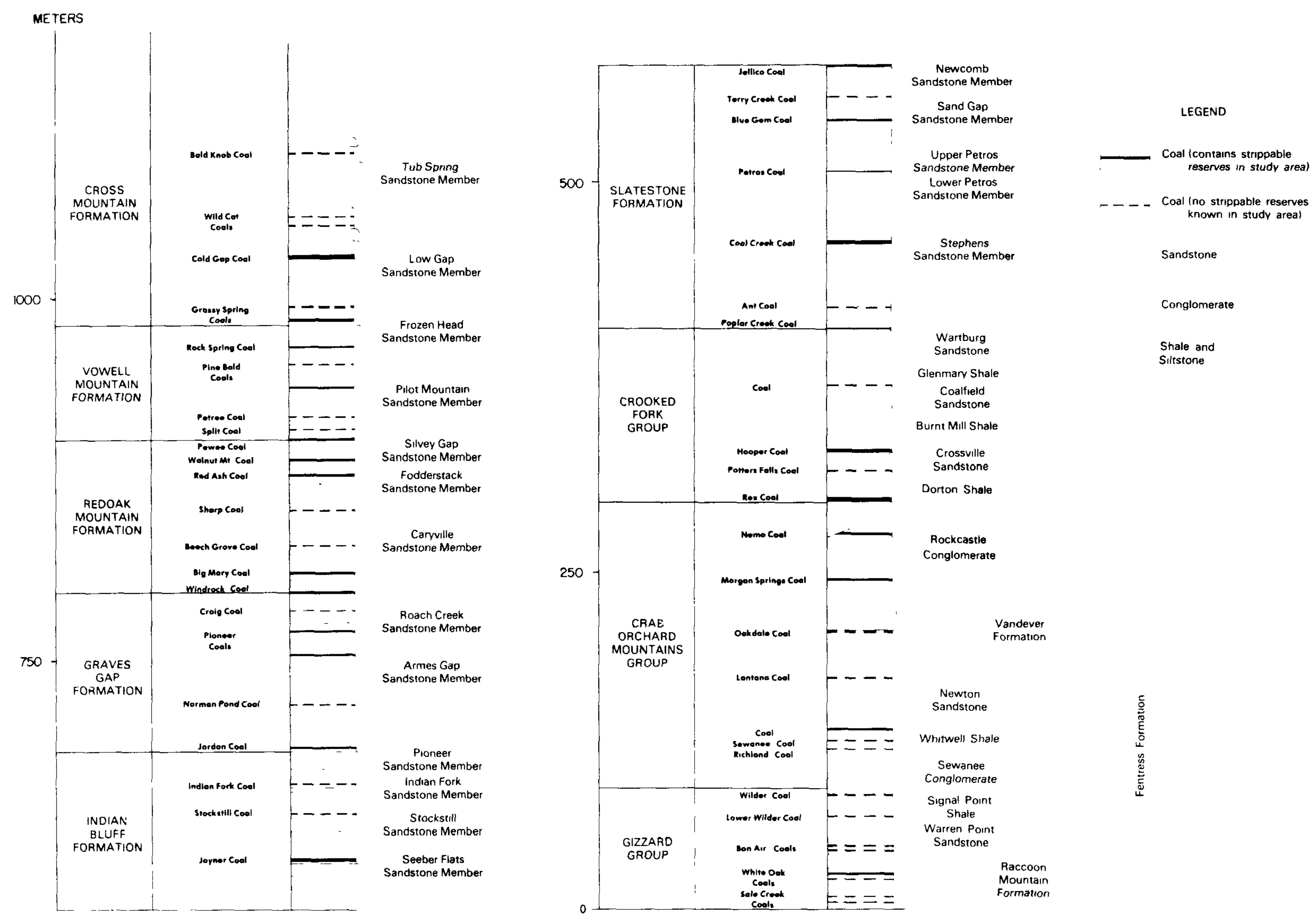

Figure 2. Generalized Stratigraphic Sequence of Pennsylvania Rocks in Tennessee. Figure is taken from Johnson and Luther (1972).

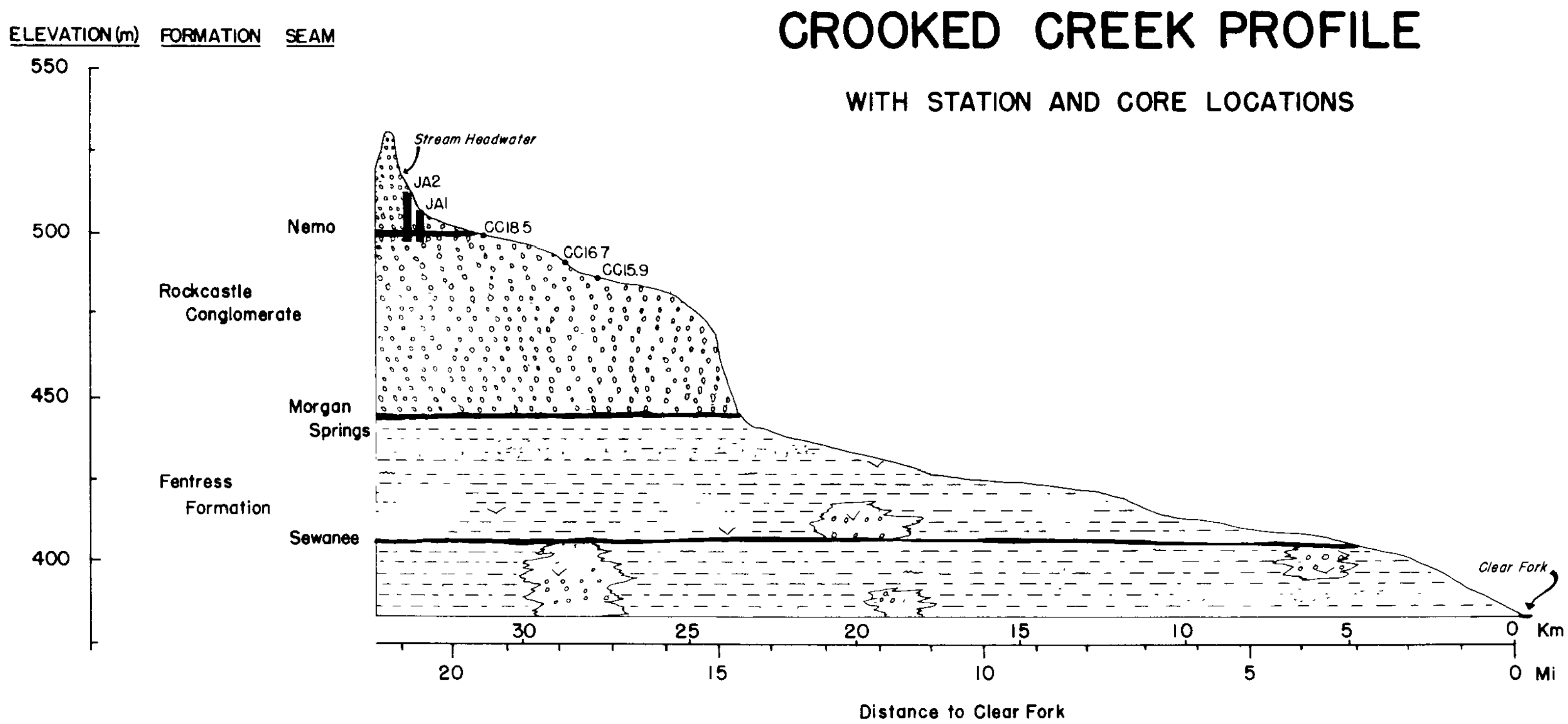

Figure 3. Elevation Profile of Crooked Creek with Station and Core Locations. Elevation magnification is exaggerated 100 X.

this region is substantially different from the area-mined sites, composed of narrow, winding ridges separated by narrow, deeply cut stream gorges. The roughness of the terrain is primarily due to the erodibility of softer shales and thin sandstones through which the streams flow. These softer shales and thin sandstones are a part of the middle Pennsylvanian series which includes the Vowell Mountain, Redoak Mountain, Graves Gap, Indian Bluff, and Slatestone Formations, previously referred to collectively as the Briceville Formation. Economically recoverable coal seams in these formations include the Pewee, Walnut Mountain, Big Mary, Windrock, Joyner, and Jellico seams, although all may not be accessible or present in any one study watershed. A cross-sectional profile of Anderson Branch illustrating the predominant coal seams and formations through which it flows is presented in figure 4.

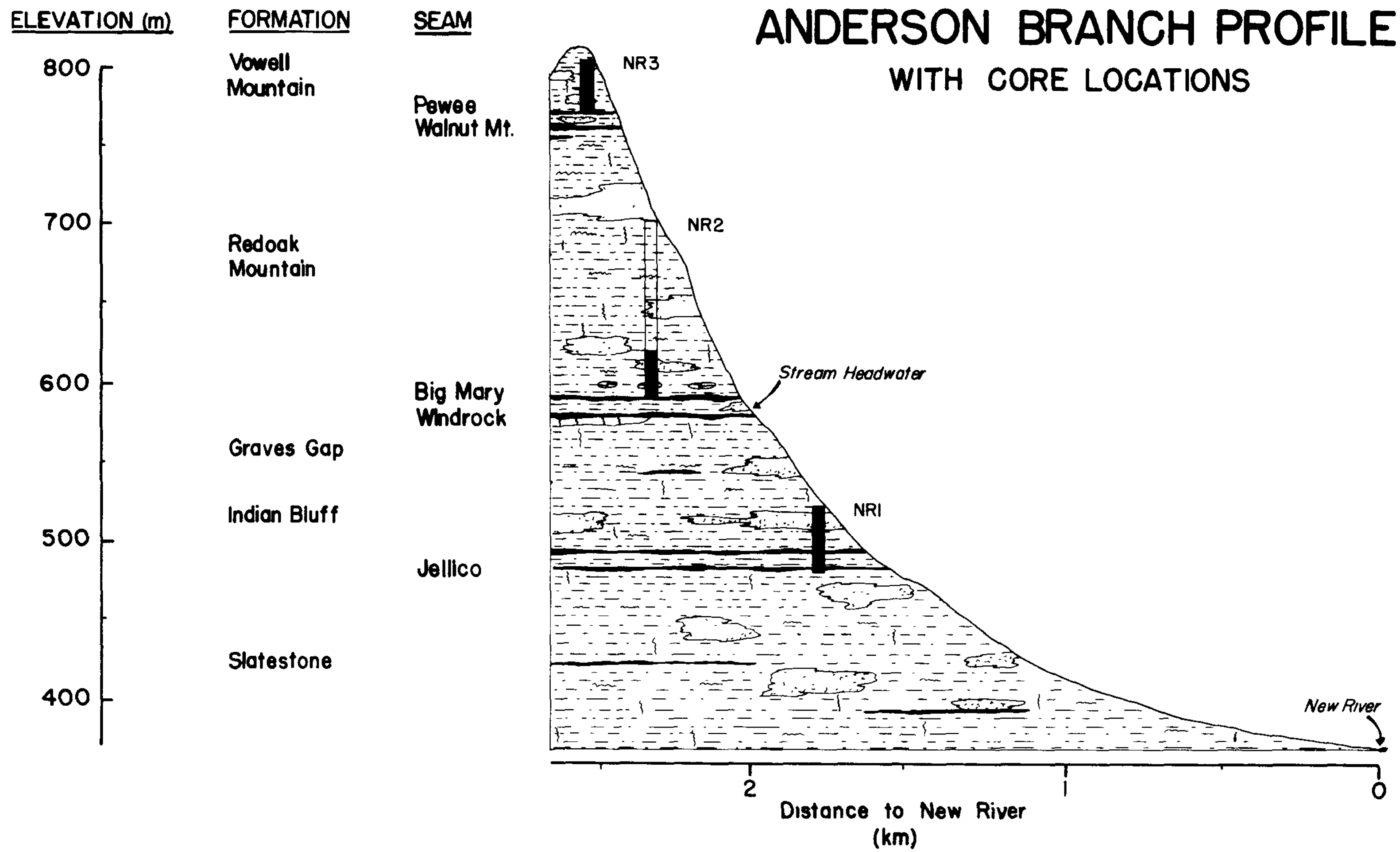

Figure 4. Elevation Profile of Anderson Branch with Core Locations. Elevation magnification is exaggerated 5 X.

Chapter III.

OVERBURDEN AND COAL CHEMISTRY

A. GEOLOGICAL SOURCES OF TOXIC MATERIALS

The sources and ultimate fates of potentially toxic substances in the aquatic environment are determined by the geochemical and biological cycling of minerals. Any attempt to predict the effects of surface mine drainage on the aquatic resource would be fruitless without a knowledge of the rocks and the associated mineral assemblages characteristic to the study area. Geological properties, such as the age and type of rocks present, the length of previous exposure time, rock texture and porosity, the purity and crystal size of minerals, the regional structure, and the degree of fissuring, are important factors influencing the composition of surface and ground water (Hem, 1970). Surface mining can accelerate the geochemical weathering of major and minor mineral constituents by exposing previously unexposed rock strata. Changes in the rate of release and in availability of the ionic and precipitate species of heavy metals and sediment associated with this weathering are important in understanding the effects of mining on water quality and the biotic community.

Geological sources of elements arise from the weathering of minerals and other particles characteristic to different rock types. In the Cumberland Plateau region, sandstones and shales are the primary sources of elemental species. Coal may also be a source of reduced mineral species such as pyrite. These rocks were formed from the deposit of sediments in the electrochemically reducing environments of shallow, Paleozoic era seas. These sediments were transformed by increasing temperature and pressure into sedimentary rocks containing elements in proportion to their relative abundance in the ocean and their affinity for mineral and colloidal associations. The disturbance and weathering of these rocks result in the breakdown of minerals associated with particular strata, elevating the ionic and sediment concentrations of receiving streams.

The precise amounts of the elements contributed from geologic sources to rivers and streams and, ultimately, to the oceans, are poorly known. Average concentrations of elements found in shales, sandstones, and coal are known and are listed in table 2; concentrations in coal dust are also listed since fugitive dust can be created during mining operations.

Although oxides of silica, alumina, and iron are the most common minerals in rocks from the Cumberland Plateau (table 3), abundance

TABLE 2. COMPARISON OF THE CONCENTRATIONS IN PARTS PER MILLION, OF SOME ELEMENTS FOUND IN SEDIMENTARY ROCKS†

Element*	Shales	Sandstones	Coal	Coal dust
Si	260,000	359,000	-	294,000
Al	80,100	32,100	-	283,000
Fe	38,800	18,600	1,600	79,200
Ca	22,500	22,400	4,000	13,200
Na	4,850	3,870	5,000	755
Mg	16,400	8,100	4,500	792
K	24,900	13,200	410	16,600
Mn	575	392	30	45.3
Cr	423	120	4.5	170
Ni	29	2.6	2.7	755
Zn	130	16	10	415
Cu	45	15	25	868
Co	8	.33	2.3	11.3
Pb	80	14	3.9	26.4
Cd	0.18	0.02	0.19	3.80
Hg	0.27	0.06	-	-

*Arranged in order of abundance in the earth's crust (from Krauskopf, 1979).

†Sources -
Coal data: Blackwood and Wachter (1978)
Shale and sandstone data: Hem (1970)

TABLE 3. CHEMICAL ANALYSIS OF ROCKS FROM THE CUMBERLAND PLATEAU REGION OF KENTUCKY, TENNESSEE, AND ALABAMA. DATA COLLECTED BY ENGINEERING AND DESIGN BRANCH - TENNESSEE VALLEY AUTHORITY

Major oxides (percent)	Formation and sample												
	Sewanee conglomerate		Breathitt sandstone		Pottsville sandstone		Warren Point sandstone		Raccoon Mt. sandstone		Carbondale formation		
	1*	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	98.3	98.4	64.02	-	89.90	97.64	95.3	79.2	72.1	62.2	78.10	71.92	51.86
Al_2O_3	0.74	0.17	11.36	-	6.12	1.57	1.9	2.7	11.9	5.6	8.46	4.04	17.74
Fe_2O_3	0.34	0.42	11.91	37.75	0.68	0.14	0.76	9.7	4.8	5.5	4.14	7.70	5.38
FeO			7.98	26.45									0.02
CaO	0.028	0.016	1.08	1.05	0.11	0.00	0.06	0.53	0.21	10.9	2.15	6.44	3.04
MgO	0.025	0.009	0.32		0.17	0.01	0.10	0.81	1.03	1.04	1.16	2.41	2.56
MnO							0.005	0.31	0.06	0.21			
TiO	0.04	0.04				0.10	0.07	0.14	0.81	0.34	0.00	0.00	tr†
Na_2O					0.10		0.12	0.23	0.63	0.74	0.98	0.00	0.35
K_2O					0.62		0.43	0.56	2.60	0.91	0.82	0.00	0.21
P_2O_5													
S				<0.02									
Zn				<0.01									
H_2O			0.24								0.11	0.02	1.27
Ignition loss	0.30	0.20	9.02		1.61	0.60	0.30	5.90	4.70	12.20	4.08	7.39	17.21
TOTAL	99.77	99.26	105.43	(65.28)	99.31	100.06	99.05	100.08	98.84	99.64	100.00	99.92	99.64

*Sample locations:

1. Unwashed sand from pit of Sewanee Silica Sand Company, Sewanee Silica Sand Company, Sewanee, Tennessee.
2. Washed and screened sand (30-100 mesh) from Sewanee Silica Sand Company, Sewanee, Tennessee.
3. Sandstone - Artemus Steam Plant Site, Artemus, Knox County, Kentucky.
4. Dark nodules from Breathitt Sandstone, Artemus Steam Plant Site, Artemus, Kentucky.
5. Sandstone - near Crossville, Cumberland County, Tennessee.
6. Marion County, Alabama - North of Hamilton (average of five samples).
7. Raccoon Mountain pumped storage, Hole Y-2-11 + 55, depth 11.2.
8. Raccoon Mountain pumped storage, Hole 3L-19 + 00, depth 24 feet.
9. Raccoon Mountain pumped storage, Hole 24 + 49.60, depth 76.8 feet.
10. Raccoon Mountain pumped storage, Hole 4B-44 + 00, depth 87.5 feet.
11. Sandstone - dark gray - Paradise Steam Plant Site, Muhlenberg County, Kentucky.
12. Sandstone - light gray - Paradise Steam Plant Site, Muhlenberg County, Kentucky.
13. Shale - dark - above No. 9 coal seam, Paradise Steam Plant Site, Muhlenberg County, Kentucky.

†Trace

in any one strata can vary dramatically. Many of the oxides are bound together with hydrogen or covalent bonds to form complex mineral assemblages. Sandstone, which is composed primarily of quartz, may also contain appreciable quantities of sodium and potassium feldspars. Quartz and feldspar minerals are extremely resistant to chemical alteration by weathering of the parent rock (Hem, 1970). Given enough time and the right conditions, however, feldspars will weather into complex clay-mineral species such as kaolinite and illite clay:

$$\underset{\text{Potassium Feldspar}}{KAlSi_3O_8} + \underset{\text{rainwater}}{9H_2O + 6CO_2} \rightarrow 2K^+ + 6SiO_2(aq.) + \underset{\text{Kaolinite}}{3Al_2Si_2O_3(OH)_4} \qquad \text{Eq 1.}$$

Illite clay can be formed from the rearrangement and substitution of cations as kaolinite enters an ion-rich, seawater environment:

$$\underset{\text{Kaolinite}}{3Al_2Si_2O_5(OH)_4} + 2K^+ + 2HCO_3 \rightarrow \underset{\text{Illite}}{2K(AlSiO_4)Al_2(OH)_2O_2(Si_2O_4)} + 5H_2O + 2CO_2\uparrow \qquad \text{Eq. 2}$$

Furthermore, the degradation of illite clay to kaolinite clay can be an important mechanism by which waters of low pH are neutralized. Fletcher (1977) offers the following reaction which may serve to neutralize some of the acid generated by oxidizing sulfides in the Piney Creek Watershed, Van Buren County, Tennessee:

$$\underset{\text{Illite}}{2KAl_2(AlSi_3)O_{10}(OH)_2} + 5H_2O \rightarrow \underset{\text{Kaolinite}}{3Al_2Si_2O_5(OH)_4} + 2\ KOH \qquad \text{Eq. 3}$$

This is a very slow reaction compared to sulfide oxidation, however, and unlikely to neutralize much acid.

Once aluminosilicates such as kaolinite and illite have been formed, they will, over long geological time spans, be incorporated into sedimentary rocks such as those found in the Cumberland Plateau strata. Much remains to be learned about complex aluminosilicates and their importance as a source and/or method of transport of potentially toxic chemical elements. Couture (1977), Krickenberger (1977), and Krauskopf (1979) discuss clay-minerals and their interactions with other elements and compounds.

Although the quartz and feldspar minerals common to sandstones do not undergo rapid weathering, the cementing materials holding the coarser grains together can dissolve and thus influence the quality of water passing through the strata. The most common cementing materials are calcium carbonate ($CaCO_3$), silica, ferric hydroxide, ferrous carbonate, and clay minerals (Hem, 1970). These cementing materials can be easily leached from their sandy substrate since they were deposited from water which passed through the strata at some past time.

Shales and other fine-grained sedimentary rocks are hydrolysates composed primarily of clay minerals and other particles that have been formed by chemical reactions like those presented in equations 1 and 2 (Hem, 1970). They almost always contain finely divided quartz and other minerals characteristic of resistates, but smaller in size. Reduced minerals such as pyrite are also found associated with hydrolysates. Waters flowing through these strata may be unusually high in dissolved solids, especially if the hydrolysate strata originally precipitated from seawater.

In summary, geochemical sources of elements and other potentially toxic materials in surface waters can be quite varied in quality and quantity. The types and origin of rock and minerals present, the types of weathering processes taking place, and the degree and time of exposure can readily influence surface and ground water. The following section describes the procedures and results of the geochemical analysis of the coal and overlying strata present in each study site.

B. ANALYTICAL PROCEDURES

In order to characterize the geological factors which determine the quality of water draining the mine sites, cores were drilled through representative strata at each study site. Cox, et al. (1979) describes the location of and the procedures used to analyze each of the seven cores and presents preliminary geochemical results of the Jamestown area sites. The samples from each strata were regrouped into definitive rock types so that each lithologic unit could be characterized. Stratigraphic sections of each core are shown in figures 5 and 6 (one Jamestown area core was drilled through spoil and not shown).

1. Geochemical and Metals Analysis

About 220 grams of each composite sample were ground to pass through a No. 50 sieve, yet be retained by a No. 100 sieve, and were analyzed for total sulfur, pyritic sulfur, cation exchange capacity (CEC), calcium carbonate, soil pH, potential acidity with peroxide, and total neutralization potential. Excess neutralization potential (ENP) was calculated by subtracting potential acidity from total neutralization potential. Concentrations of Ca, Mg, Fe, Mn, Al, Cd, Co, Cr, Cu, Ni, Pb,

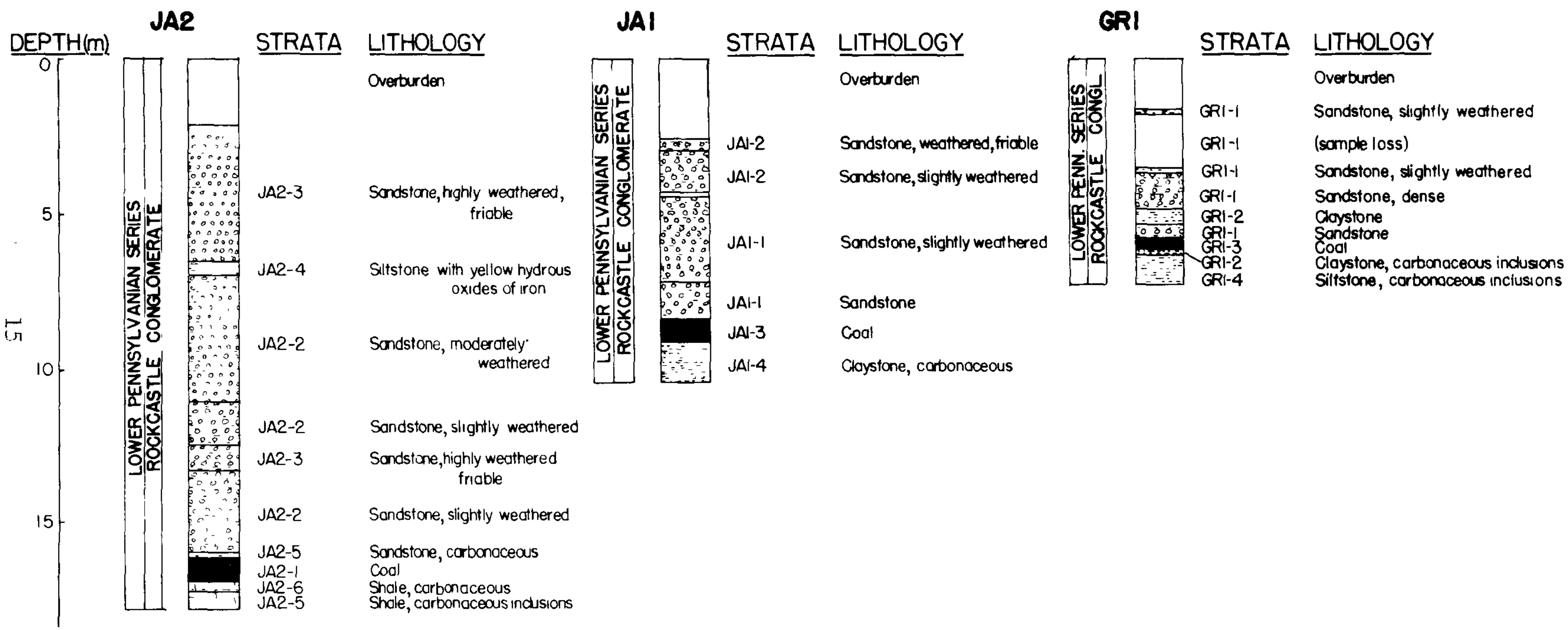

Fig 5 Stratigraphic Sections of the Jamestown Area Cores with Strata Descriptions

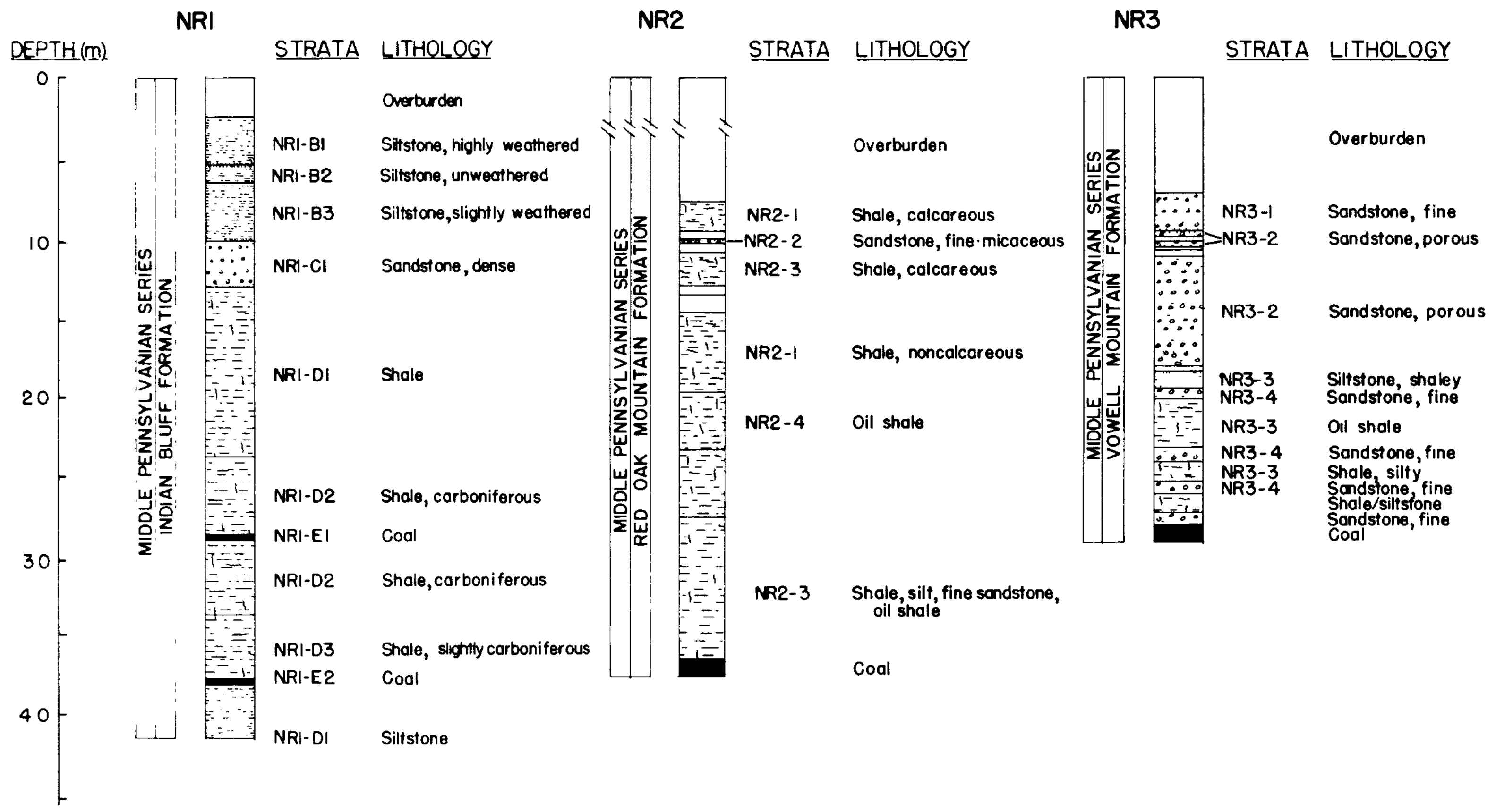

Fig. 6 Stratigraphic Sections of the New River Basin Cores with Strata Descriptions

and Zn were also determined for each sample by wet acid digestion followed by atomic absorption. Composite samples of about 2 kg, ground to pass through a No. 10 sieve, were retained for the leaching study.

2. Leaching Study

This study was designed to simulate field conditions by exposing a sample from each stratum to a moist atmosphere and periodically washing the strata with de-ionized water. A modification of the methods of Caruccio (1968) and Geidel (1976) was used in this study. A 100-g portion from each of the 42 strata identified was placed in a leaching chamber that consisted of a plastic sediment cup and lid. The experimental apparatus is shown in figure 7. Moist air was continually pumped across the strata at a rate of 100 cubic feet per minute. At 7-day intervals, the strata were washed with 100 ml of de-ionized water, filtered, and then returned to the leaching chamber with the filter pad. The leachate (filtrate) was then analyzed for oxidation reduction potential (ORP), pH, alkalinity, and acidity. Each stratum was subjected to this procedure for approximately 63 days or nine washings.

C. RESULTS AND DISCUSSION OF OVERBURDEN AND COAL CHEMISTRY ANALYSIS

1. Jamestown and New River Area Lithology

A description of the overburden and coal lithology present at the Jamestown and New River area sites is presented in tables 4 and 5. Sandstone was the dominant rock type of the Jamestown area representing approximately 80 percent of the total lithology analyzed. These creamy white to tan to gray sandstones ranged from slightly weathered to highly weathered, depending on depth and location. Claystones were present in cores JA1 and GR1, in close proximity to the coal seam. Claystone represented approximately 7 percent of the total lithology analyzed. Shale was present only in core JA2, also located in close proximity to the coal seam, and represented only 1.4 percent of the total lithology analyzed. Siltstone was distributed throughout the length of cores JA2 and GR1, representing 1.7 percent of the total lithology. Coal was sampled from each core and represented approximately 6 percent of the total lithology analyzed. All coal samples collected from the Jamestown sites were of the Nemo seam and varied in thickness from 30 to 80 cm.

Shale dominated the strata found in the New River area sites, representing approximately 70 percent of the total lithology analyzed. These shales were either carbonaceous, carboniferous, or calciferous in nature, depending on depth and location.

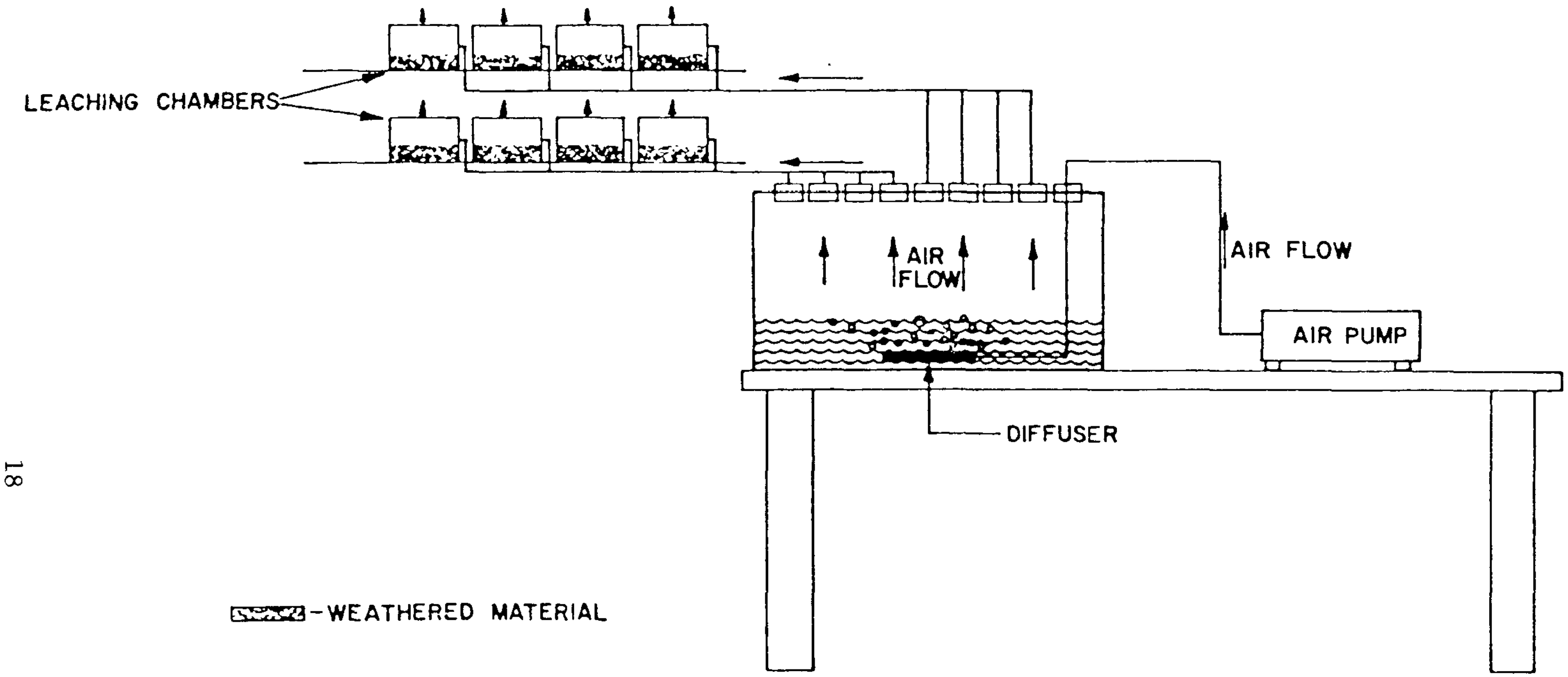

Figure 7. Coal-strata weathering apparatus.

TABLE 4. DESCRIPTION OF JAMESTOWN AREA OVERBURDEN LITHOLOGY

Rock type	Strata#	Strata thickness (m)	Percent of total lithology analyzed	Percent of total core length sampled	Color	Variation
Sandstone	JA1-1	4.1m	14.1%	11.5%	creamy white to yellow; dense grey to tan	slightly weathered
Sandstone	JA1-2	1.8	6.2	5.1	white to yellow creamy white	slightly weathered to weathered; friable, micaceous
Sandstone	JA2-2	8.1	28.0	22.9	tan to greyish tan	slightly to moderately weathered
Sandstone	JA2-3	5.2	18.0	14.7	creamy white to tan; yellow to tan	highly weathered; friable
Sandstone	JA2-5	0.9	3.1	2.5	grey	carbonaceous
Sandstone	GR1-1	3.2	11.0	9.0	yellow-tan to light grey	slightly weathered
Total Sandstone		23.3	80.4	65.7		
Shale	JA2-6	0.4	1.4	1.1	dark grey	carbonaceous
Siltstone	JA2-4	0.5	1.7	1.4	yellow to tan	yellow-like hydrous oxides of iron
Siltstone	GR1-4	1.0	3.4	2.8	light grey	small amount of carbonaceous inclusions
Total Siltstone		1.5	5.1	5.3		
Claystone	JA1-4	1.3	4.5	3.7	light to medium grey	carbonaceous inclusions
Claystone	GR1-2	0.7	2.4	2.0	light to medium grey	considerable black carbonaceous inclusions
Total Claystone		2.0	6.9	5.7		
Coal	JA1-3	0.8	2.8	2.3	shiny black	
Coal	JA2-1	0.7	2.4	2.0	shiny black	
Coal	GR1-3	0.3	1.0	0.8	shiny black	
Total Coal		1.8	6.2	5.1		
TOTAL		29.0m	100%	81.6%		

TABLE 5. DESCRIPTION OF NEW RIVER OVERBURDEN LITHOLOGY

Rock type	Strata#	Strata thickness (m)	Percent of total lithology analyzed	Percent of total core length sampled	Color	Variation
Sandstone	NR1-C1	2.5m	3.1%	2.7%		dense, carbonaceous strata
Sandstone	NR2-2	0.9	1.1	1.0	light to medium grey	fine, micaceous; slightly calcareous
Sandstone	NR3-1	2.4	3.0	2.7	medium grey	fine
Sandstone	NR3-2	7.2	8.9	7.9	tan to light brown	medium to coarse; porous, friable
Sandstone	NR3-4	3.4	4.2	3.7	light tan to medium grey	fine
Total Sandstone		16.4	20.3	18.0		
Shale	NR1-D1	11.1	13.7	12.1		carbonaceous/ carboniferous
Shale	NR1-D2	9.8	12.1	10.7		carbonaceous/ carboniferous
Shale	NR1-D3	4.1	5.1	9.5		slightly carboniferous
Shale	NR2-1	6.9	8.5	7.5	medium to dark grey	calcereous and noncalcareous strata
Shale	NR2-3	11.1	13.7	12.1	medium to dark grey	oil shale
Shale	NR2-4	6.6	8.2	7.3	dark grey	noncalcareous oil shale
Shale	NR3-3	6.3	7.8	6.9	light to dark grey	highly decomposed
Total Shale		55.9	69.1	61.1		
Siltstone	NR1-B1	2.9	3.6	3.2		highly weathered
Siltstone	NR1-B2	1.2	1.5	1.3		unweathered, dense
Siltstone	NR1-B3	4.0	5.0	4.4		slightly weathered
Total Siltstone		8.1	10.1	8.9		
Coal	NR1-E2	0.4	0.5	0.4	shiny black	
TOTAL		80.8m	100%	88.4%		

Oil shale was found in core NR2. Sandstones represented approximately 20 percent of the total lithology analyzed and varied from a very dense, carbonaceous strata to a very porous and fiable strata. Colors ranged from tan to medium gray. Approximately 10 percent of the total lithology analyzed was siltstone, varying from a highly weathered to an unweathered, dense species. Siltstone was present only at the upper and lower ends of core NR1. Coal was present in all cores, but only analyzed in core NR1. Two seams were present, the Joyner and the Jellico seams, spaced approximately 10 meters apart. The Jellico seam was approximately 40 cm in thickness; the Joyner seam was not analyzed.

2. Geochemical and Metals Analysis

Geochemistry--

Average values for geochemical characteristics of each stratum are shown graphically in figures 8 and 9. New River area strata were generally more alkaline than Jamestown area strata, reflected by higher soil pH, $CaCO_3$ concentrations, and excess neutralization potentials. This more alkaline character of the overburden and coal would seem to explain the higher pH and alkalinity of New River reference streams.

Total and pyritic sulfur concentrations were low, averaging less than 1 percent of each rock type analyzed. Total and pyritic sulfur concentrations were predictably higher in the coal seams, although the relative proportions of pyritic sulfur to total sulfur varied from seam to seam and from core to core. Pyritic sulfur comprised 93 to 100 percent of the total sulfur content of the Nemo seam compared to 39 percent of the Jellico seam.

Cation (or ion) exchange involves reversible solution and deposition reactions in which water molecules are not altered (Hem, 1970) and is an important mechanism by which metal ions are redistributed between solution and sediment. Cation exchange capacity (CEC) is a measure of adsorption and commonly expressed as milliequivalents of exchanged cation per 100 g of exchanger material. In mining environments where sedimentation of streams is particularly severe, cation exchange reactions are important mechanisms by which metal ions are transported downstream, attached to mineral or colloidal particles.

Clay minerals such as montmorillonite and illite often provide excellent exchange sites for metal ions. Any disturbance of clay-mineral rich sediments such as shale and claystone during surface mining may lead to the adsorption of metal ions and their transport downstream.

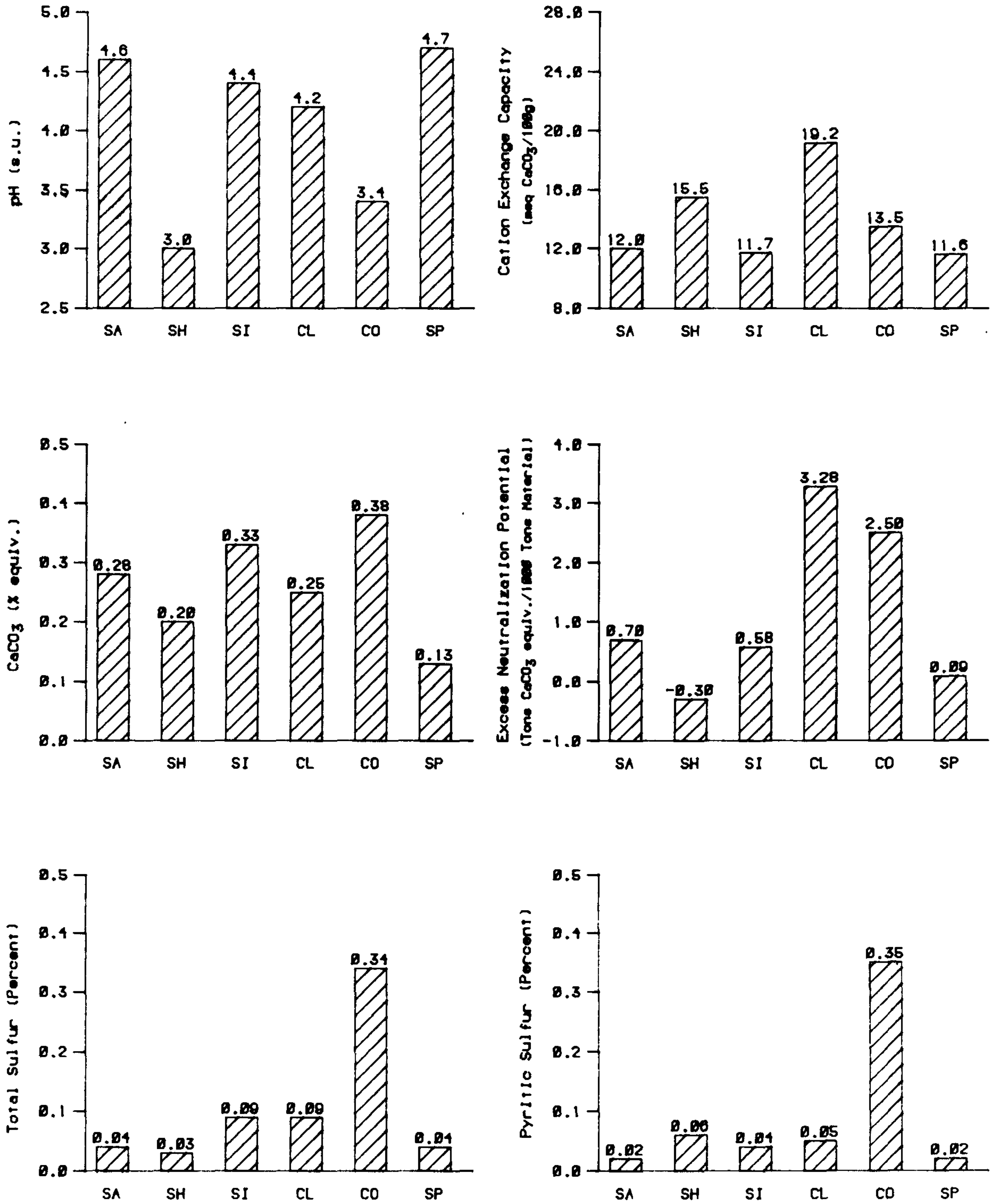

Figure 8. Average geochemical values for Jamestown area strata. SA-Sandstone, SH-Shale, SI-Siltstone, CL-Claystone, CO-Coal, SP-spoil

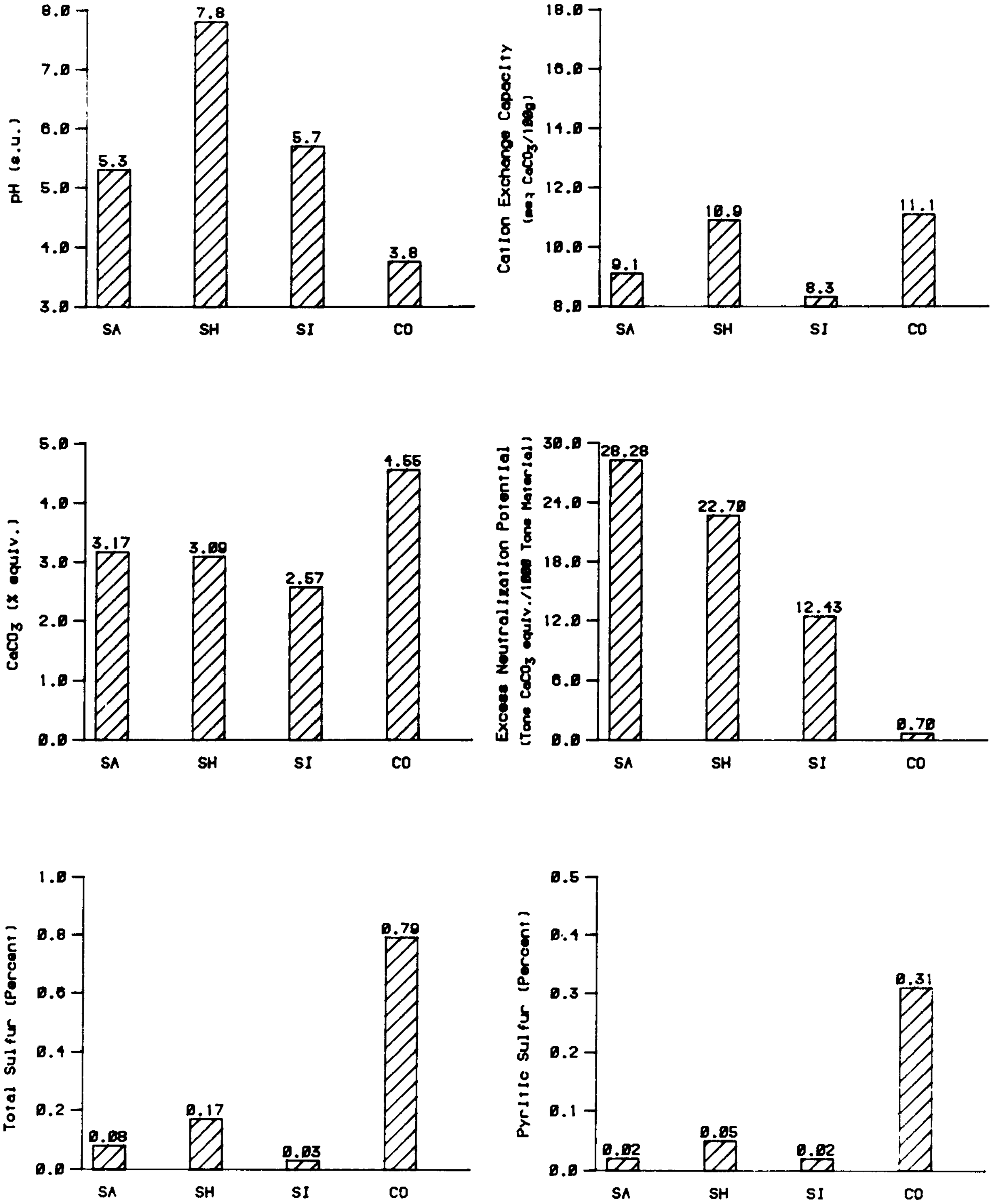

Figure 9. Average geochemical values for New River area strata. SA-Sandstone, SH-shale, SI-siltstone, CO-Coal

Cation exchange capacities of the Jamestown and New River area strata were relatively low, although higher for Jamestown area strata, ranging approximately from 8 meq $CaCO_3$ per 100 g of New River area siltstone to 19.2 meq $CaCO_3$ per 100 g of Jamestown area claystone. Cation exchange capacities of shale and coal were higher at each area than those of siltstone and sandstone strata reflecting their greater clay-mineral content. Spoil material at the Jamestown area averaged about 12 meq $CaCO_3$ per 100 g, the lowest value of the Jamestown area strata analyzed.

Metals--

Surface water concentrations of metals depend largely on the type of the metal-bearing rock being drained (igneous, metamorphic, or sedimentary) and the extent of weathering and exposure time. Solubility differences, adsorption processes, the activity of micro-organisms, and atmospheric input are also important factors which determine the availability and quantity of metals in surface waters.

Concentrations of metals in each strata from Jamestown and New River area core samples are listed in tables 6 and 7. Average concentrations of metals in the various sedimentary rock strata examined are presented graphically in figures 10 and 11, expressed as micromoles per gram (μmoles per g) so as to provide a more realistic picture of their relative abundance in the strata.

Aluminum and iron were present in greatest concentrations in each study area strata, reflecting their importance as major elements in the earth's outer crust. Aluminum ions can substitute for silicon, magnesium, and iron in some silicate rock minerals due to their small size and charge characteristics. The most common sedimentary aluminum-bearing minerals are clays. Coal contained greatest concentrations of aluminum at each study area with concentrations ranging from about 367 μmoles per g in the New River area to 556 μmoles per g in the Jamestown area. Claystone, shale, and spoil material also had appreciable quantities of aluminum. Sandstones contained the least amounts of aluminum ranging from 94 μmoles per g in the Jamestown area to 198 μmoles per g in the New River area.

Primary sources of iron in sedimentary rock are the polysulfides, pyrite and macrosite, the carbonate siderite, and magnetite. Ferric oxides and hydroxides (Fe_2O_3 or $Fe[OH]_3$) give sandstones their red or yellow colors. Iron concentrations were significantly greater in the New River area strata ranging from about 218 μmoles per g of coal to 662 μmoles per g of sandstone. In the Jamestown area, values ranged from 59 μmoles per g in the shale to 423 μmoles per g of coal. Spoil material contained 211 μmoles per g.

TABLE 6. METAL CONCENTRATIONS OF THE JAMESTOWN AREA STRATA MEASURED FROM CORE SAMPLES AND EXPRESSED AS μg/g

Rock type	Strata #	Strata thickness (m)		Metal* Ca	Mg	Fe	Mn	Al	Cd	Co	Cr	Cu	Ni	Pb	Zn
Sandstone	JA1-1	4.1		95	82	7200	90	590	1	1	5	2	1	5	5
	JA1-2	1.8		12	6	1000	1	320	1	1	5	1	1	5	3
	JA2-2	8.1		26	20	2000	8	420	1	1	5	1	1	5	5
	JA2-3	5.2		68	350	8200	37	6600	1	1	24	5	1	5	11
	JA2-5	0.9		710	670	3800	37	3800	1	5	26	33	10	15	120
	GR1-1	3.2		290	980	6800	71	3500	1	1	12	4	5	5	79
		23.4	x̄	200	351	4833	41	2538	1	2	13	7	3	7	37
Shale	JA2-6	0.4		500	480	3300	30	2900	1	11	10	28	23	21	38
Siltstone	JA2-4	0.5		57	51	5800	15	820	1	1	9	4	1	5	5
	GR1-4	1.0		200	1900	9300	72	5200	1	1	36	14	15	10	130
		1.5	x̄	129	976	7550	44	3010	1	1	23	9	8	8	68
Claystone	JA1-4	1.3		500	920	1200	59	6300	1	1	14	70	27	5	57
	GR1-2	0.7		530	4000	26000	360	9900	1	7	27	26	42	5	140
		2.0	x̄	515	2460	13600	210	8100	1	4	21	48	35	5	99
Coal	JA1-3	0.8		760	640	10400	55	10000	1	11	13	25	10	28	51
	JA2-1	0.7		710	620	50000	15	9000	1	4	10	19	12	18	19
	GR1-3	0.3		1500	1100	10500	25	26000	0	2	15	130	11	32	60
		1.8	x̄	990	769	23633	32	15000	1	6	13	58	11	26	43
Spoil	JA3-1+	0.9		82	340	15000	48	7800	1	1	25	6	1	5	14
	JA3-2	0.3		25	16	2500	5	4500	1	1	22	1	1	6	7
	JA3-3	0.3		73	290	11000	130	6700	1	2	25	5	1	5	14
	JA3-4	0.3		71	230	9200	69	4400	1	1	21	4	1	5	10
	JA3-5	0.3		140	81	950	32	1200	1	1	18	5	1	5	5
	JA3-6	0.3		92	700	7500	51	2100	1	1	10	10	6	5	34
	JA3-7	0.3		63	220	8500	18	4100	1	1	16	8	1	10	12

(continued)

TABLE 6. (continued)

Rock type	Strata #	Strata thickness (m)		Metal*											
				Ca	Mg	Fe	Mn	Al	Cd	Co	Cr	Cu	Ni	Pb	Zn
Spoil	JA3-8	0.3		16	70	14000	40	2800	1	1	22	7	1	8	11
	JA3-9	0.3		170	290	25000	40	6400	1	1	24	9	1	13	13
	JA3-10	0.3		65	340	9800	60	5800	1	2	15	11	7	5	22
	JA3-11	0.3		110	420	23000	32	11000	1	1	22	6	1	5	17
	JA3-12	0.3		200	2100	15000	62	4600	1	5	19	31	22	18	110
		4.3	$\bar{x}$	92	425	11788	49	5117	1	2	20	9	4	8	22
	Overall mean			272	651	11037	56	5644	1	3	17	18	8	10	39

+Strata # increases with increasing depth of sample.

TABLE 7. METAL CONCENTRATIONS OF THE NEW RIVER STRATA MEASURED FROM CORE SAMPLES AND EXPRESSED AS μg/g

Rock type	Strata #	Strata thickness (m)		Metal* Ca	Mg	Fe	Mn	Al	Cd	Co	Cr	Cu	Ni	Pb	Zn
Sandstone	NR1-C1	2.5		4300	4000	18000	370	3300	1	7	18	7	8	10	35
	NR2-2	0.9		11000	7400	40000	670	9900	1	1	30	38	31	6	140
	NR3-1	2.4		470	580	76000	160	1100	1	2	16	10	17	7	47
	NR3-4	7.2		1600	3800	26000	480	8900	1	5	25	24	33	20	150
	NR3-4	3.4		130	35	12000	10	490	1	0	8	1	1	5	6
		16.4	$\bar{x}$	3500	3163	34400	338	4738	1	3	19	16	18	10	76
Shale	NR1-D1	11.1		3700	9600	42000	840	9100	1	11	25	22	22	10	91
	NR1-D2	9.8		3500	7100	46000	150	11000	1	8	26	58	40	21	160
	NR1-D3	4.1		2400	6800	30000	110	9600	1	8	25	25	31	8	120
	NR2-1	6.9		13000	4700	18000	440	4700	1	2	17	13	17	5	79
	NR2-3	11.1		4300	5800	28000	500	6100	1	4	19	20	19	5	60
	NR2-4	6.6		2200	5400	25000	610	9500	1	3	23	29	28	8	67
	NR3-3	6.3		130	35	12000	10	490	1	0	8	1	1	5	6
		55.9	$\bar{x}$	4176	5634	28714	380	7213	1	5	20	24	23	9	83
Siltstone	NR1-B1	2.9		350	5000	21000	160	7500	1	8	22	41	31	24	170
	NR1-B2	1.2		1100	3900	30000	490	5900	1	4	15	31	19	7	89
	NR1-B3	4.0		1000	4300	39000	500	7100	1	12	18	23	18	34	200
		8.0	$\bar{x}$	817	4400	30000	383	6833	1	8	18	32	23	22	153
Coal	NR1-E2	0.4		640	1600	12200	33	9900	1	5	8	21	14	7	86
Overall mean				3418	4570	30513	388	6724	1	5	19	24	21	11	98

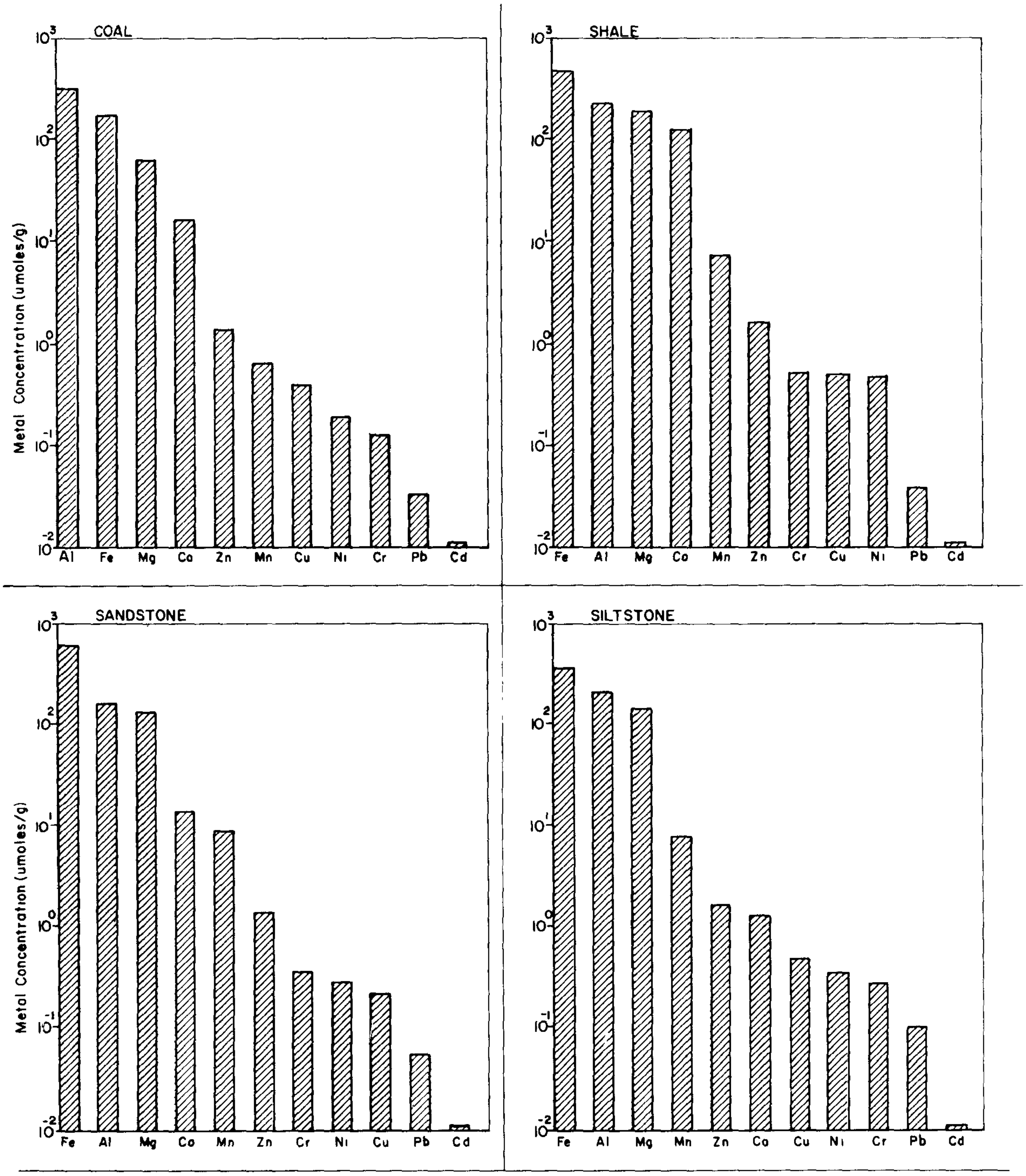

Figure 10. Mean metal concentrations of the New River area strata.

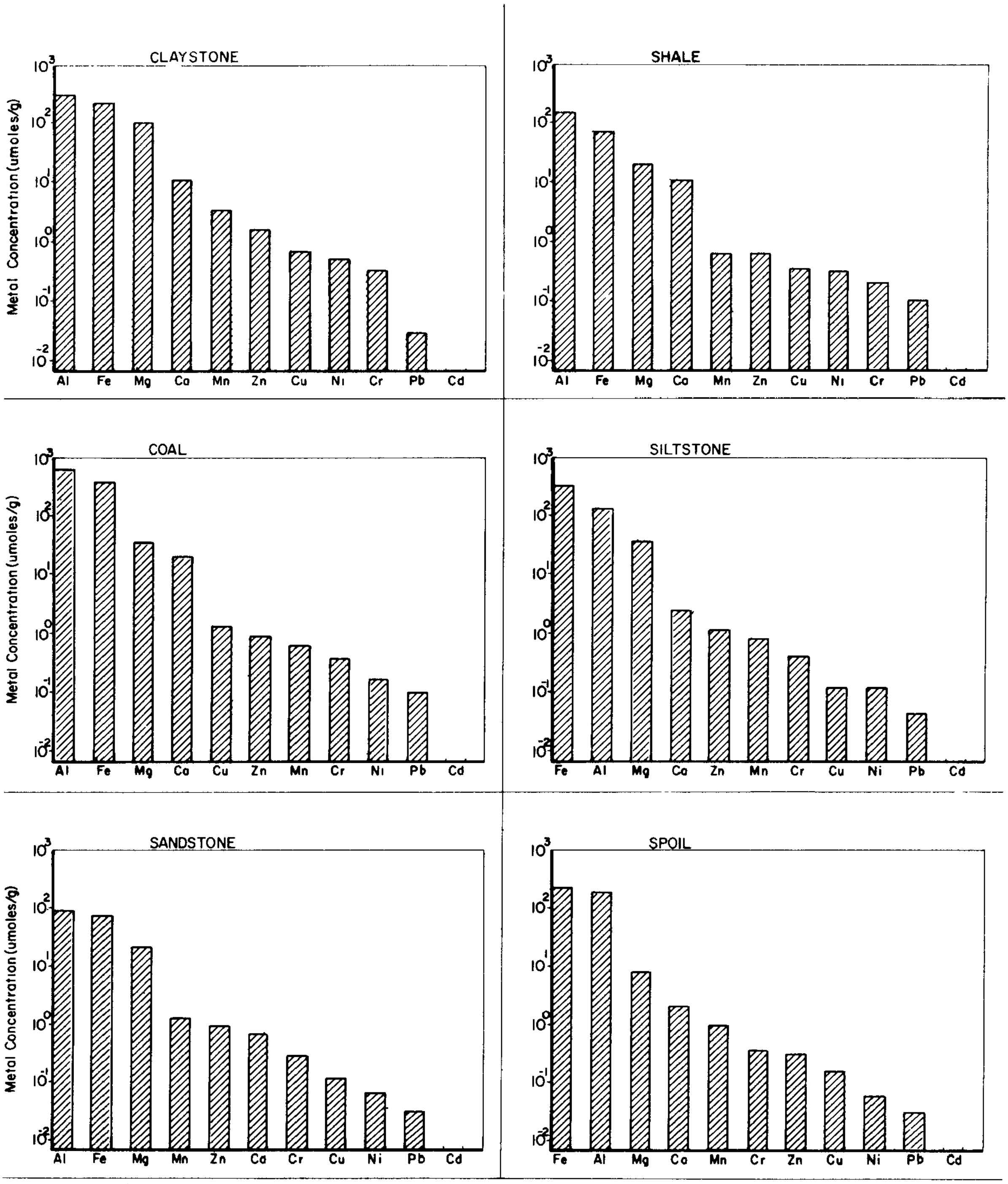

Figure 11. Mean metal concentrations of the Jamestown area strata.

Although calcium and magnesium are the principal causes of hardness, their geochemical behavior is substantially different. Magnesium ions, being smaller than sodium or calcium, have a stronger charge density and a greater attraction for water molecules (Hem, 1970). Sedimentary sources of calcium and magnesium include carbonates such as limestone ($CaCO_3$), magnesite ($MgCO_3$), and dolomite ($CaMg[CO_3]_2$) and sulfates such as gypsum ($CaSO_4 \cdot 2H_2O$) and Epsom salt ($MgSO_4$). Magnesium concentrations were significantly higher than calcium concentrations in all samples analyzed. In addition, magnesium concentrations, as well as calcium concentrations, were higher in the New River area ranging from 66 µmoles per g of coal to 232 µmoles per g of shale. Calcium concentrations in the New River area ranged from 16 µmole per g of coal to 42 µmoles per g of sandstone. In the Jamestown area, magnesium concentrations ranged from 15 µmoles per g of sandstone to 101 µmoles per g of claystone. Calcium values ranged from 2 µmoles per g of spoil to 26 µmoles per g of coal. Manganese and zinc concentrations were higher than calcium concentrations in New River siltstones and Jamestown sandstones.

Manganese, an essential element in plant metabolism, was present in higher concentrations in New River strata. Concentrations ranged from approximately 1 µmole per g of coal to 9 µmoles per g of sandstone. Jamestown area concentrations ranged from 1 µmole per g of shale to 4 µmoles per g of claystone.

Among the other trace elements present, zinc concentrations were greatest with few exceptions. New River area values were generally higher ranging from 1 µmole per g of shale to 2 µmoles per g of siltstone. Jamestown area values ranged from less than 1 µmole per g of spoil to 2 µmoles per g of claystone. Chromium, copper, and nickel concentrations were less than 1.0 µmoles per g ranging from <0.05 µmoles nickel per g of Jamestown sandstone to 1 µmole copper per g of Jamestown coal. Lead and cobalt (not illustrated) concentrations were lower in each area, rarely exceeding 0.2 µmoles per g. Cadmium concentrations were below detectable limits in every case.

3. Results of Leaching Study

Closely correlated to the geochemical analysis were the results of the leaching study, the purpose of which was to determine the weathering characteristics of the various rock types. Changes in pH, alkalinity, acidity, and oxidation-reduction potential (ORP) of the leachate are presented in figures 12, 13, 14, 15, 16, 17, 18, and 19 for each area and rock type. Cumulative alkalinities and acidities, which reflect the rate at which weathering takes place, are also presented.

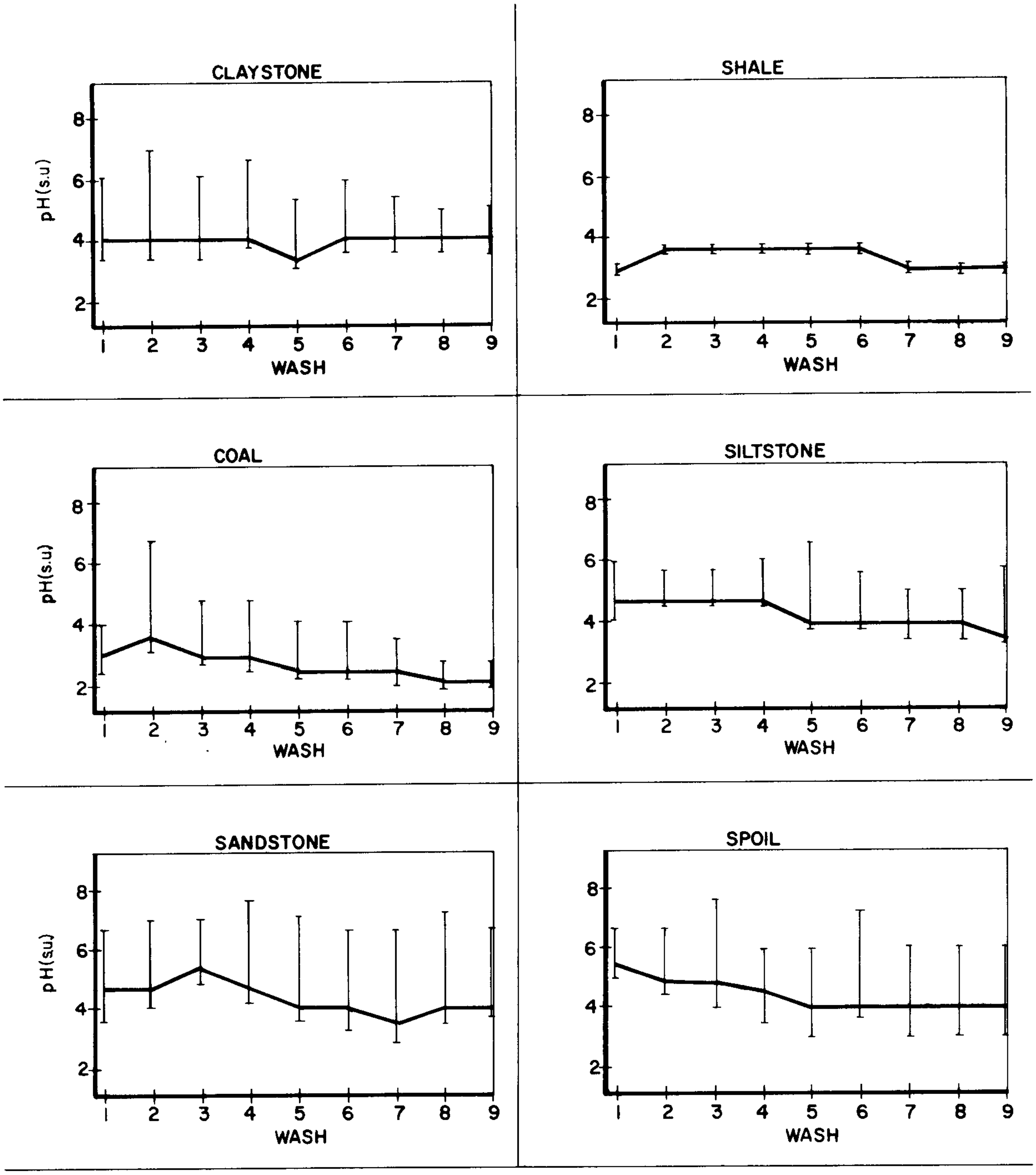

Figure 12. Changes in the pH of the Jamestown area lithology through consecutive washings. Vertical bars indicate the range of values where n>1.

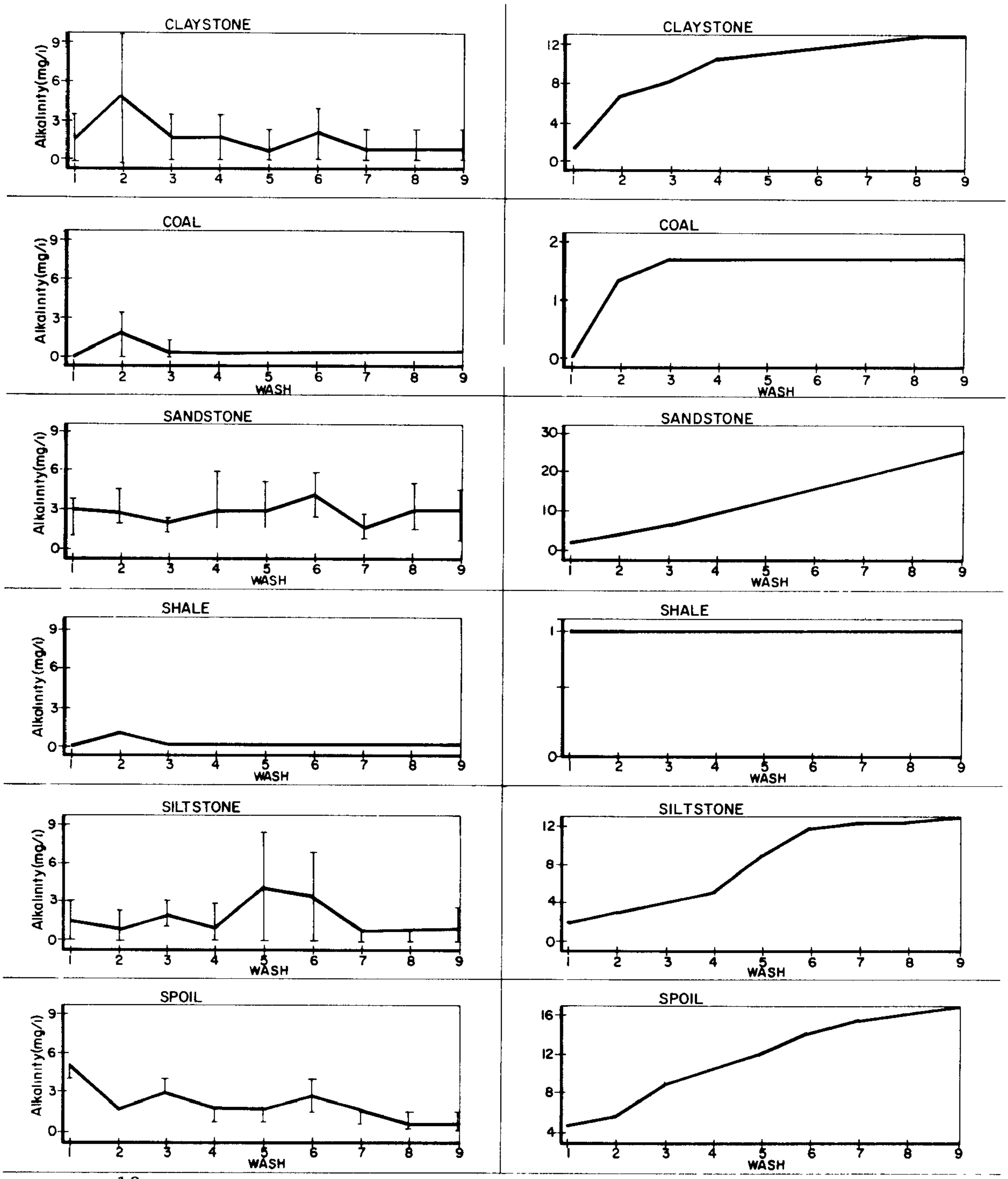

Figure 13. Changes in the alkalinity of the Jamestown area lithology through consecutive washings. Plots on the right are cummulative. Vertical bars are standard errors of mean values where n > 1.

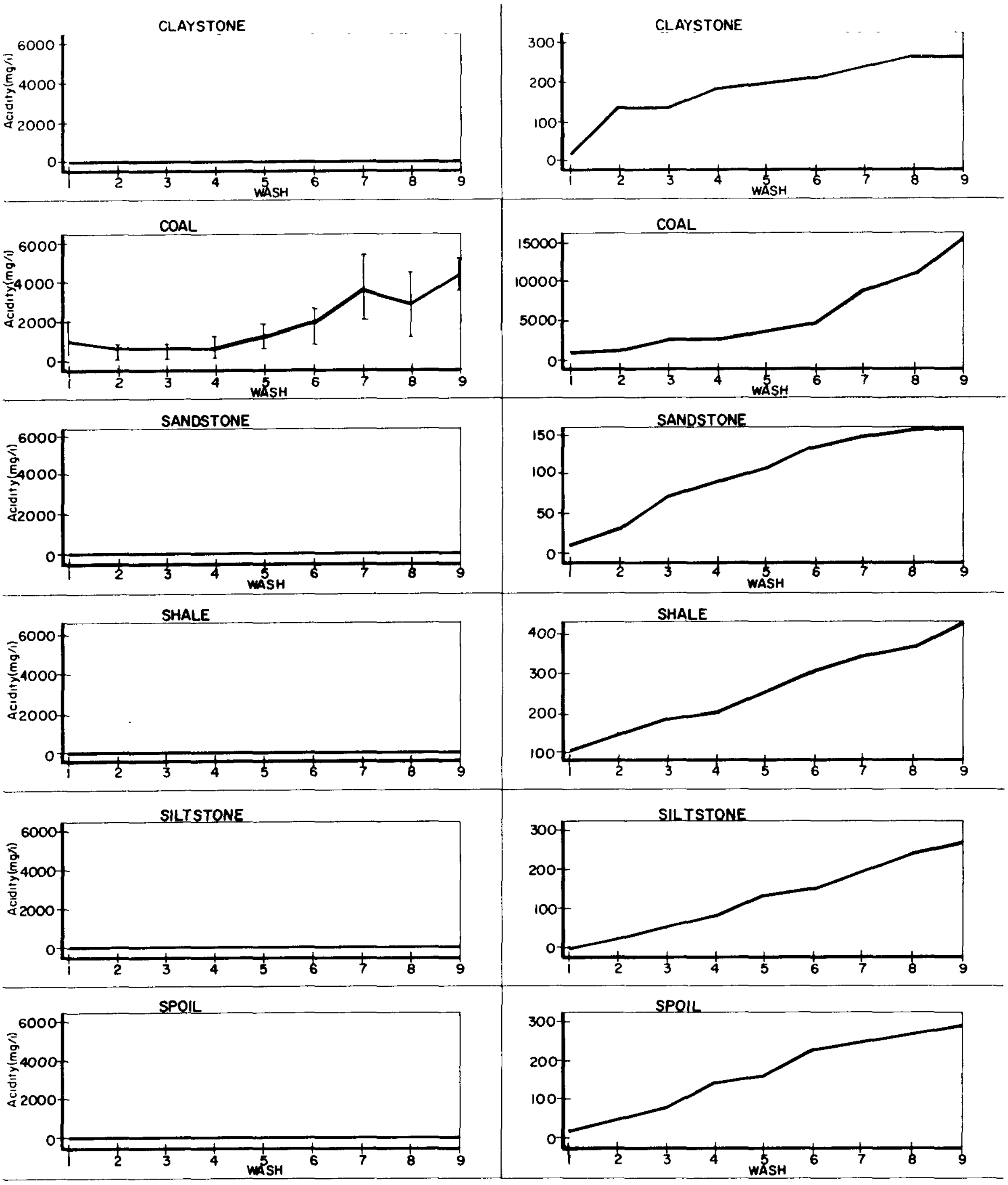

Figure 14. Changes in the acidity of the Jamestown area lithology through consecutive washings. Plots on the right are cummulative. Vertical bars are standard errors of mean values where n>l.

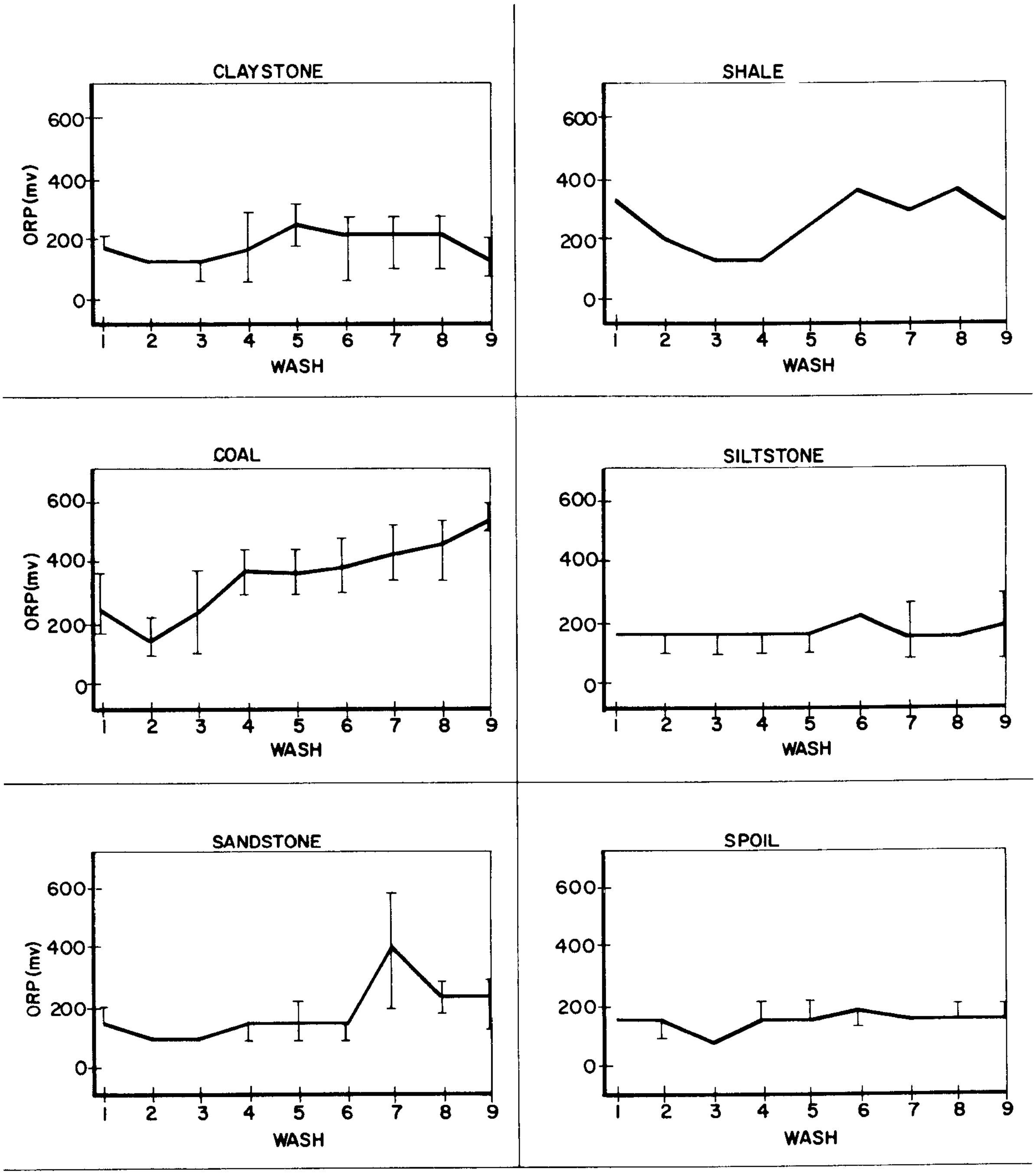

Figure 15. Changes in the oxidation reduction potentials of the Jamestown area lithology through consecutive washings. Vertical bars are standard errors of mean values where n>1.

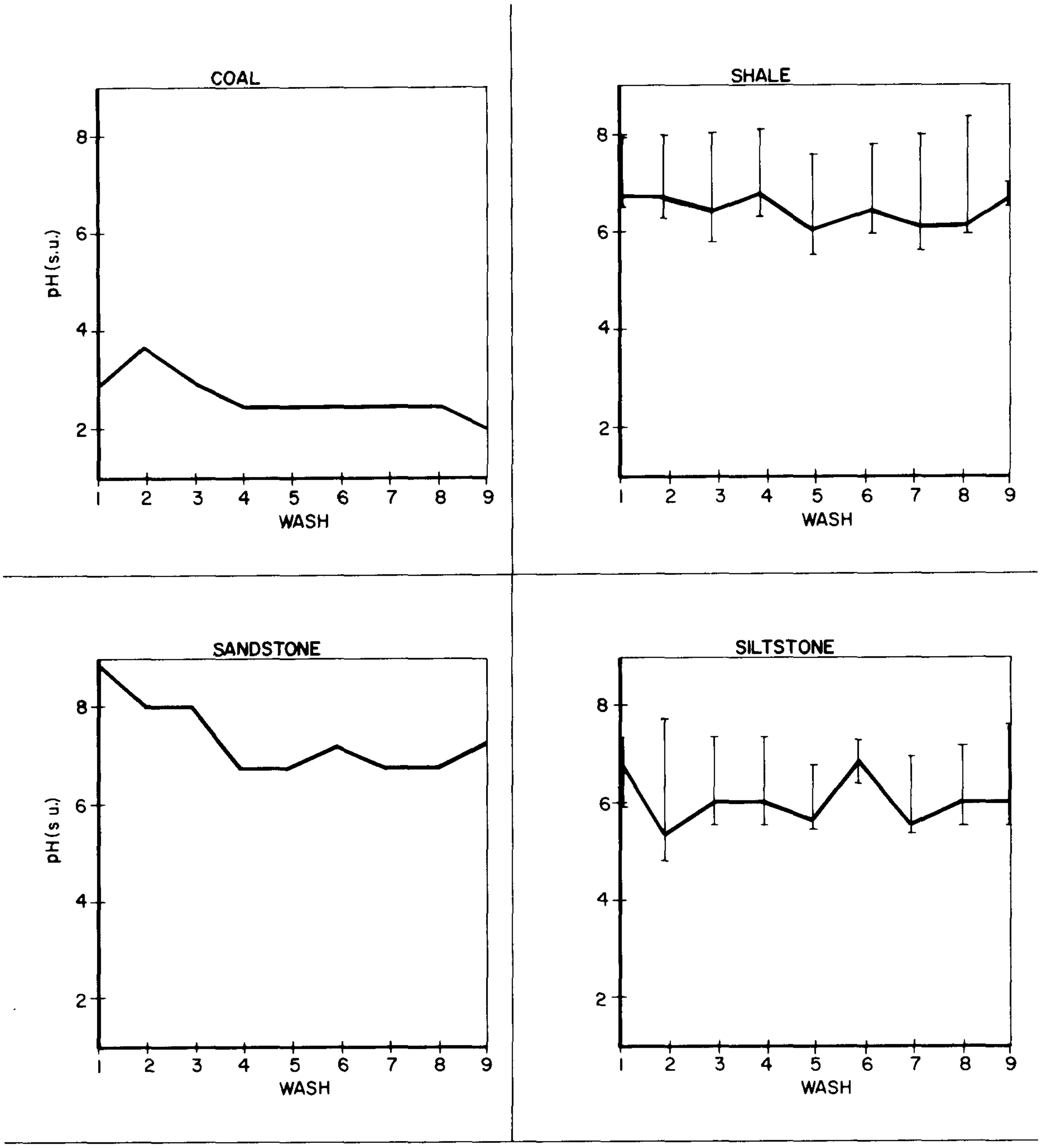

Figure 16. Changes in the pH of the New River area lithology through consecutive washings. Vertical bars indicate the range of values where n>1.

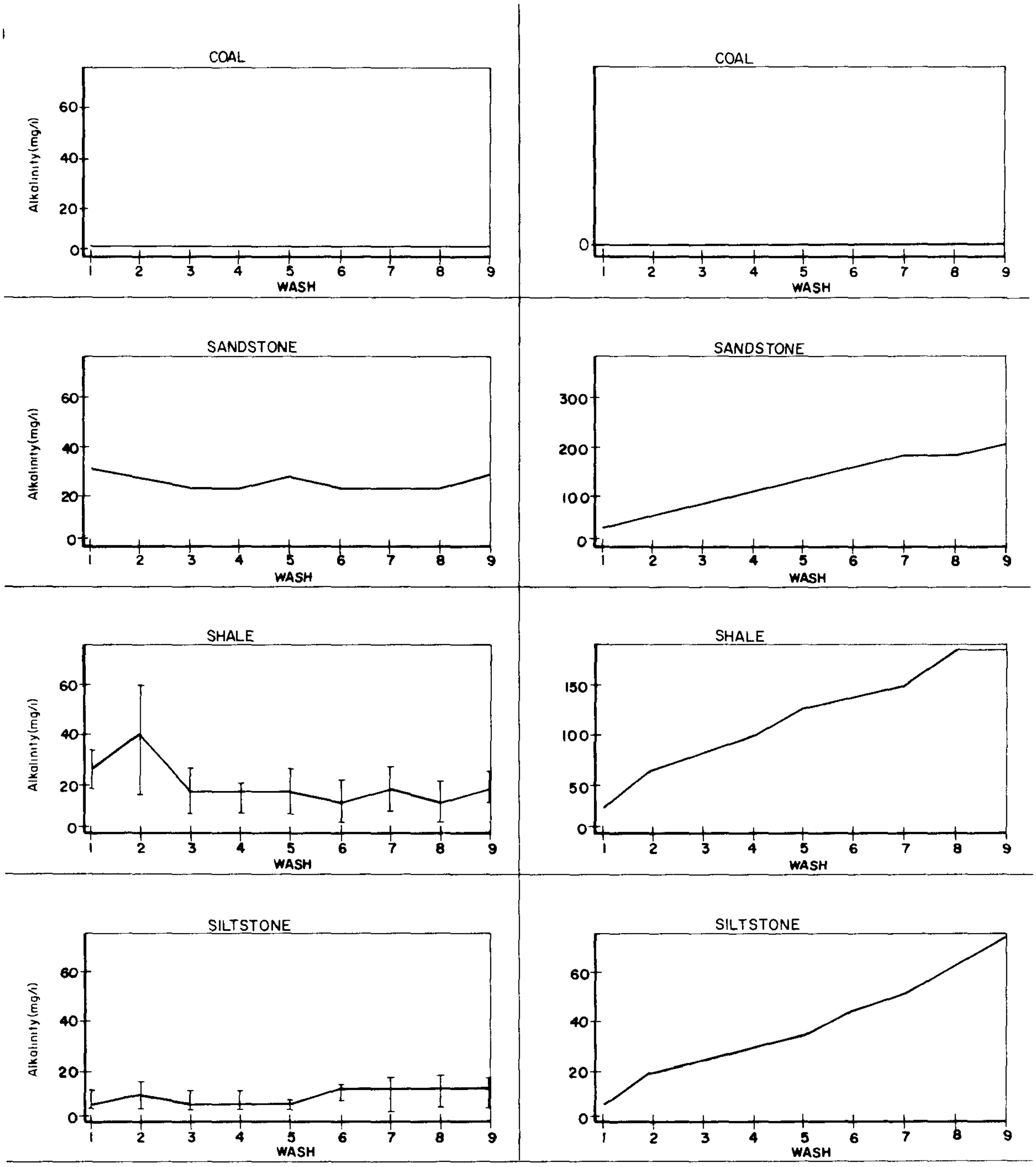

Figure 17. Changes in the alkalinity of the New River area lithology through consecutive washings Plots on the right are cummulative. Vertical bars are standard errors of mean valves where n > 1.

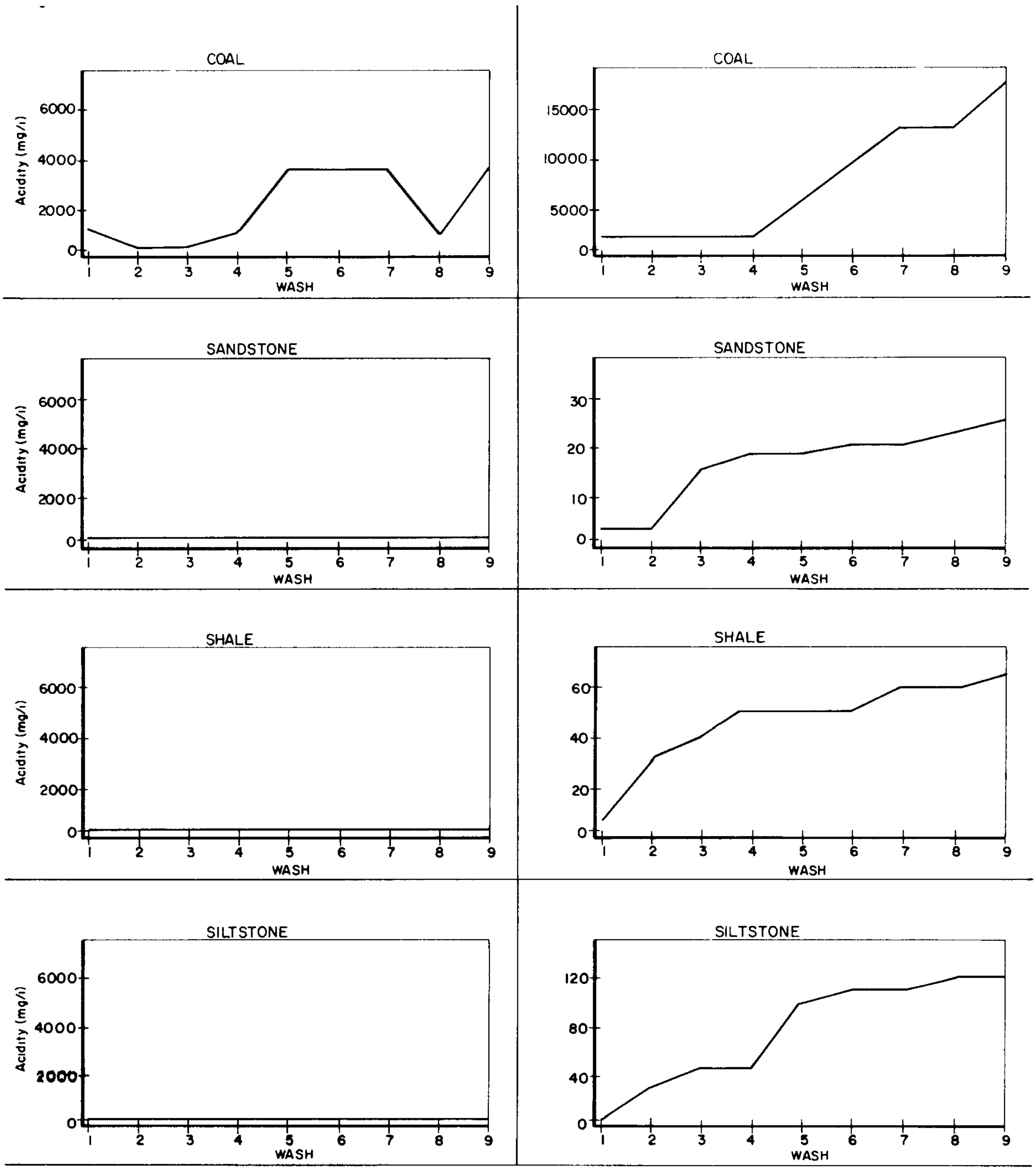

Figure 18. Changes in the acidity of the New River area lithology through consecutive washings
Plots on the right are cummulative

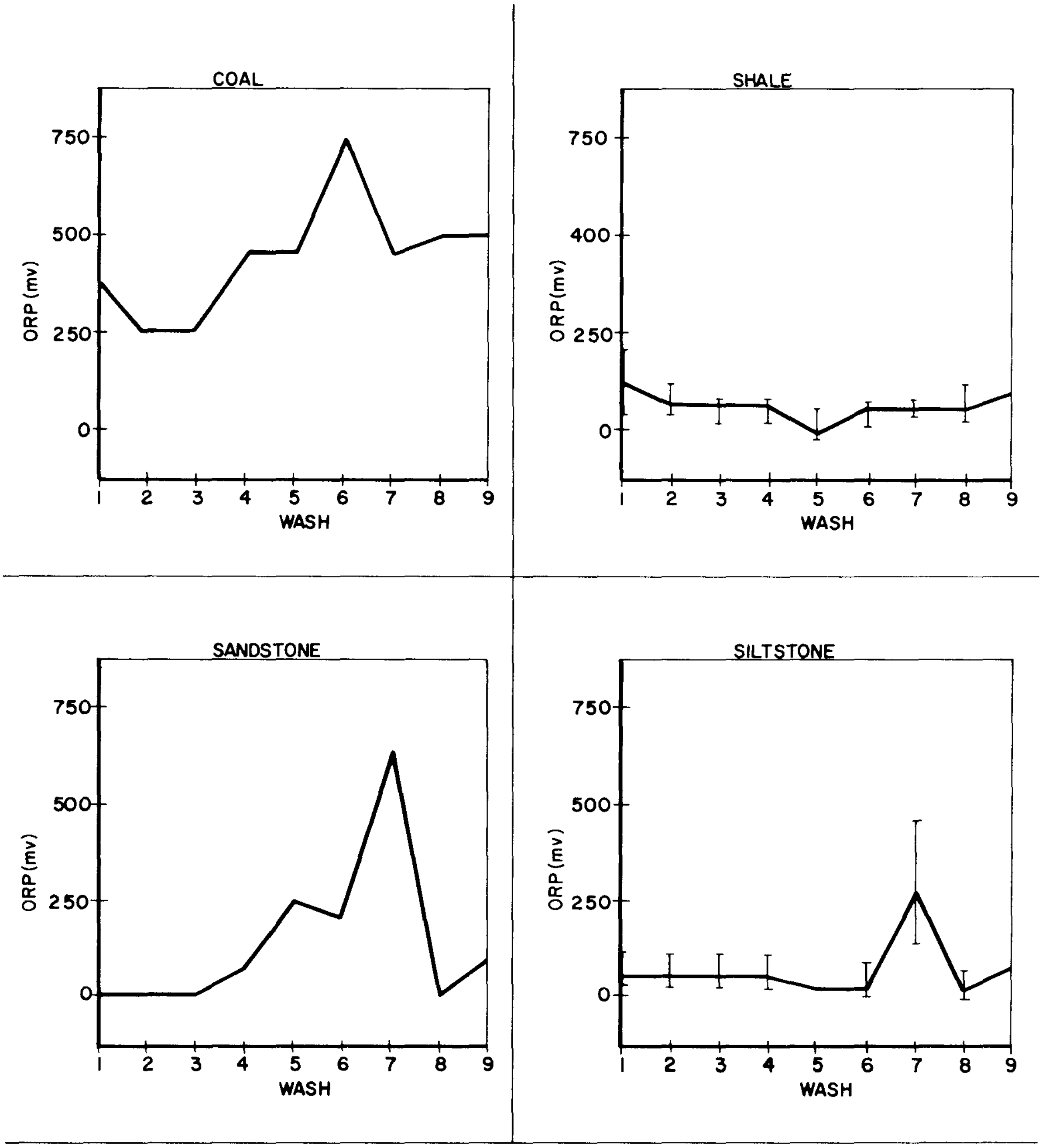

Figure 19. Changes in the oxidation reduction potentials of the New River area lithology through consecutive washings. Vertical bars are standard errors of mean values where n >1.

Values of pH usually declined through the nine washings due possibly to the increase in the rate of the oxidation of pyrite or other minerals present in the strata or to the rapid leaching of neutralizing materials throughout the weathering processes. Cumulative alkalinities were greatest for sandstones at each site, New River shales, and Jamestown spoil. Cumulative acidities were highest for all coal samples and were also high for Jamestown shale and siltstone. Furthermore, the positive slope of the cumulative acidity plots near the end of the weathering process indicated that acidity could continue to be produced beyond the ninth washing for most strata. Oxidation-reduction potentials tended to peak at various stages in the weathering process, depending on the site and the strata analyzed. Values were nearly all positive indicating the oxidizing nature of the leachate.

Generally, pH values of New River strata leachate were higher than those for Jamestown strata leachate, except for coal in which case the values were comparably low. At both sites, the pH of the leachate was highest for sandstone reflecting higher excess neutralization potentials and lower pyritic sulfur content. Alkalinity, a measure of the amount of OH^-, $HCO^{-}3$, and/or CO_3^{-2}ions released by the rock sample, like pH was higher in the New River strata and strongly correlated to excess neutralization potential and pyritic sulfur content. Alkalinity peaked early in the weathering process for the Jamestown claystone and coal and New River shale samples, but peaked later in the process for Jamestown sandstone and siltstone samples. Cumulative alkalinities were greatest for Jamestown and New River sandstones, New River shales, and Jamestown spoil. New River and Jamestown coal alkalinity was negligible, as well as Jamestown shale.

Acidity, a measure of the quantity of H^+ ions produced in a reaction, was highest for all coal samples, exceeding 4,000 mg $CaCO_3$ per l and 3,500 mg $CaCO_3$ per l after the ninth washing of Jamestown and New River coal, respectively. Cumulative values were also high for Jamestown shale and New River siltstone. Differing rates of H^+ production were also observed for each strata with acidity values peaking either early, late, or gradually increasing throughout the weathering process. In addition, the positive slope of the cumulative acidity plots between the eighth and ninth washing indicated that acidity could continue to be produced beyond the ninth washing for most strata.

Oxidation reduction potential (ORP), a measure of the relative intensity of oxidizing or reducing conditions in solutions, was positive for all strata leachate except for New River shale leachate, which dipped below zero at the fifth wash.

ORP was highest for coal leachate, climbing to a high of 0.78 volts by the sixth wash of the New River coal leachate and 0.63 volts for Jamestown coal leachate. New River sandstone peaked at 0.63 volts by the seventh wash, then dropped to 0.03 volts by the eighth. Jamestown sandstone leachate also peaked by the seventh wash.

Plots of ORP (Eh) versus pH for each strata are presented in figures 20 and 21. Diagrams such as these are commonly used to illustrate the theoretical mineral and ionic composition of solutions under specific Eh and pH conditions. The parallelogram within each plot depicts the usual limits of ORP and pH found in near surface environments (after Krauskopf, 1979, page 199). Except for coal leachate, all New River values fell within these limits while many of the Jamestown values were more acidic, falling to the left of the parallelogram. The stable ionic and mineral forms of some elements expected under these study conditions are generally in an oxidized form although their solubility would depend on specific pH conditions. They include Fe^{+2}, Fe^{+3}, Fe_2O_3, $Fe(OH)_3$, Pb^{+2}, Mn^{+2}, $Mn(OH)_2$, Ni^{+2}, $Ni(OH)_2$, SO_4^{-2}, Cu^{+2}, Cu^{+}, $Cu(OH)_2$, and Cu_2O.

4. Statistical Interdependence of Overburden Geochemistry

Pearson correlation coefficients (r) were calculated in order to explain the statistical interdependence of the various geochemical parameters analyzed. Calculations were made using the Statistical Analysis System (SAS) CORR procedure (SAS, 1979). A list of significant correlation coefficients where $r \geq \pm 0.5$ and $p \leq 0.001$ for geochemical parameters from both sites is given in table 8.

Correlations between parameters generally reflect similar geochemical behavior or lattice substitutions by atoms or ions of similar atomic or ionic size or like ionic charge (Bogner, et al. 1979). For instance, calcium and magnesium concentrations were positively correlated with excess neutralization potential, $CaCO_3$, alkalinity, and soil and leachate pH, leading one to believe that calcium and magnesium carbonates are a major source of buffering capacity in the strata. Pyritic and total sulfur concentrations were likewise positively correlated with acidity and H^+ concentrations and negatively correlated with soil and leachate pH.

D. SUMMARY - OVERBURDEN AND COAL CHEMISTRY ANALYSIS

Core drilling studies were conducted at the area-mined (Jamestown area) and contour-mined (New River area) sites to determine the geochemical and weathering characteristics and metal contents of rock formations and spoil material. Lithologic analysis indicated

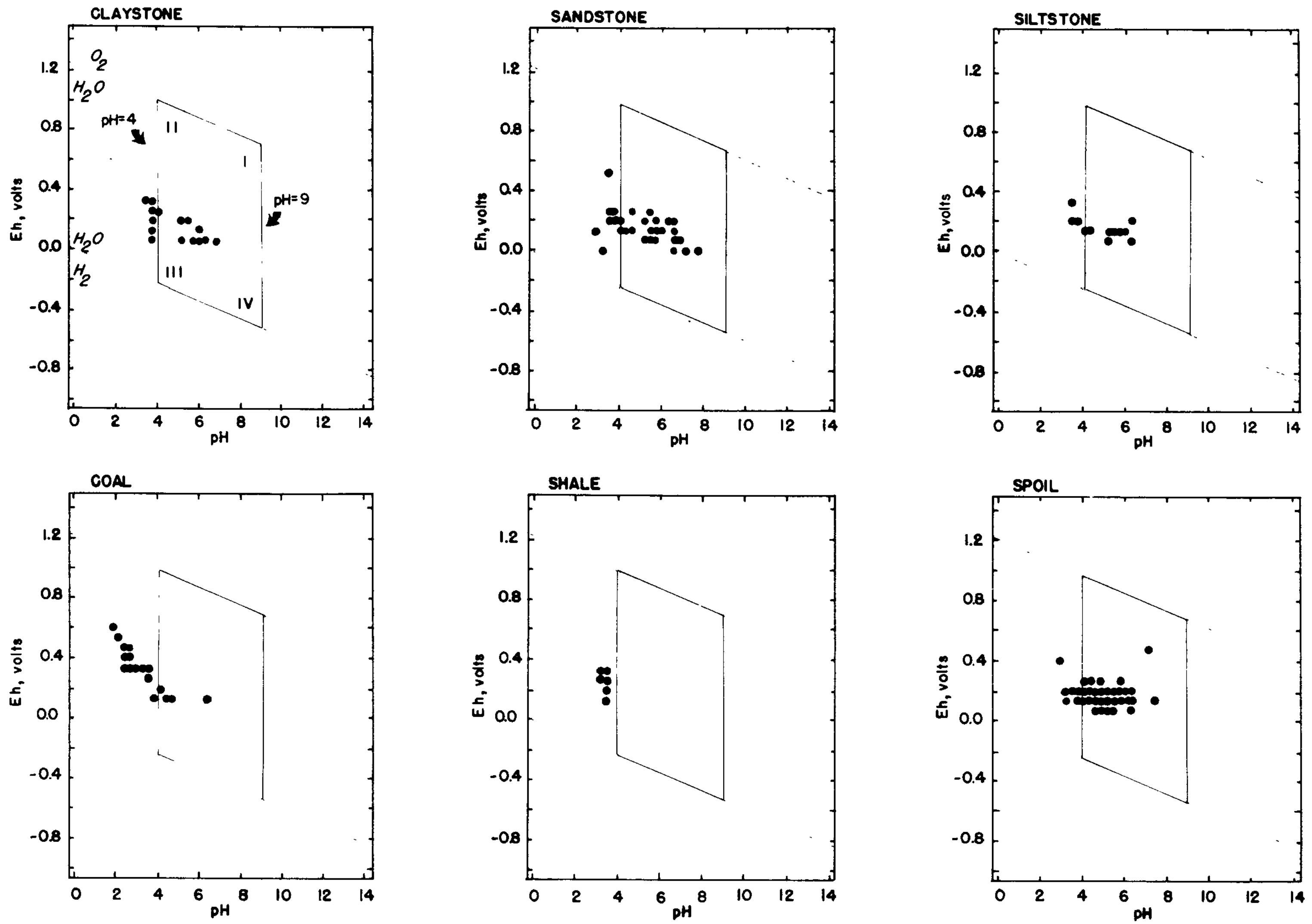

Figure 20. Eh-pH Diagrams for Jamestown Area Strata. Parallelogram defines the usual limits of Eh and pH found in near surface environments (after Krauskopf, 1979, page 199). I = Oxidizing, basic; II = Oxidizing, acidic; III = Reducing, acidic; IV = Reducing, basic.

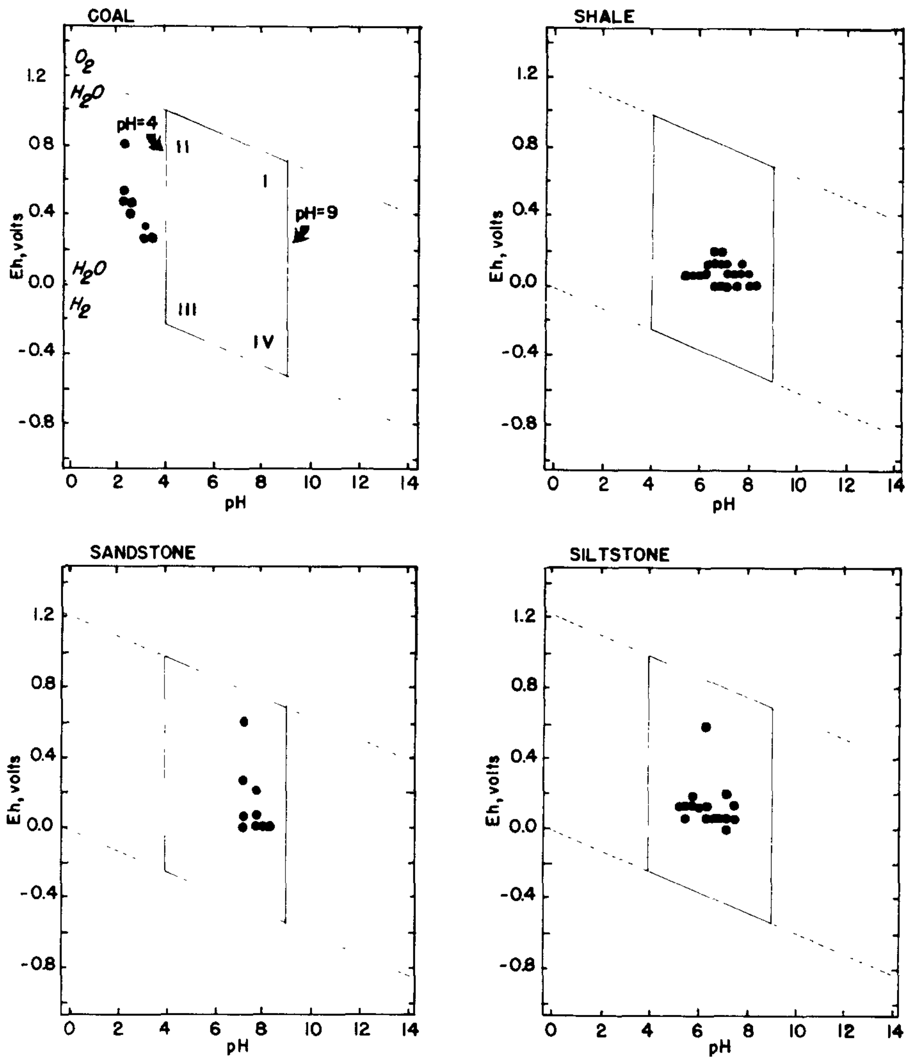

Figure 21. Eh-pH Diagrams for New River Area Strata. Parallelogram defines the usual limits of Eh and pH found in near surface environments (after Krauskopf, 1979, page 199). I = Oxidizing, basic; II = Oxidizing, acidic; III = Reducing, acidic; IV = Reducing, basic.

TABLE 8. PEARSON CORRELATION COEFFICIENTS FOR OVERBURDEN PARAMETERS ($|r| \geq 0.5$; $p < 0.001$)

Variable A	Variable B	r	Variable A	Variable B	r
pH(H_2O)	pH($CaCl_2$)	.99	(H+)*	Acidity*	.95
	pH(KCl)	.97		ORP*	.86
	Alkalinity*	.86		Pyritic S	.76
	ENP	.82		pH*	-.65
	Mn	.79		Total S	.55
	Mg	.74			
	$CaCO_3$	.73	Acidity*	(H+)*	.95
	ORP*	-.67		ORP*	.85
	Ca	.67		Pyritic S	.72
				pH*	-.60
pH($CaCl_2$)	pH(H_2O)	.99		Total S	.55
	pH(KCl)	.98			
	Alkalinity*	.85	PACID	CEC	.56
	ENP	.82		ORP*	.54
	Mn	.79			
	$CaCO_3$	.77	Alkalinity*	ENP	.92
	Mg	.77		pH(KCl)	.87
	Ca	.67		pH(H_2O)	.86
	ORP*	-.60		pH($CaCl_2$)	.85
				Ca	.78
pH(KCl)	pH($CaCl_2$)	.98		Mg	.78
	pH(H_2O)	.97		Mn	.78
	Alkalinity*	.87		pH*	.71
	ENP	.85		$CaCO_3$	.70
	Mn	.81			
	$CaCO_3$	.76	ENP	Alkalinity*	.92
	Mg	.75		pH(KCl)	.85
	Ca	.70		pH($CaCl_2$)	.82
				pH(H_2O)	.82
pH*	pH(H_2O)	.84		Ca	.80
	ORP*	-.80		Mn	.78
	pH($CaCl_2$)	.80		Mg	.78
	pH(KCl)	.75		$CaCO_3$	.70
	Alkalinity*	.71			
	(H+)*	-.65	$CaCO_3$	pH($CaCl_2$)	.77
	ENP	.60		pH(KCl)	.76
	Acidity*	-.60		Mg	.74
	Pyritic S	-.60		pH(H_2O)	.73
	Mn	.58		ENP	.70
	PACID	-.53		Ca	.70
	Mg	.52		Alkalinity*	.70
				Mn	.66
				Zn	.51

(continued)

Table 8. (Continued)

Variable A	Variable B	|r|	Variable A	Variable B	|r|
CEC	PACID	.56	Fe	Mg	.55
				Mn	.50
ORP*	(H+)*	.86		Ni	.50
	Acidity*	.85		ENP	.49
	pH*	-.80			
	Pyritic S	.69	Mn	pH(KCl)	.81
	pH(H_2O)	-.67		Mg	.80
	pH($CaCl_2$)	-.60		pH(H_2O)	.79
	PACID	.54		pH($CaCl_2$)	.79
				Alkalinity*	.79
Total S	Pyritic S	.80		ENP	.78
	Acidity*	.55		$CaCO_3$	.66
	(H+)*	.55		Ca	.64
				Ni	.52
Pyritic S	(H+)*	.76		Fe	.50
	Acidity*	.72			
	ORP*	.69	Al	Cu	.77
	Al	.63		Cd	-.70
	Cu	.62		Pyritic S	.62
	Cd	-.60		Pb	.51
	Pb	.55			
			Co	Ni	.67
Ca	ENP	.80		Pb	.65
	Alkalinity*	.79		Zn	.59
	$CaCO_3$	.70		Mg	.53
	pH(KCl)	.70			
	pH($CaCl_2$)	.67	Cr	Zn	(.46)
	pH(H_2O)	.67			
	Mn	.64	Cu	Al	.77
	Mg	.63		Cd	-.75
				Pyritic S	.62
Mg	Mn	.80		Pb	.58
	Alkalinity*	.78		Ni	.51
	ENP	.78			
	pH($CaCl_2$)	.77	Ni	Zn	.81
	Ni	.76		Mg	.76
	pH(KCl)	.75		Co	.57
	$CaCO_3$	.75		Mn	.52
	pH(H_2O)	.74		Cu	.50
	Zn	.70		Fe	.50
	Ca	.63			
	Fe	.55			
	Co	.53			

(continued)

Table 8. (continued)

Variable A	Variable B	|r|
Pb	Co	.65
	Cu	.57
	Pyritic S	.54
	Al	.50
	Zn	.50
Zn	Ni	.81
	Mg	.70
	Co	.58
	$CaCO_3$	.51
	Pb	.50

*From leaching data.

that sandstone is the dominant rock type of the Jamestown strata, whereas clay-mineral rich shale dominates New River strata. Results of the geochemical analysis of the strata and the leaching tests show that New River strata is more alkaline and possesses greater neutralization potential than the Jamestown strata, corresponding to higher pH and alkalinity of New River area reference streams. Total and pyritic sulfur concentrations were low at each site, although pyritic sulfur was proportionately higher in Jamestown area coal. Cation exchange capacities were low for all strata ranging from 8.3 meq $CaCO_3$ per 100 g of New River siltstone to 19.2 meq $CaCO_3$ per 100 g of Jamestown claystone.

Of the metals analyzed in each area, aluminum and iron were present in greatest concentrations followed by calcium, magnesium, manganese, zinc, chromium, copper, nickel, lead, and cobalt. In some instances, zinc concentrations were higher than either calcium or manganese. Cadmium concentrations were below detectable limits in every case.

Values of leachate pH declined through the nine washings of nearly all strata analyzed in the leaching study, due possibly to the increase in the rate of pyrite oxidation or to rapid leaching of neutralizing materials throughout the weathering processes. Cumulative alkalinities were greatest for sandstones at each site, New River shales, and Jamestown spoil. Cumulative acidities were highest for all coal samples and were also high for Jamestown shale and siltstone. Furthermore, the positive slope of the cumulative acidity plots near the end of the weathering process indicated that acidity could continue to be produced beyond the ninth washing for most strata. Oxidation-reduction potentials tended to peak at various stages in the weathering process, depending on the site and the strata analyzed. Values were nearly all positive indicating the oxidizing nature of the leachate.

Eh-pH diagrams were constructed for each strata so that the theoretical mineral and ionic composition of the leachate could be surmised. Almost all values of Eh and pH fell within the usual limits found in near surface environments as determined by Krauskopf (1979). Under these conditions, elements would generally be in an oxidized form with their solubility depending on specific pH conditions.

Correlation analysis confirmed earlier observation of the interdependence of geochemical and metals analyses, reflecting similar geochemical behavior or lattice substitutions by atoms or ions of similar atomic or ionic size or like ionic charge.

CHAPTER IV.

WATER QUALITY

A. INTRODUCTION

The previous chapter illustrated the complex nature of overburden chemistry which could be influenced by surface mining activities. Surface mining can promote the geochemical and physical processing of major and minor mineral constituents by exposing previously unexposed rock strata to atmospheric forces.

Presented here is an analysis of the quality and quantity of waters draining the area-mined (Jamestown area) and contour-mined (New River area) study sites. Emphasis was placed on the characterization of water quality and quantity conditions unique to each site and the identification of significant water-related impacts due to surface mining and those factors associated with or causing those impacts. In this way, a better understanding of the hydrological and geochemical forces which extinguish each coal-mining region could be made.

B. ANALYTICAL PROCEDURES AND EXPERIMENTAL DESIGN

In order to achieve the objective of site characterization, a wide variety of physical and chemical parameters were measured. Data were collected at approximately monthly intervals at the Jamestown area sites by TVA field personnel beginning in February 1976 and continuing through December 1978. Analysis for pH, acidity, and alkalinity and filtrations for dissolved metals were carried out in the field whenever possible. Other analyses were conducted in the laboratory by TVA Laboratory Branch using standard methods. Continuous rainfall and streamflow gaging stations were installed at stations UT0.01, LB4.0, and CC15.9 during 1976 and are described in detail in chapter III.

New river area sites were sampled at approximately weekly intervals by the University of Tennessee beginning in January 1975 and continuing through December 1979. All analyses were conducted using standard methods. Continuous hydrologic gaging stations for rainfall and streamflow were completed at all New River sites by mid-December 1974.

All water quality parameters measured, as well as analytical methods used and lower detection limits, are presented in table 9.

C. RESULTS AND DISCUSSION OF WATER QUALITY ANALYSIS

TABLE 9. WATER QUALITY PARAMETERS MEASURED AT JAMESTOWN AND NEW RIVER AREA SAMPLING SITES BETWEEN 1975 AND 1979

Parameter	Analytical method	Method reference†	Abbreviation	Lower detection limit
pH	Potentiometric	- -	pH	- -
Alkalinity (as $CaCO_3$)	Titrimetric	a	ALK	1.0 mg/l
Acidity (as $CaCO_3$)*	Titrimetric	a	ACID	1.0 mg/l
Specific conductance*	Wheatstone Bridge	- -	COND	0.0 µmhos/cm
Turbidity	Turbidimeter	a	TURB	1.0 JTU
Suspended solids	Filtration	a	SSOL	1.0 mg/l
Dissolved solids	Residue on evaporation	b	DSOL	10.0 mg/l
Total Solids°	Direct evaporation continuous streamflow gage	-	TOT_SOL	10.0 mg/l
Streamflow	Direct evaporation continuous streamflow gage	-	FLOW	1 CFS
Streamflow-nearest hour*	Direct evaporation continuous streamflow gage	-	FLOWNHR	1 CFS
Dissolved oxygen*	Modified Winkler	a	DO	1.0 mg/l
Water temperature	Mercury bulb thermometer	- -	WTEMP	1°C
Nitrogen-Kjeldahl*	Automated, phenate	a	KJELN	0.02 mg/l
NO_2-NO_3*	Automated, cadmium reduction	a	NO2 NO3	0.01 mg/l
Phosphate (total)*	Automated, ascorbic acid	a	TP04	0.01 mg/l
Total organic carbon*	Oxidation	a	TOC	0.2 mg/l
Total inorganic carbon*	Oxidation	a	TIC	0.2 mg/l
Hardness*	Titrimetric, EDTA	a	HARD	1.0 mg/l
Sodium*	Atomic absorption (A.A.) - Direct	a	NA	0.1 mg/l

(continued)

TABLE 9. (continued)

Parameter	Analytical method	Method reference[†]	Abbreviation	Lower detection limit
Potassium*	A.A. - Direct	a	K	0.1 mg/l
Chloride	Auto ferricyanide	a	CL	1.0 mg/l
Sulfate	Turbidimetric method	a	SO4	1.0 mg/l
Floride*	A.A. - Direct	a	F	0.1 mg/l
Silica*	Automated colorimetric	a	SIO2	0.01 mg/l
Al (T,D*,S*)[+]	A.A. - Direct	a	ALT,ALD,ALS	100 μg/l
As (T,D*)	A.A. - Gaseous hydride	a	AST,ASD	2.0 μg/l
Ca (T,D[o])	A.A. - Direct	a	TCA,DCA	1.0 μg/l
Cd (T,D,S*)	A.A. - Heated graphite	a	TCD,DCD,CDS	1.0 μg/l
Cr (T,D,S*)	A.A. - Heated graphite	a	CRT,CRD,CRS	5 μg/l
Co (T,D,S*)	A.A. - Direct	a	TCO,DCO,SCO	5 μg/l
Cu (T,D,S*)	A.A. - Direct	a	TCU,DCU,CUS	10 μg/l
Fe (T,D,S*)	A.A. - Direct	a	TFE,DFE,FES	50 μg/l
Hg (T,D*)	A.A. - Manual cold vapor	c	HGT,HGD	0.2 μg/ml
Mg (T,D[o])	A.A. - Direct	a	TMG,DMG	0.01 mg/l
Mn (T,D,S*)	A.A. - Direct	a	TMN,DMN,MNS	10 μg/l
Ni (T,D,S*)	A.A. - Direct	a	TNI,DNI,NIS	50 μg/l
Pb (T,D,S*)	A.A. - Heated graphite	a	TPB,DPB,PBS	10 μg/l
Se (T*,D*)	A.A. - Gaseous hydride	c	SET.SED	1 μg/l
Zn (T,D,S*)	A.A. - Direct	a	TZN,DZN,ZNS	10 μg/l

[†]a = Methods for Chemical Analysis of Water and Wastes. U.S. Environmental Protection Agency (EPA), 1979

b = Standard methods for the Examination of Water and Waste Water. 14th Edition, American Public Health Assoc., 1975

c = Methods for Chemical Analysis of Water and Waste. U.S. EPA, 1974

[o]Parameters measured at New River area sampling sites only. New River area analytical work conducted by University of Tennessee, Knoxville

*Parameters measured at Jamestown area sampling sites only. Jamestown area analytical work conducted by TVA Laboratory Branch - Chattanooga, Tennessee.

[+]T = Total; D = Dissolved; S = Suspended

1. <u>Mean Values and Seasonal Trends</u>

Mean values, standard errors of the mean, and ranges for many of the mine-related water quality parameters are presented for Jamestown and New River area sampling sites in tables 10 and 11. Below is a discussion of the more important results observed.

pH and alkalinity: The neutralization of acidity--

It is well known that acid mine drainage arises in eastern mining regions from the oxidation of sulfide minerals, primarily iron disulfide (FeS_2) or pyrite. Other sulfide minerals (Cu_2S,ZnS, or PbS) may be associated with coal deposits (Herricks and Cairns, undated). In the Jamestown and New River areas of the Cumberland Plateau, however, alkaline mine drainage seems to be the rule rather than the exception. Mean pH values (calculated from average hydrogen ion concentrations) were significantly higher at the mined sites than at the reference sites, ranging from 6.2 at Anderson Branch (7.5 percent contour-mined watershed) to 7.0 at Green Branch (24.1 percent contour-mined watershed). Reference (background) site pH values ranged from 4.4 at Long Branch (LB4.0) to 6.2 at Bowling Branch. (New River area reference sites had invariably higher pH values than Jamestown area reference sites which was most likely due to higher excess neutralization potentials, $CaCO_3$, and cation exchange capacity of New River strata [see chapter II].)

Mean total alkalinity values were also higher at mined sites, ranging from 11.5 mg/l $CaCO_3$ at Unnamed tributary (UT0.01; 43 percent area-mined watershed) to 31.0 mg/l $CaCO_3$ at Green Branch. Reference sites ranged from 3.8 mg/l $CaCO_3$ at Lynn Branch (LY0.4) to 9.0 mg/l $CaCO_3$ at Bowling Branch. Acidity, measured only at Jamestown area sites, was not discernibly different between mined and reference sites.

In order to observe seasonal trends, values of pH and total alkalinity were plotted throughout the sampling periods and are presented in figures 22 and 23. Seasonal trends were observed only for total alkalinity, which was usually highest during the warmer summer months when bicarbonate-dependent CO_2 concentrations are low, and lowest during the cold winter months. A number of pH values were observed below the lower effluent limitation (pH = 6) established by the Surface Mine Control and Reclamation Act of 1977 (SMCRA). Approximately 63 percent of the pH values measured at the LB4.0 reference site were below a pH of 6, while 10 percent of the values were below a pH of 6 at the Bowling Branch reference site. Most mined site values were above this limit.

TABLE 10. MEANS, RANGES, AND STANDARD ERRORS OF WATER QUALITY PARAMETERS FROM JAMESTOWN AREA STREAMS. MEAN VALUES WERE CALCULATED FROM DATA COLLECTED BETWEEN 1975 AND 1979 AND ARE EXPRESSED AS mg/l UNLESS OTHERWISE INDICATED

Variable		Station					
		UT0.01	CC15.9	CC16.7	CC18.5	LY0.4	LB4.0
% mined		43	13	13	0	0	0
pH	mean	6.3	6.5	6.5	6.2	5.3	4.4
(s.u.)	range	5.8-7.8	5.7-8.5	5.6-7.9	4.8-7.9	3.8-8.2	3.0-7.3
Alkalinity	mean	11.5	16.3	17.8	22.9	3.8	4.4
(mg/l $CaCO_3$)	S.E.	0.81	1.14	1.46	1.4	0.49	0.8
	range	2.0-28.0	3.0-45.0	5.0-61.0	10.0-48.0	0.0-0.5	0.0-24.0
Acidity	mean	9.2	5.5	6.0	5.3	5.8	9.9
(mg/l $CaCO_3$)	S.E.	1.15	0.67	1.20	0.90	1.21	1.38
	range	0.0-39.0	0.0-18.0	0.0-42.0	0.0-32.0	0.0-38.0	0.0-41.0
Dissolved	mean	9.1	9.3	9.5	9.1	9.4	8.2
Oxygen	S.E.	0.22	0.29	0.25	0.54	0.22	0.59
	range	8.1-10.1	8.0-11.9	8.6-11.2	7.2-10.3	8.5-10.7	4.3-10.6
Suspended	mean	32.5	27.6	23.9	57.7	5.1	10.4
Solids	S.E.	6.3	10.4	8.68	16.9	1.42	2.3
	range	3.0-180.0	1.0-400.0	2.0-300.0	3.0-530.0	1.0-41.0	1.0-75.0
Dissolved	mean	66.2	74.1	62.0	74.6	22.5	24.8
Solids	S.E.	2.9	7.8	2.5	3.4	1.6	2.3
	range	20.0-120.0	30.0-330.0	30.0-100.0	40.0-140.0	10.0-50.0	10.0-60.0
Conductivity	mean	103.2	97.2	87.1	114.9	34.2	33.7
(∂mhos/l)	S.E.	5.30	6.00	3.08	6.45	8.66	6.68
	range	44.0-260.0	17.0-260.0	2.8-180.0	40.0-260.0	9.0-250.0	7.0-280.0

(continued)

TABLE 10. (continued)

Variable		Station UTO.01	CC15.9	CC16.7	CC18.5	LYO.4	LB4.0
SO_4	mean	17.4	16.8	10.4	9.9	3.3	5.2
	S.E.	1.0	1.1	0.64	0.65	0.36	0.6
	range	6.0-41.0	9.0-56.0	2.0-22.0	2.0-21.0	1.0-15.0	1.0-23.0
Fe	mean	3394.1	1454.1	1198.4	2006.1	363.1	1024.4
(μg/l)	S.E.	414.0	120.01	162.9	455.3	93.0	198.4
	range	1200.0-15000.0	630.0-3400.0	200.0-4600.0	420.0-12000.0	50.0-3100.0	50.0-3900.0
Mn	mean	1114.8	477.06	357.1	134.8	30.3	143.2
(μg/l)	S.E.	84.7	73.1	97.1	11.7	5.8	38.6
	range	200.0-2000.0	90.0-2400.0	70.0-3100.0	70.0-380.0	10.0-200.0	10.0-1300.0
Ca	mean	9.3	10.4	10.1	12.4	2.5	3.0
	S.E.	0.44	0.45	0.33	0.45	0.14	0.67
	range	1.0-17.0	7.0-21.0	7.0-15.0	7.0-19.0	1.0-4.6	0.9-26.0
Mg	mean	2.5	2.0	1.7	1.7	0.57	0.8
	S.E.	0.08	0.09	0.06	0.05	0.03	0.06
	range	1.0-3.6	1.1-4.5	1.2-2.8	1.4-2.7	0.3-1.0	0.4-2.0
Water	mean	13.0	12.3	11.8	12.9	11.6	12.6
Temperature	S.E.	1.11	1.08	1.00	1.35	0.85	0.91
(^{o} C)	range	0.0-22.5	0.0-23.0	0.3-21.5	0.0-28.0	0.0-21.0	0.0-23.5

TABLE 11. MEANS, RANGES, AND STANDARD ERRORS OF WATER QUALITY PARAMETERS FROM NEW RIVER AREA STREAMS. MEAN VALUES WERE CALCULATED FROM DATA COLLECTED BETWEEN 1975 AND 1979 AND ARE EXPRESSED AS mg/l UNLESS OTHERWISE INDICATED

Variable		Station: Green Branch	Indian Fork	Bills Branch	Anderson Branch	Bowling Branch	Lowe Branch
% mined		24.1	18.9	9.0	7.5	0	0
pH	mean	7.0	6.5	6.7	6.2	6.2	6.1
(s.u.)	range	6.4-7.8	5.2-8.0	6.0-7.6	4.7-8.0	4.8-7.6	5.1-7.6
Alkalinity	mean	31.0	24.7	15.4	26.0	9.0	6.7
(mg/l	S.E.	0.54	1.07	0.50	2.44	0.47	0.29
$CaCO_3$)	range	13.3-60.7	1.8-71.4	0.0-36.5	1.0-96.7	0.1-33.2	0.2-28.2
Suspended	mean	774.3	111.9	464.2	116.4	107.8	6.9
Solids	S.E.	269.79	29.85	162.12	26.85	29.65	0.85
	range	0.0-29500.0	0.0-3300.0	0.0-17280.0	0.0-2168.0	0.0-3060.0	0.0-54.0
Dissolved	mean	731.9	1221.2	234.9	100.1	56.4	43.4
Solids	S.E.	128.03	179.49	32.60	11.56	4.09	3.01
	range	22.0-15188.0	112.0-12700.0	0.0-2600.0	0.0-1176.0	0.0-350.0	0.0-150.0
SO_4	mean	150.0	381.9	40.4	12.6	10.2	10.6
	S.E.	4.52	19.16	1.37	0.63	0.53	0.38
	range	45.0-285.0	88.0-1250.0	5.0-84.0	0.0-33.0	0.0-37.0	0.0-22.0
Fe	mean	4.4	8.1	2.6	2.6	1.9	0.2
	S.E.	0.87	0.61	0.74	0.50	0.39	0.01
	range	0.0-64.8	0.8-54.0	0.0-80.0	0.05-41.0	0.0-41.0	0.0-1.0
Mn	mean	0.3	1.0	0.1	0.1	0.1	0.0
	S.E.	0.02	0.05	0.02	0.01	0.01	0.00
	range	0.0-2.5	0.1-3.7	0.0-1.8	0.0-0.8	0.0-1.0	0.0-0.2

(continued)

TABLE 11 (continued)

Variable		Station					
		Green Branch	Indian Fork	Bills Branch	Anderson Branch	Bowling Branch	Lowe Branch
Ca	mean	32.8	67.7	8.4	6.2	1.3	1.2
	S.E.	1.06	2.67	0.35	0.74	0.09	0.04
	range	2.5-57.0	14.7-152.0	1.4-17.0	0.4-34.0	0.1-8.5	0.0-2.7
Mg	mean	18.1	27.3	6.1	2.8	1.7	1.5
	S.E.	0.45	1.04	0.22	0.20	0.07	0.03
	range	5.0-28.3	9.5-66.0	1.3-11.3	0.8-8.9	0.5-4.7	0.4-2.1
Water	mean	14.3	13.7	13.9	13.5	13.9	13.2
Temperature	S.E.	0.56	0.59	0.57	0.58	0.59	0.58
(^{o} C)	range	0.0-25.0	0.0-25.0	0.0-25.0	0.0-24.0	0.0-27.0	0.0-26.0

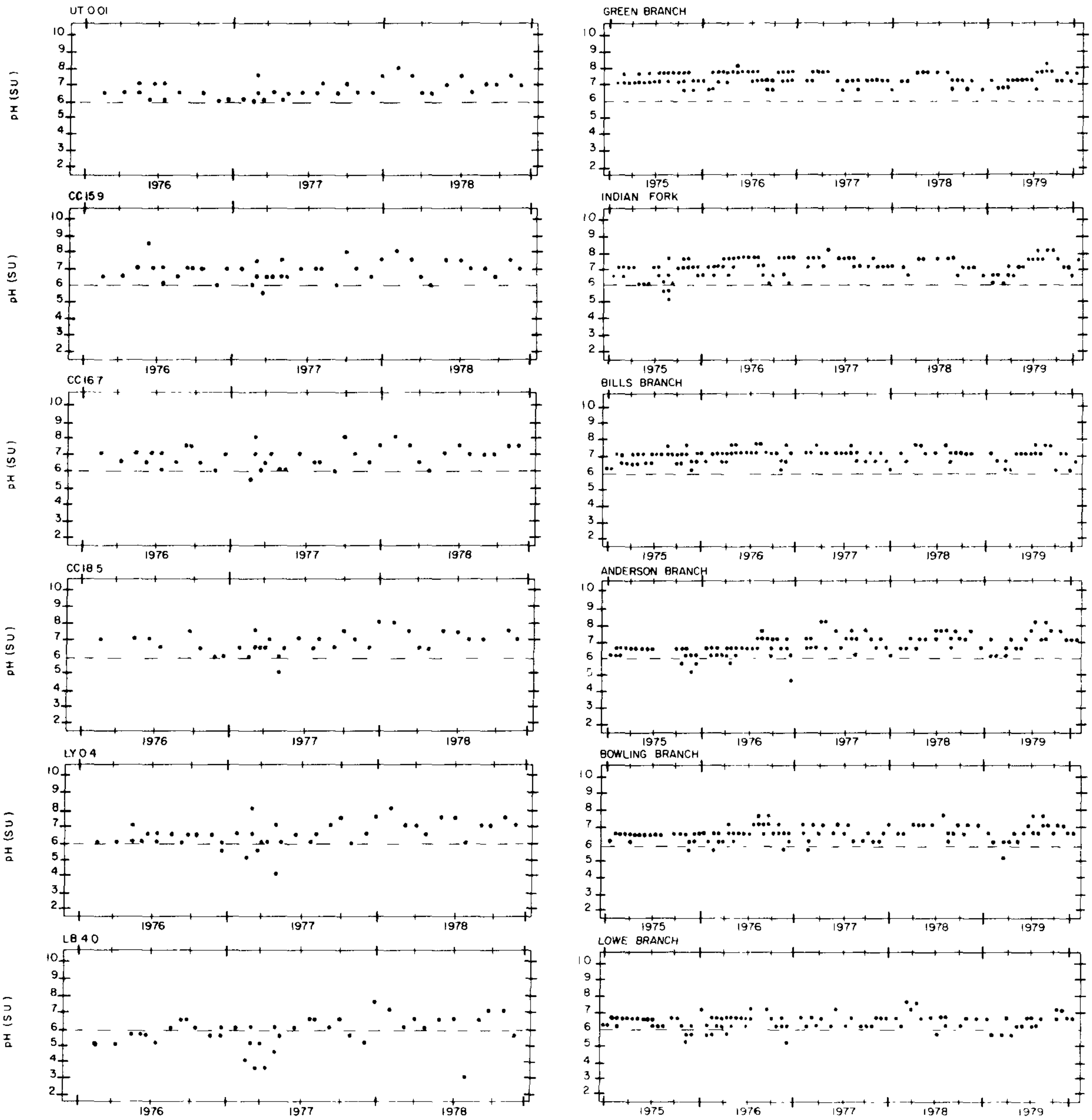

Figure 22. Hydrogen ion concentrations (pH) of Jamestown and New River area streams between 1975 and 1979. Dashed line is lower pH effluent limitation established under the Surface Mine Control and Reclamation Act of 1977.

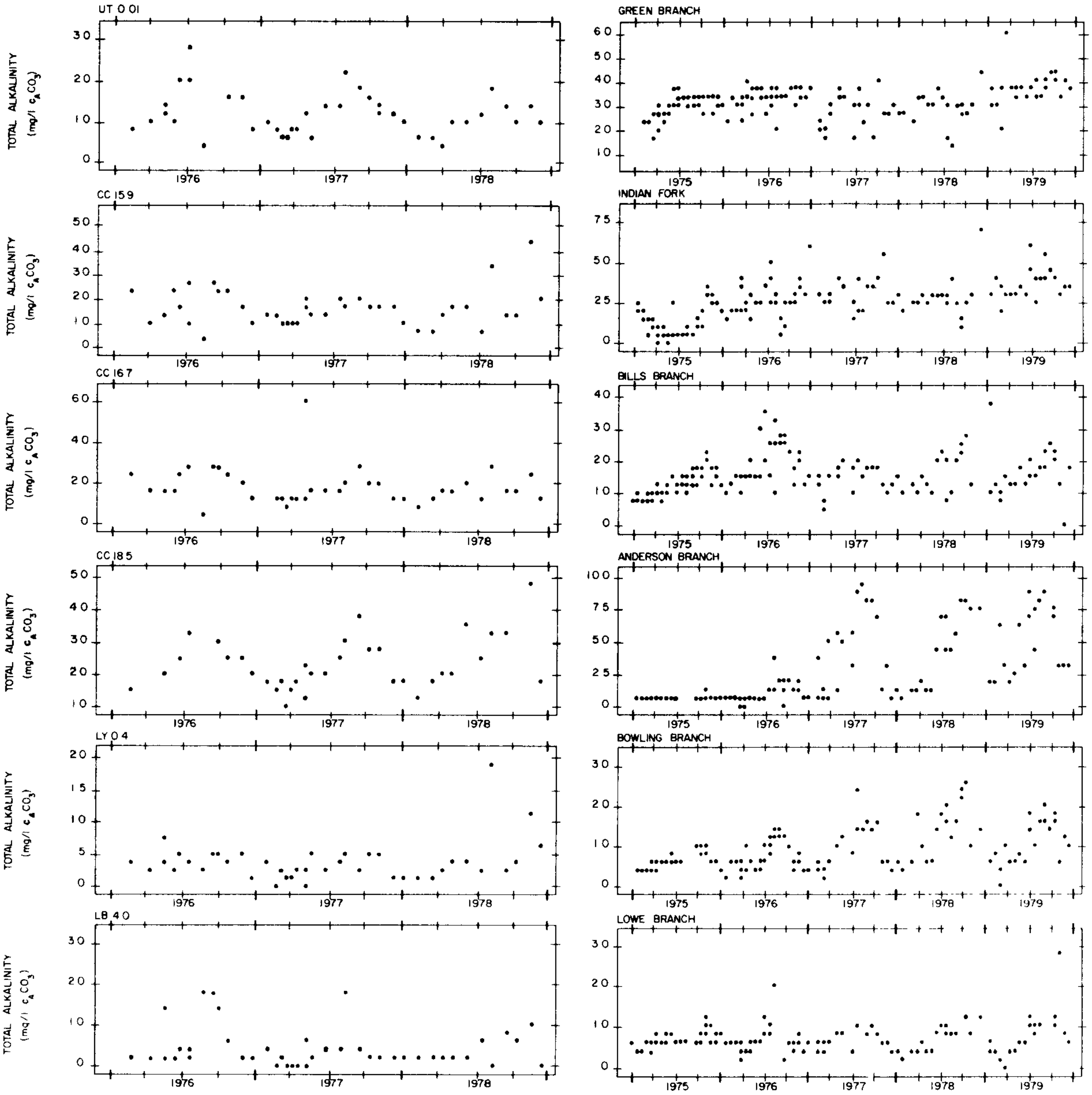

Figure 23. Total alkalinity of Jamestown and New River area streams between 1975 and 1979.

Numerous other investigators have also observed alkaline mine drainage in the Appalachian region (Minear and Tschantz, 1976; Geidel and Caruccio, 1977; Caruccio, Geidel, and Pelleteer, 1980; Caruccio, Geidel, and Sewell, 1976). Several factors are important in alkaline mine drainage production and include: (1) the calcium carbonate and clay content and cation exchange capacity of the rock strata, (2) the pH and buffering capacity of ground water, and (3) the morphology and quantity of the pyrite mineral.

Calcium carbonate ($CaCO_3$), a commonly occurring cementing material in sandstones and found in all rock strata analyzed, dissolves fairly readily as bicarbonate in carbonic acid and can effectively neutralize acid containing waters. Calcium carbonate bicarbonate reactions are summarized by the following equations:

$$CaCO_3 + CO_2 + H_2O \rightleftarrows Ca^{++} + 2HCO_3^- \quad \text{Eq. 4}$$
$$HCO_3^- + H_2O \rightleftarrows H_2CO_3 + OH^- \quad \text{Eq. 5}$$

(After Caruccio, 1968 and Gerrels and Christ, 1965)

These reactions are limited, however, by the solubility of the specific carbonate containing mineral or rock (calcite, dolomite, or limestone) in water and depend upon the partial pressure of CO_2 (Caruccio and Geidel, 1980). In addition, each reaction depends on the length of time the acid-forming material is permitted to weather before exposure to water and the length of contact time between alkaline material and water. Higher ground water pH values resulting from the production of alkalinity can effectively surpress iron bacteria, a prime catalyst in the oxidation of ferrous iron. Furthermore, the dissolution of aluminum silicate minerals, as discussed in the previous chapter, can liberate hydroxide to produce alkalinity:

$$Al_2Si_2O_5(OH)_4 + 5H_2O \rightarrow 2Al^{+3} + 2H_4SiO_4(aq.) + 6OH^- \quad \text{Eq. 6}$$

(After Gardner, 1970)

This additional alkalinity is also available to neutralize acidity and can be generated through the decomposition of clay-rich shales.

Cation exchange reactions, also discussed in the previous chapter, were identified as important mechanisms by which metal ions are transported downstream. Cation exchange reactions have also been shown to enhance mineral weathering of clay minerals and serve to neutralize acidity by replacing Ca, Na, K, Fe, and Al in the clay crystal lattice with free H^+ ions.

Alkalinity can, therefore, result from the presence and solubility of carbonates and aluminum silicates and the cation exchange capacity of the rock strata. All rock strata analyzed contained varying quantities of alkalinity producing materials and cation exchange capacity sufficient to cause alkaline drainage. The following section discusses the results of iron and sulfate analysis and the importance of these elements relating to increased acidity.

Iron, Sulfate, and the Production of Acidity--

The presence of alkalinity-producing strata can be particularly important in regions where acid-forming iron disulfide minerals occur. Without the neutralization and buffering effects of alkalinity, acid production can become particularly severe. The resulting drop in stream pH can increase the solubility of heavy metals such as iron, calcium, magnesium, manganese, copper, and zinc causing further pollution. As Hill (1973) reports

> "[Acid] water of this type supports only limited water flora, such as acid-tolerant molds and algae; it will not support fish life, destroys and corrodes metal pipes, culverts, barges, etc., increases the cost of water treatment for power plants and municipal water supplies, and leaves the water unacceptable for recreational uses."

The general chemical reactions showing the oxidation of FeS_2 (pyrite) and the production of acidity (H^+) are given by the following equations:

$$2FeS_2(S) + 7O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+ \qquad \text{Eq. 7}$$

$$4Fe^{+2} + O_2 + 4H^+ \rightarrow 4Fe^{+3} + 4H_2O \qquad \text{Eq. 8}$$

$$Fe^{+3} + 3H_2O \rightleftarrows Fe(OH)_3(S) + 3H^+ \qquad \text{Eq. 9}$$

$$FeS_2(S) + 14Fe^{+3} + 8H_2O \rightarrow 15Fe^{+2} + 2SO_4^{-2} + 16H^+ \qquad \text{Eq. 10}$$

(after Cox et al., 1979)

The oxidation of Fe^{+2} to Fe^{+3} is usually rate-limited under normal conditions but can be greatly enhanced and accelerated by certain acid-tolerant bacteria, such as the sulfur-oxidizing bacteria Thiobacillus thiooxidans and Ferrobacillus ferrooxidans and the iron-oxidizing bacterium Thiobacillus ferrooxidans (Caruccio et al., 1976). The reactivity of the pyrite is also a function of the morphology of the mineral in which the finely granulated, large surface area framboidal variety is the most reactive of all pyrite types (Geidel and Caruccio, 1977). Increasing concentrations of iron and sulfate would, therefore, be observed in the water column if pyrite or other iron disulfide minerals were being oxidized according to the above reaction sequence. Acidity would also be produced, but values would be tempered, depending on the available buffering and neutralization capacities of the strata and ground water.

The most useful indicator of acid mine drainage according to Herricks and Cairns (undated) is sulfate. A sulfate concentration greater than 250 mg/l is given as a criteria for the presence of acid mine drainage, although values greater than 20 mg/l are cause for concern especially in Appalachian waters, which naturally contain less than 20 mg/l sulfate.

Mean sulfate concentrations for the Jamestown area-mined sites were significantly higher than reference sites, ranging from 10.4 mg/l at CC16.7 to 17.4 at UT0.01, but were well below the acid mine drainage criteria. Mean concentrations for the New River area mined sites were also significantly higher than reference sites, ranging from 12.6 mg/l at Anderson Branch to 381.9 mg/l at Indian Fork. In addition, 77 percent of Indian Fork values exceeded 250 mg/l. Green Branch also had high sulfate values, 4.5 percent of which exceeded 250 mg/l. Mean sulfate values for the reference sites ranged from 3.3 mg/l at LB4.0 to 10.6 mg/l at Lowe Branch. Plots of sulfate data are presented in figure 24. No discernible seasonal trends were evident, although higher values occurred during the late summer and early fall for some of the New River area sites.

Total iron concentrations can be highly elevated in strip mine environments due to the release of Fe^{+2} and Fe^{+3} during the oxidation of pyrite. SMCRA established a maximum effluent limit of 7.0 mg/l total iron from strip mine operations. In addition the Environmental Protection Agency (EPA) proposed a 1 mg/l criteria for fresh water aquatic life (EPA, 1976).

Mean total iron concentrations were all below the 7.0 mg/l limit at the Jamestown and New River area sites except for the 8.1 mg/l mean value observed at Indian Fork. Although mean values were well below the effluent limit in most cases some individual values, however, were significantly higher

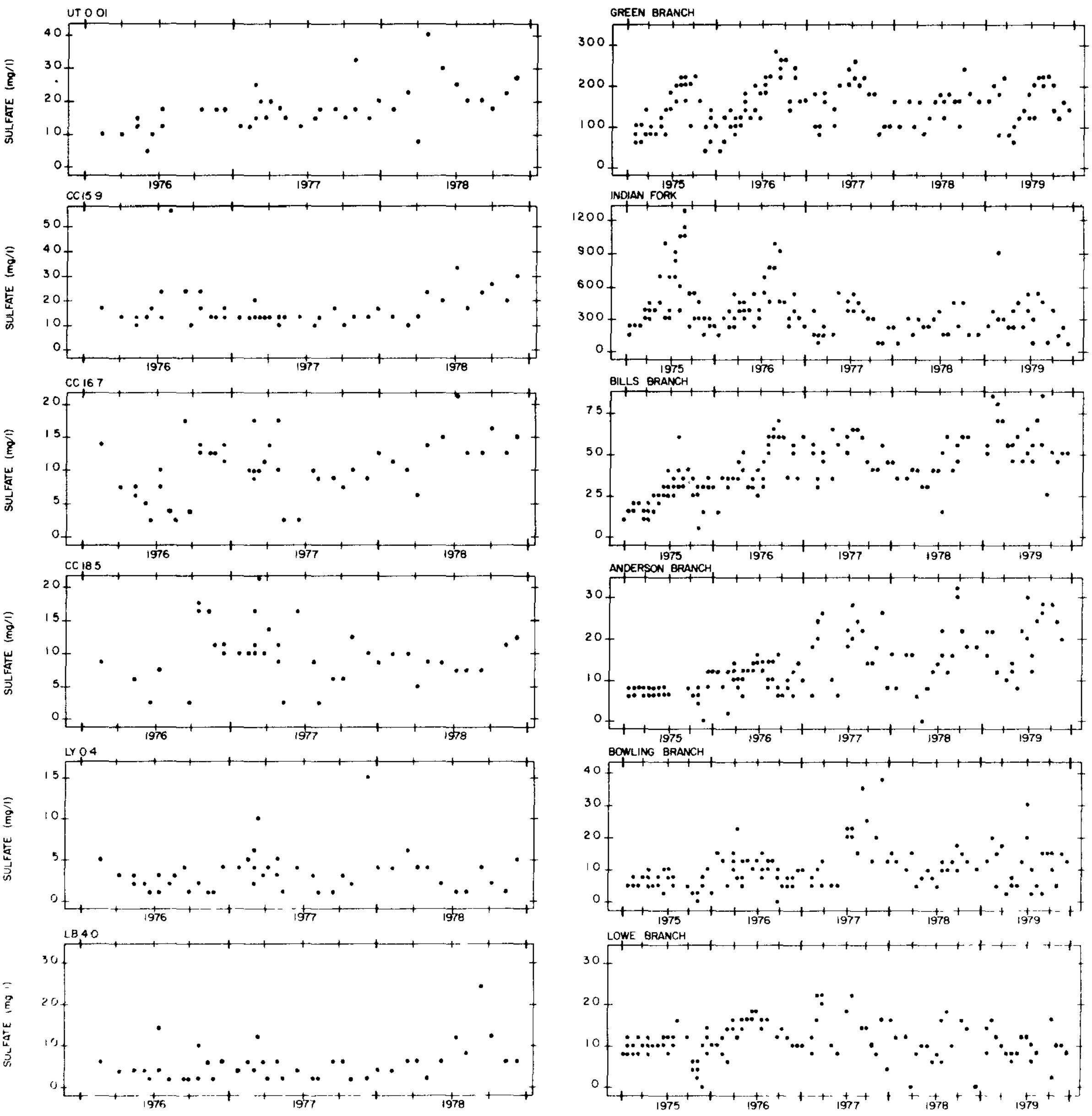

Figure 24. Sulfate of Jamestown and New River area streams between 1975 and 1979.

(figure 25). Thirty-three percent of the values exceeded the effluent limitat CC18.5 (a site drain) whereas 43.5 percent exceeded the limit at Indian Fork. Total iron at Green Branch was also relatively high, with 15.7 percent of the values exceeding 7.0 mg/l over the 5-year sampling period. Lowest values (actual and mean) were observed at the mined sites CC15.9 and CC16.7 and at the reference sites LY0.4, LB4.0, and Lowe Branch.

Dissolved iron concentrations were significantly lower than total iron values. Mean values never exceeded 1 mg/l while actual values, plotted in figure 26, rarely exceeded 7 mg/l except for a 10.5 mg/l value at Indian Fork. Lower dissolved iron values relative to total iron indicate that most of the iron in the water column was in suspended form, either as $Fe(OH)_3$ or adsorbed on to clay particles. No seasonal trends for either dissolved or total iron were evident except for a slight elevation in total iron values during the fall of each year at LB4.0, due perhaps to leaf litter decomposition.

Acidity, a major reaction product of iron pyrite oxidation, was measured only at the Jamestown sites. Acidity was highest at LB4.0 averaging 9.9 mg/l $CaCO_3$ for the 3-year sampling period (figure 27). Other mean acidity values ranged from 5.3 mg/l $CaCO_3$ at CC18.5 to 9.2 mg/l $CaCO_3$ at UT0.01. These values were significantly higher than the acidity criteria of 3.0 mg/l for determining acid mine drainage established by Herricks and Cairns. Since pH and alkalinity values were significantly higher at the area- and contour-mined sites, however, sufficient neutralization and buffering must have been taking place. If pyrite is being oxidized, the reaction products, acidity, sulfate, and iron are quickly tempered by carbonates or cation exchange within the strata or in stream so as to yield an alkaline mine drainage.

Manganese--

Manganese is a transition element and closely related to iron. Manganese is also an important reactant in redox processes in natural waters and is an essential micronutrient of freshwater flora and fauna (Wetzel, 1975). Water quality standards proposed by the U.S. Public Health Service (1962) recommend an upper limit of 0.05 mg/l because small concentrations of manganese in water may be objectionable. Concentrations of manganese greater than 1 mg/l are common in streams receiving acid mine drainage and can persist in water for greater distances downstream from the pollution source than iron because of greater solubility at neutral pH.

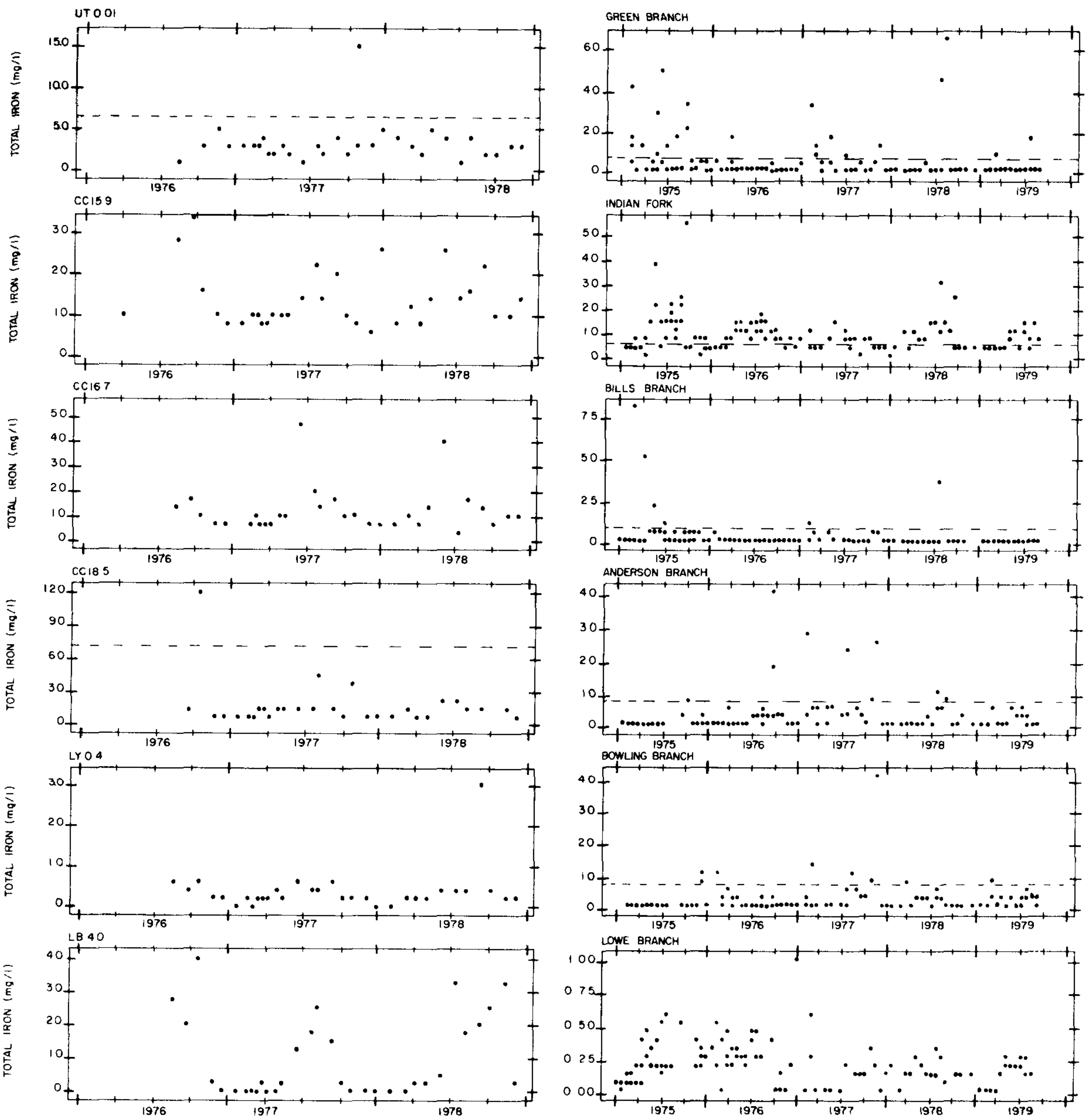

Figure 25. Total iron concentrations at Jamestown and New River area streams between 1975 and 1979. Dashed line is maximum effluent limitation established under the Surface Mine Control and Reclamation Act of 1977.

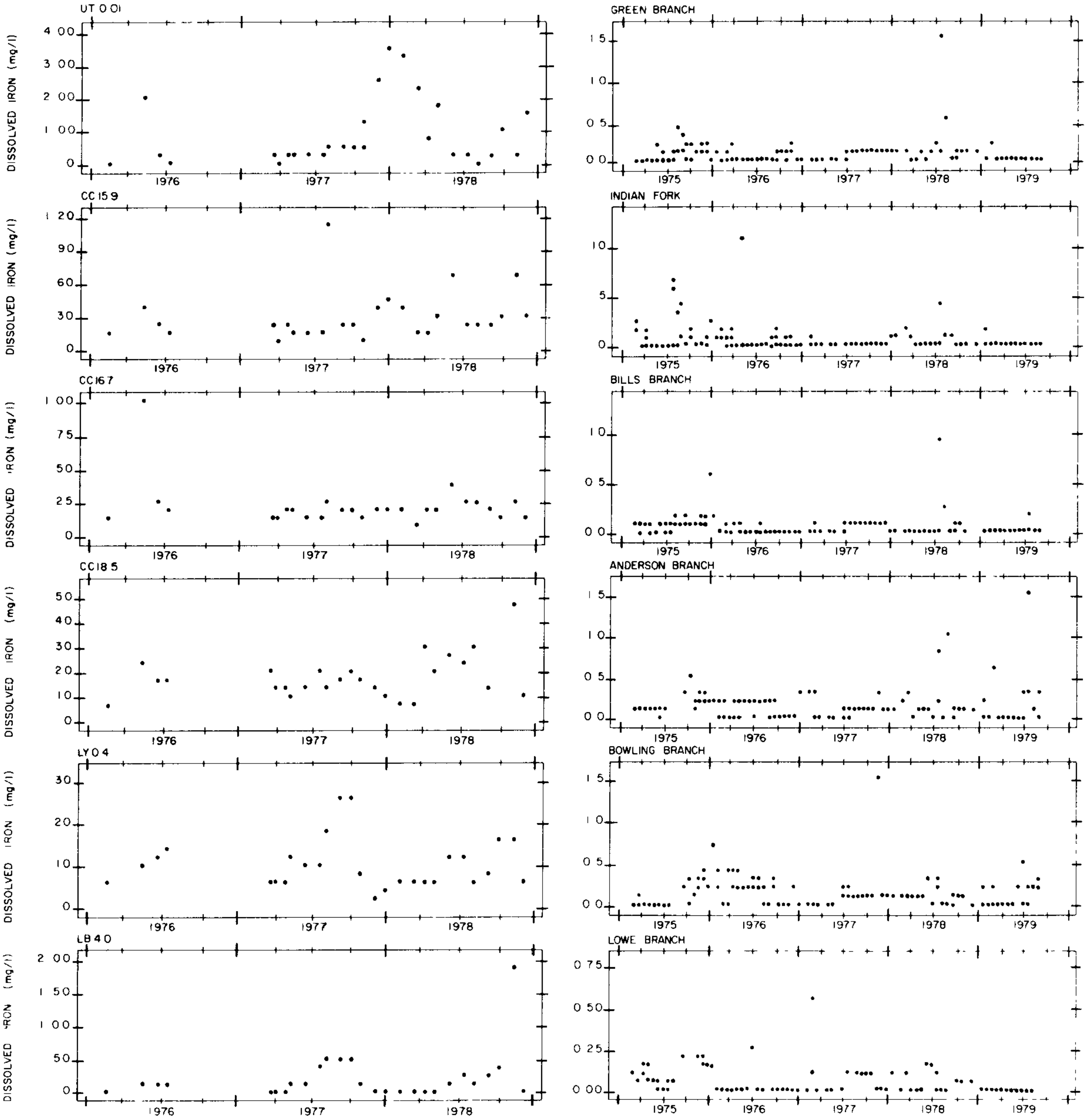

Figure 26. Dissolved iron concentrations of Jamestown and New River area streams between 1975 and 1979.

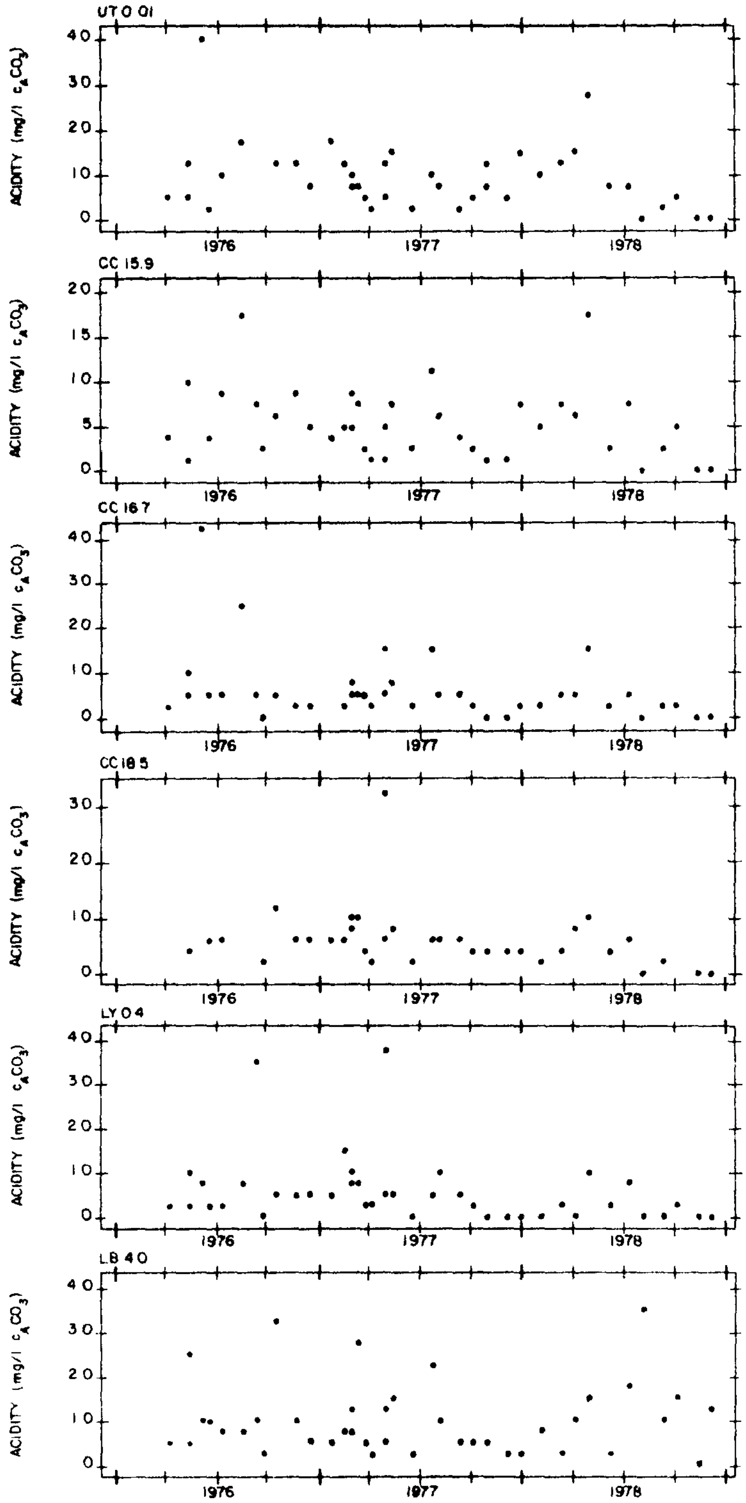

Figure 27. Acidity of Jamestown area streams between 1976 and 1978.

Average manganese concentrations were low at all sites ranging from 0.0 mg/l at Lowe Branch to 1.1 mg/l at UT0.01. None of the observed values exceeded the 4.0 mg/l effluent limit established by the SMCRA (figure 28). Apparently little manganese-containing minerals are present in the study areas.

Suspended and Dissolved Solids--

Although acid mine drainage can be effectively neutralized in areas where rock strata and ground water contain sufficient buffering and neutralization capacity, increased suspended and dissolved sediment loadings due to surface mining can impart equally serious impacts. Increased sediment loadings resulting from the erosion of exposed mine spoils and ongoing mining activities has been a major surface water quality problem, threatening aquatic ecosystems and increasing flooding and erosional problems due to alterations in stream channel morphology and stability. Suspended solid concentrations are generally flow related resulting from rainfall washing soil into streams that drain mine sites or other disturbed areas. Greatest concentrations usually occur during storm runoff. Dissolved solids also pose a threat to water quality, particularly sulfate and chloride, and are most difficult and expensive to remove from surface waters (Murray 1978).

As expected, mean suspended solids concentrations were significantly higher at the Jamestown area-mined sites than at Jamestown reference sites, ranging from 23.9 mg/l at CC16.7 to 32.5 mg/l at UT0.01. A mean concentration of 57.7 mg/l was observed at the agricultural site, CC18.5. Mean values for the reference sites ranged from 5.1 mg/l at LY0.4 to 10.4 mg/l at LB4.0. Actual values presented in figure 29 rarely exceeded the 70 mg/l effluent limit established by the SMCRA. Most of the values exceeding this limit were observed at CC18.5 where 6 out of 37 values (16.2 percent) were above 70 mg/l. The highest actual value of 530 mg/l was also observed at CC18.5.

Although these values were higher at the mined site, they only reflect moderate- to low-flow conditions and did increase dramatically during high-flow conditions. Storm event sampling at CC15.9 and UT0.01 during nine separate storm events increased suspended solids concentrations from 12 to 4000 mg/l at CC15.9 and from 34 to 6300 mg/l at UT0.01 (Cox et al., 1979).

Suspended solids concentrations were much higher in samples collected at the New River area mined sites than in the Jamestown site samples. Mean values ranged from 111.9 mg/l at Indian Fork to 774.3 mg/l at Green Branch (table 11). Bowling Branch, a reference site, also had an unusually high

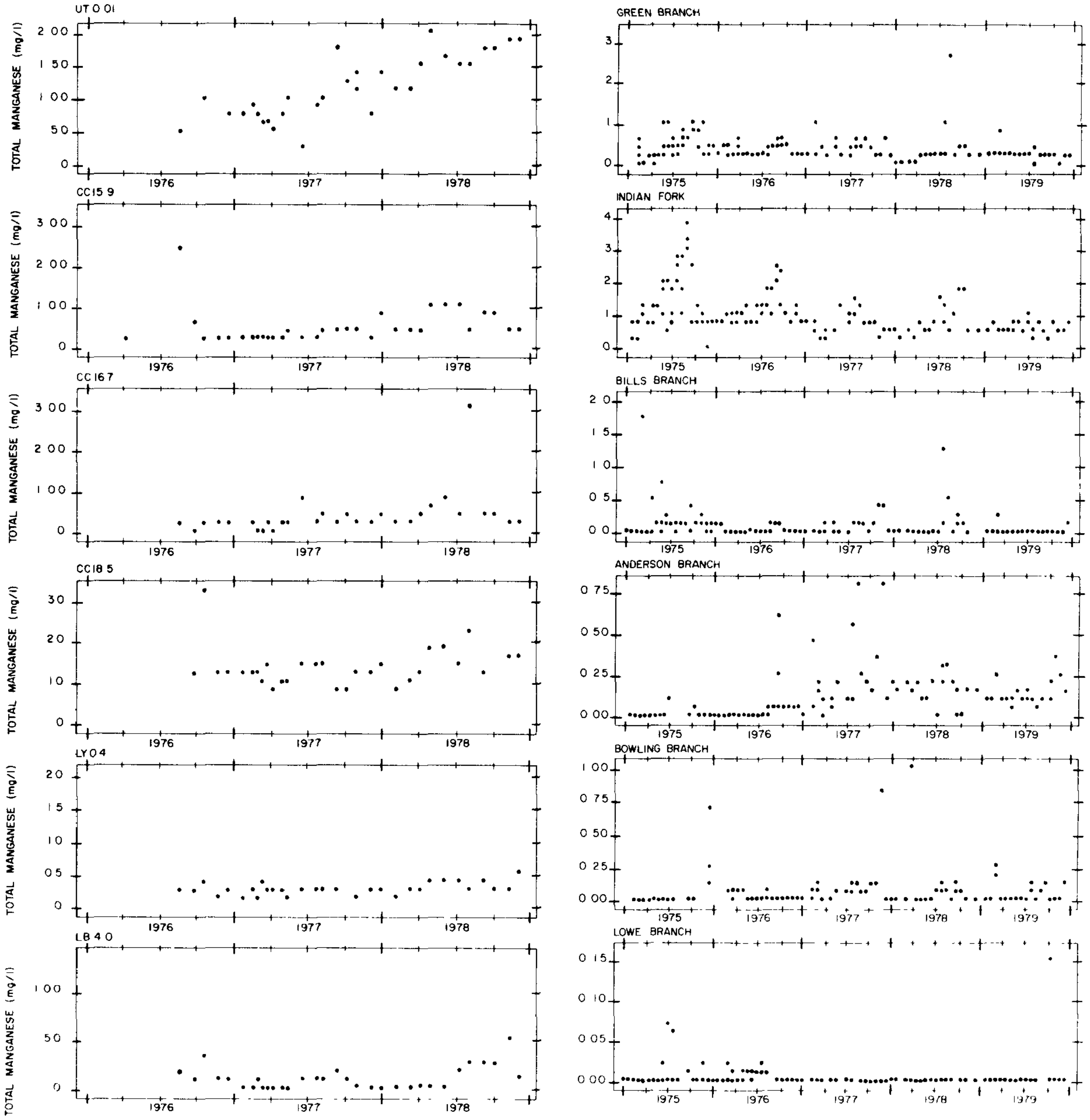

Figure 28. Total manganese concentrations of Jamestown and New River area streams between 1975 and 1979.

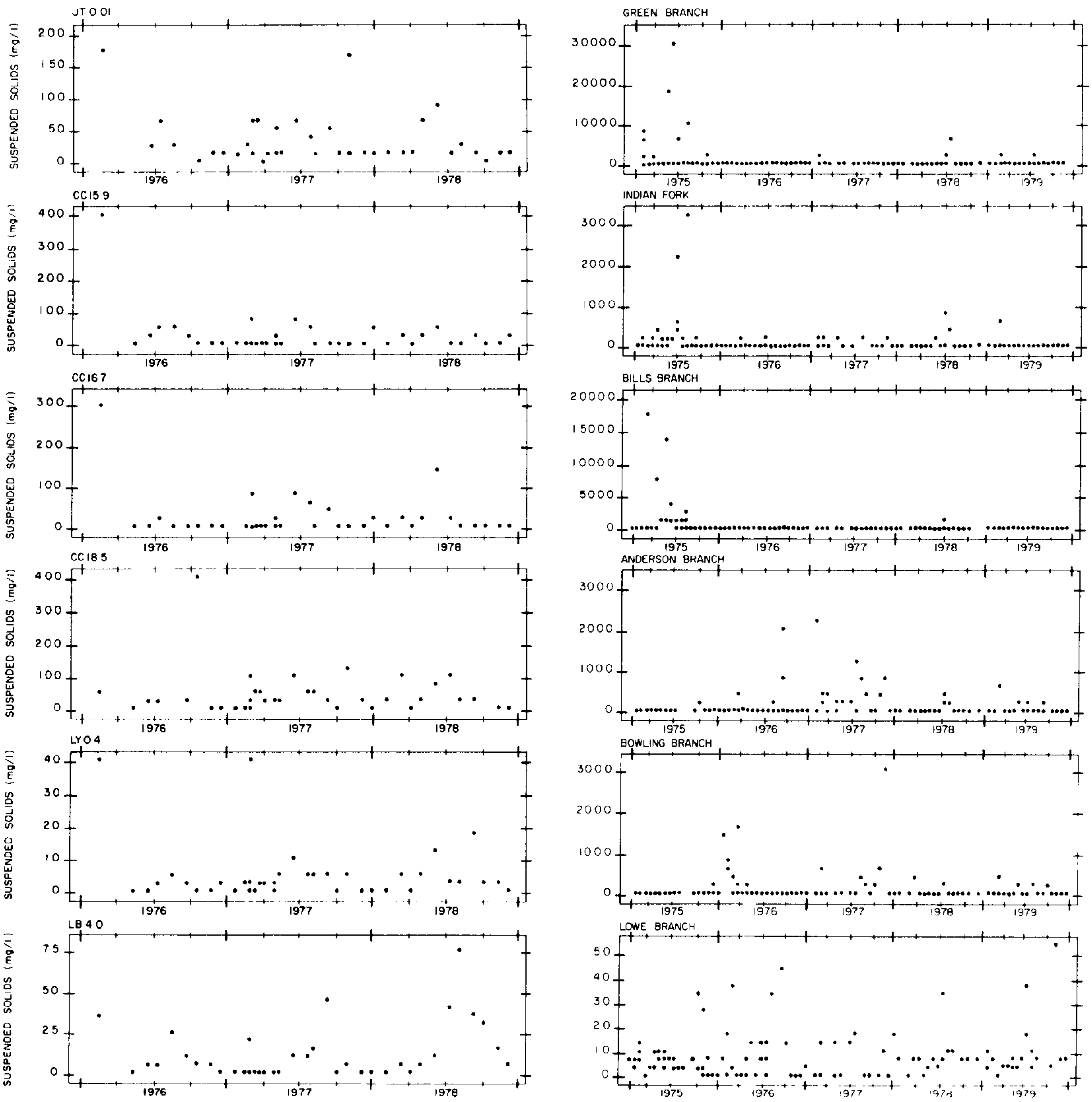

Figure 29. Suspended solid concentrations at Jamestown and New River area streams between 1975 and 1979.

mean value of 107.8 mg/l. The other reference site, Lowe Branch, had a mean value of 6.9 mg/l.

Between 17.4 and 32.1 percent of the actual values at each site presented in figure 29 exceeded the 70.0 mg/l effluent limit. No values exceeded this value at Lowe Branch. A value of 29,500 mg/l was recorded at Green Branch, the highest value observed during the study. (Again, one must exercise caution when interpeting these data because storm events can have a much greater impact on suspended sediment concentrations although the impacts may be brief.)

Dissolved solid concentrations were also signficantly higher at the mined sites in both areas. Mean values at the Jamestown area-mined sites ranged from 62.0 mg/l at CC16.7 to 74.1 mg/l at CC15.9. Jamestown area reference site mean values ranged from 22.5 mg/l to 24.8 mg/l. A mean value of 74.6 mg/l was observed at CC18.5.

New River mined site mean dissolved solid values, like suspended solid values, were much higher than Jamestown area values, ranging from 100.1 mg/l at Anderson Branch to 1221.2 mg/l at Indian Fork. Reference sites averaged from 43.4 to 56.4 mg/l at Lowe Branch and Bowling Branch, respectively.

Plots of actual dissolved solids concentrations are presented in figure 30. No seasonal trends are evident, although maximum values for Green Branch, Indian Fork, and Bills Branch occurred during the late spring and summer of 1975. These maximum values are most likely a reflection of the active mining taking place in these watersheds from December 1974 to September 1975.

An analysis of the specific anions and cations of the Jamestown area sites are presented in table 12. The cations Ca^{+2}, Mg^{+2}, Na^{+1}, and K^{+1}; the anions HCO_3^-, SO_4^{2}, and Cl^{-1}; and dissolved silica (H_4SiO_4) represented 82 to 96 percent of the total dissolved solids sampled. Calcium was the dominant cation at all sites, while sulfate dominated the anion concentrations at LB4.0, UT0.1, and CC15.9. Bicarbonate was dominant at CC18.5 and CC16.7, while chloride dominated the anions at LY0.4. Significant differences in total anion-cation concentrations were observed between the mined and reference sites. Total anion-cation concentrations, like total dissolved solids, were greater at the agricultural site, CC18.5.

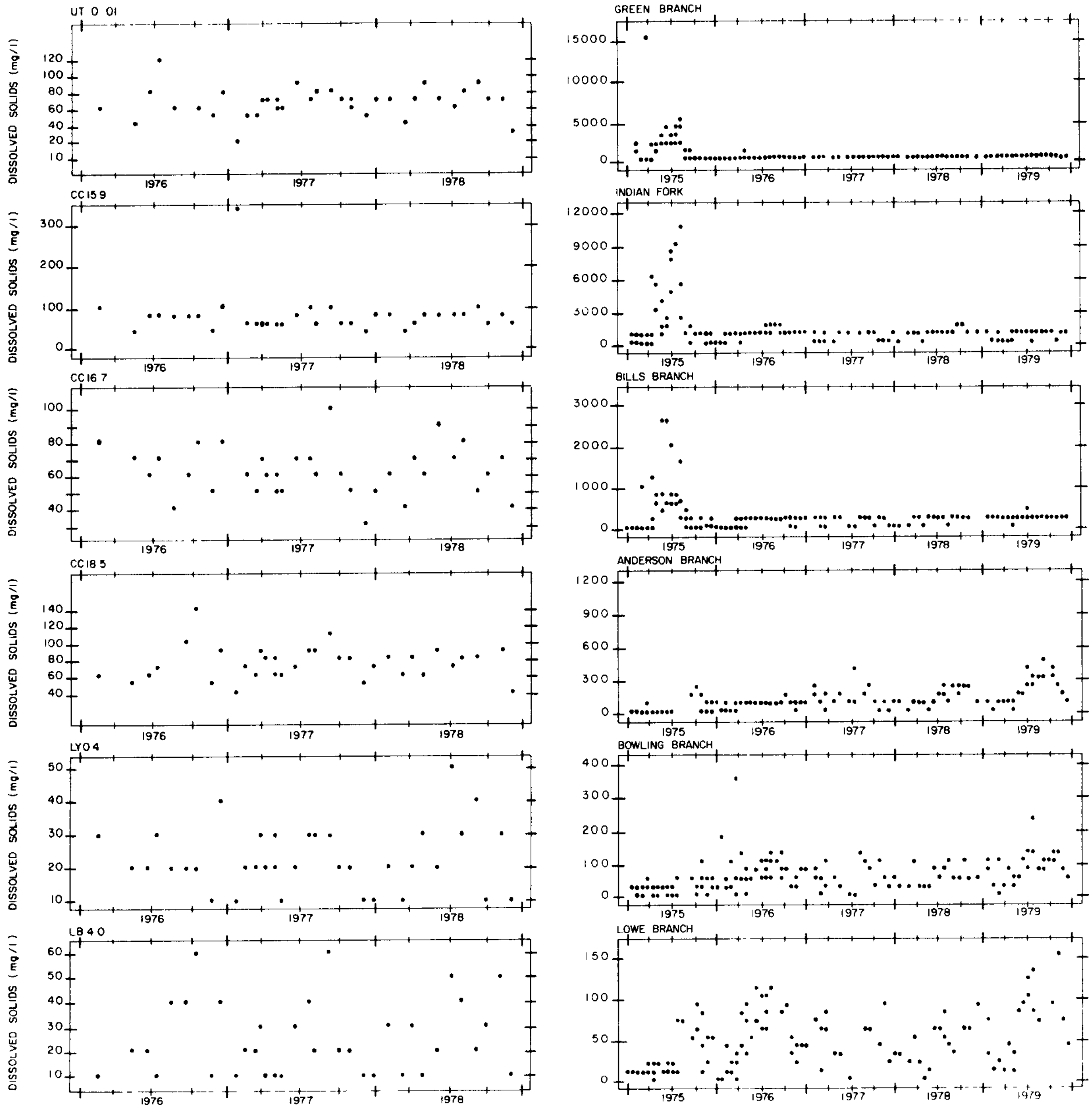

Figure 30. Dissolved solid concentrations of Jamestown and New River area streams between 1975 and 1979.

TABLE 12. AVERAGE ANION-CATION CONCENTRATIONS OF THE JAMESTOWN AREA SITES. VALUES WERE CALCULATED FROM DATA COLLECTED BETWEEN 1975 AND 1978

Station		Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	HCO_3^-	SO_4^{-2}	Cl^{-1}	H_4SiO_4	Total anion-cations	Total dissolved solids	% of total dissolved solids
LB 4.0	mg/l	2.3	0.8	1.06	1.32	5.0	5.0	3.0	4.6	23.08	24.0	96.2
	%	9.9	3.5	4.6	6.0	21.7	21.7	12.9	19.9			
	μeq	114.7	65.8	46.1	33.8	82.0	104.1	84.5	48.4	579.4		
	%	19.8	11.4	7.9	5.8	14.2	17.9	14.6	8.4			
LY 0.4	mg/l	2.5	0.6	0.93	0.43	5.0	3.0	3.0	4.8	20.26	23.0	88.1
	%	12.3	2.9	4.6	2.1	24.7	14.8	14.8	23.7			
	μeq	124.7	49.4	40.4	11.0	81.9	62.4	84.8	50.5	505.1		
	%	24.7	9.8	7.9	2.2	16.2	12.4	16.8	9.9			
UT 0.01	mg/l	9.3	2.5	2.1	2.6	11.7	17.0	6.0	4.3	55.5	66.0	84.1
	%	16.8	4.5	3.8	4.7	21.1	30.6	10.8	7.7			
	μeq	463.8	205.8	91.3	66.5	191.8	353.8	169.5	45.2	1587.7		
	%	29.2	12.9	5.8	4.2	12.1	22.3	10.7	2.8			
CC 18.5	mg/l	12.4	1.7	4.7	3.1	23.0	10.0	11.0	4.1	70.0	75.0	93.3
	%	17.7	2.4	6.7	4.4	32.9	14.3	15.7	5.9			
	μeq	618.5	139.9	204.3	79.3	377.1	208.1	310.7	43.1	1981.0		
	%	31.2	7.1	10.3	4.0	19.0	10.5	15.7	2.2			
CC 16.7	mg/l	10.1	1.7	2.85	1.98	21.4	10.0	7.0	4.7	59.7	62.0	96 3
	%	16 9	2.9	4.8	3.3	35.8	16.7	11.7	7.9			
	μeq	503.7	139.9	123.9	50.6	350.8	208.1	197.7	49.4	1624.1		
	%	31.0	8.6	7.6	3.1	21.6	12.8	12.2	3.0			
CC 15.9	mg/l	10.4	2.0	2.79	2.06	16.3	17.0	6.0	4.4	60.0	74 2	82.1
	%	17.1	3.3	4.6	3.4	26.8	27.9	9.9	7.2			
	μeq	518.7	164 6	121.3	52.7	267.2	353.8	169.5	46.3	1694.1		
	%	30.6	9.7	7.2	3.1	15.8	20.9	10.0	2.7			

2. Trace Metals in the Water Column

Average Total Concentrations--

Average trace metal concentrations for Jamestown and New River area streams are presented in tables 13 and 14, respectively. Significant differences in mean concentrations between mined and reference sites were observed only for aluminum, cobalt, iron, and manganese in the Jamestown area, whereas significant differences were observed for all metals at the New River sites except for cadmium and chromium. Significant differences in metal concentrations were also observed between New River and Jamestown area reference site concentrations of aluminum, cobalt, chromium, nickel, lead, and zinc. Furthermore, concentrations of aluminum, chromium, nickel, and lead at the Bowling Branch reference site exceeded some of the New River mined site values. Most mean metal concentrations were, however, well below safe drinking water standards established by EPA (1976) at all sites. Iron and manganese were the only exceptions, exceeding the 300 µg/l and 50 µg/l respective standards at all sites except at Lowe Branch and LY0.4. However, these values were well within the guidelines established for mine effluent under the SMCRA. Increased area and contour mining did not, therefore, notably increase trace metal contamination since differences in metal concentrations between affected and unaffected sites were insignificant. Where significant differences were observed, they were usually less than drinking water guidelines and mine effluent limits.

Dissolved and Suspended Metal Concentrations--

The uptake and possible impacts of trace metals on the aquatic biota not only depend upon the concentrations of the metals but also their availability. Metals which become associated with free iron oxides or with the carbonate lattice of calcite and dolomite minerals do not tend to go into solution at high pH and thus are not readily available to biota (Perhac, 1974). Metals which are dissolved as ions, however, can travel across cell membranes of animal and plant species, and may cause harm or death.

The relative percentage of dissolved and suspended metal concentrations in Jamestown area streams are presented in table 15. By far the greatest quantity of each element occurred in the dissolved state. This is consistent with the findings of Perhac (1974) who also analyzed the metal contents of partitioned suspended particulates. Aluminum and iron were the only exceptions, each occurring most abundantly in the suspended fraction. As Perhac suggests, the low dissolved content of iron may reflect the ease with which the divalent

TABLE 13. MEANS, RANGES, AND STANDARD ERRORS OF TOTAL TRACE METAL CONCENTRATIONS OF JAMESTOWN AREA STREAMS. MEAN VALUES WERE CALCULATED FROM DATA COLLECTED BETWEEN 1975 AND 1979 AND ARE EXPRESSED AS μg/l

Metal		Station UTO.01	CC15.9	CC16.7	CC18.5	LYO.4	LB4.0
% mined		43	13	13	0	0	0
Al	mean	906.9	897.6	638.6	2382.3	413 3	514.4
	S.E.	251.8	203.3	212.5	1328.0	93.7	147.0
	range	120.0-4300.0	260.0-3500.0	100.0-3000.0	160.0-18000.0	60.0-1500.0	90.0-2600.0
As	mean	3.9	4.1	3.4	4.5	3.3	3.2
	S.E	0.7	0.6	0.5	0.8	0.5	0.5
	range	2.0-10.0	2.0-10.0	2.0-10.0	2.0-12.0	2.0-10.0	2.0-10.0
Cd	mean	1.2	1.1	1.1	1.1	1.0	1.0
	S.E.	0.2	0.1	0.1	0.1	0.0	0.0
	range	1.0-4.0	1.0-3.0	1.0-2.0	1.0-2.0	1.0-1.0	1.0-1.0
Co	mean	11.2	6.8	5.1	5.3	5.0	5.0
	S.E.	1.5	1.0	0.1	0.3	0.0	0.0
	range	5.0-26.0	2.0-16.0	5 0-6.0	5.0-9.0	5.0-5.0	5.0-5.0
Cr	mean	5.3	5.1	7.1	5.1	5.3	5.0
	S.E.	0.2	0.06	1.9	0.1	0.2	0.0
	range	5.0-9.0	5.0-6.0	5.0-33.0	5.0-6.0	5.0-8 0	5.0-5.0
Cu	mean	25.8	28.7	27.4	30.0	26.8	22.4
	S.E.	3.7	4.1	5.0	4 5	4.0	3.5
	range	8.0-110.0	5.0-110.0	8.0-130 0	7.0-100.0	6.0-110.0	5.0-120.0
Fe	mean	3394.1	1454.1	1198.4	2006.1	363.1	1024.4
	S.E.	414.0	120.0	162.9	455.3	93.0	198.4
	range	1200 0-15000.0	630.0-3400.0	200.0-4600.0	420 0-12000.0	50.0-3100.0	50.0-3900.0
Hg	mean	0 2	0 2	0.3	0.2	0.2	0.2
	S.E.	0.01	0.01	0 05	0.02	0.01	0.02
	range	0 2-0.4	0 2-0 4	0.2-0.1	0.2-0.5	0.2-0 4	0.2-0 5

(continued)

TABLE 13. (continued)

Metal		Station					
		UTO.01	CC15.9	CC16.7	CC18.5	LYO.4	LB4.0
Mn	mean	1114.8	477.1	357.1	134.8	30.3	143.2
	S.E.	84.7	73.1	97.1	11.7	5.8	38.6
	range	200.0-2000.0	90.0-2400.0	70.0-3100.0	70.0-380.0	10.0-200.0	10.0-1300.0
Ni	mean	50.0	50.0	50.0	-	50.0	50.0
	S.E.	0.0	0.0	0.0	-	0.0	0.0
	range	50.0-50.0	50.0-50.0	50.0-50.0	-	50.0-50.0	50.0-50.0
Pb	mean	10.9	10.7	11.2	11.8	10.6	10.6
	S.E.	0.6	0.6	0.8	0.8	0.4	0.4
	range	10.0-26.0	10.0-32.0	10.0-37.0	10.0-30.0	10.0-22.0	10.0-23.0
Se	mean	1.3	1.3	1.2	1.4	1.3	1.3
	S.E.	0.1	0.1	0.1	0.1	0.1	0.1
	range	1.0-2.0	1.0-2.0	1.0-2.0	1.0-2.0	1.0-2.0	1.0-2.0
Zn	mean	43.2	30.0	22.9	23.2	22.2	33.1
	S.E.	7.2	4.2	2.9	3.3	3.8	4.9
	range	10.0-230.0	10.0-110.0	10.0-80.0	10.0-90.0	10.0-100.0	10.0-170.0

TABLE 14. MEANS, RANGES, AND STANDARD ERRORS OF TOTAL TRACE METAL CONCENTRATIONS OF NEW RIVER AREA STREAMS. MEAN VALUES WERE CALCULATED FROM DATA COLLECTED BETWEEN 1975 AND 1979 AND ARE EXPRESSED AS μg/l

Metal		Station					
		Green Branch	Indian Fork	Bills Branch	Anderson Branch	Bowling Branch	Lowe Branch
% mined		24.1	18.9	9.0	7.5	0	0
Al	mean	1183.1	473.8	2572.4	782.7	1001.4	23.9
	S.E.	659.8	195.1	744.6	238.6	392.3	10.9
	range	0.0-77700.0	0.0-22110.0	0.0-80000.0	0.0-20080.0	0.0-50900.0	0.0-910.0
Cd	mean	0.1	0.3	0.3	0.2	0.4	0.1
	S.E.	0.03	0.1	0.1	0.0	0.2	0.0
	range	0.0-2.5	0.0-5.8	0.0-7.0	0.0-2.8	0.0-24.7	0.0-1.7
Co	mean	5.1	9.7	0.5	3.2	1.0	0.02
	S.E.	1.3	0.6	0.2	0.7	0.3	0.02
	range	0.0-70.0	4.0-47.0	0.0-12.6	0.0-35.1	0.0-20.1	0.0-1.4
Cr	mean	2.0	0.8	9.8	1.0	5.3	0.1
	S.E.	1.2	0.3	8.8	0.3	3.9	0.03
	range	0.0-140.0	0.0-29.0	0.0-1250.0	0.0-36.0	0.0-546.0	0.0-2.5
Cu	mean	15.0	7.8	12.1	4.8	4.7	2.4
	S.E.	3.5	0.9	2.9	0.6	1.2	0.5
	range	0.0-355.0	0.6-68.8	0.0-323.2	0.0-44.8	0.0-110.0	0.0-48.4
Fe	mean	4422.5	8125.7	2572.3	2552.4	1944.8	188.8
	S.E.	868.5	612.2	744.6	504.5	392.0	14.8
	range	0.0-64800.0	800.0-54000.0	0.0-80000.0	50.0-41000.0	11.0-41000.0	0.0-1000.0
Mn	mean	327.9	1010.1	90.1	99.0	52.9	4.1
	S.E.	24.7	53.3	16.9	12.6	12.5	1.5
	range	0.0-2500.0	50.0-3700.0	0.0-1760.0	0.0-790.0	0.0-1000.0	0.0-150.0

(continued)

TABLE 14. (continued)

Metal		Station					
		Green Branch	Indian Fork	Bills Branch	Anderson Branch	Bowling Branch	Lowe Branch
Ni	mean	20.4	21.8	4.5	4.5	7.1	0.7
	S.E.	5.2	1.6	0.9	0.9	1.9	0.3
	range	0.0-307.4	0.0-110.0	0.0-68.0	0.0-50.0	0.0-145.0	0.0-25.0
Pb	mean	3.2	0.2	5.6	1.6	1.6	0.4
	S.E.	1.1	0.1	3.1	0.5	0.5	0.3
	range	0.0-102.0	0.0-13.0	0.0-282.0	0.0-35.0	0.0-57.0	0.0-40.0
Zn	mean	33.1	37.2	21.5	17.8	12.0	0.7
	S.E.	7.3	2.3	8.2	3.8	3.5	0.3
	range	0.0-520.0	0.0-130.0	0.0-900.0	0.0-200.00	0.0-310.0	0.0-20.0

and reference sites were observed only for aluminum, cobalt, iron, and manganese in the Jamestown area, whereas significant differences were observed for all metals at the New River sites except for cadmium and chromium. Significant differences in metal concentrations were also observed between New River and Jamestown area reference site concentrations of aluminum, cobalt, chromium, nickel, lead, and zinc. Furthermore, concentrations of aluminum, chromium, nickel, and lead at the Bowling Branch reference site exceeded some of the New River mined site values. Most mean metal concentrations were, however, well below safe drinking water standards established by EPA (1976) at all sites. Iron and manganese were the only exceptions, exceeding the 300 µg/l and 50 µg/l respective standards at all sites except at Lowe Branch and LY0.4. However, these values were well within the guidelines established for mine effluent under the SMCRA. Increased area and contour mining did not, therefore, notably increase trace metal contamination since differences in metal concentrations between affected and unaffected sites were insignificant. Where significant differences were observed, they were usually less than drinking water guidelines and mine effluent limits.

Dissolved and Suspended Metal Concentrations--

The uptake and possible impacts of trace metals on the aquatic biota not only depend upon the concentrations of the metals but also their availability. Metals which become associated with free iron oxides or with the carbonate lattice of calcite and dolomite minerals do not tend to go into solution at high pH and thus are not readily available to biota (Perhac, 1974). Metals which are dissolved as ions, however, can travel across cell membranes of animal and plant species, and may cause harm or death.

The relative percentage of dissolved and suspended metal concentrations in Jamestown area streams are presented in table 15. By far the greatest quantity of each element occurred in the dissolved state. This is consistent with the findings of Perhac (1974) who also analyzed the metal contents of partitioned suspended particulates. Aluminum and iron were the only exceptions, each occurring most abundantly in the suspended fraction. As Perhac suggests, the low dissolved content of iron may reflect the ease with which the divalent form (Fe^{+2}) is oxidized to the more insoluble Fe^{+3} hydroxide. The solubility of aluminum reaches a minimum between high and low pH regions, especially if complexing species such as sulfate and silica are present (Hem 1970). This is the most likely explanation for the higher suspended aluminum fraction present at the mined and agricultural sites where pH is close to neutral. A higher dissolved fraction of aluminum was

TABLE 15 PERCENTAGE OF DISSOLVED OR SUSPENDED METAL CONCENTRATIONS IN JAMESTOWN AREA STREAMS

		Station											
		CC18.5		CC16.7		CC15.9		UT0.01		LB4.0		LB0.4	
Metal	Year	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Al	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	0.19	0.81	0.32	0.68	0.28	0.72	0.26	0.74	0.83	0.17	0.77	0.23
	1978	0.25	0.75	0.43	0.57	0.13	0.87	0.23	0.77	0.35	0.65	0.45	0.55
As	1976	0.82	0.18	-	-	0.93	0.07	-	-	0.94	0.06	0.94	0.06
	1977	-	-	-	-	-	-	-	-	-	-	-	-
	1978	-	-	-	-	-	-	-	-	-	-	-	-
Cd	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	-	-	-	-	-	-	0.88	0.13	-	-	-	-
	1978	-	-	0.88	0.13	-	-	-	-	-	-	-	-
Co	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	-	-	-	-	-	-	0.72	0.28	-	-	-	-
	1978	-	-	0.96	0.04	0.83	0.17	0.91	0.09	-	-	-	-
Cu	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	-	-	0.31	0.69	0.96	0.04	-	-	0.71	0.29	0.62	0.38
	1978	0.83	0.17	-	-	0.79	0.21	0.52	0.48	0.96	0.04	0.81	0.19
Fe	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	0.13	0.87	0.17	0.83	0.23	0.77	0.21	0.79	0.62	0.38	0.38	0.62
	1978	0.17	0.83	0.27	0.73	0.24	0.76	0.38	0.62	0.40	0.60	0.36	0.64
Hg	1976	0.99	0.01	-	-	-	-	-	-	0.88	0.12	-	-
	1977	-	-	-	-	-	-	-	-	0.92	0.08	-	-
	1978	-	-	-	-	-	-	-	-	-	-	-	-
Mn	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	0.73	0.27	0.74	0.26	0.88	0.12	-	-	0.74	0.26	0.66	0.34
	1978	0.79	0.21	0.80	0.20	0.94	0.06	0.94	0.06	0.93	0.07	0.79	0.21
Pb	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	0.85	0.15	0.99	0.01	0.99	0.01	-	-	0.81	0.19	0.96	0.04
	1978	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

Table 15. (continued)

Metal	Year	Station											
		CC18.5		CC16.7		CC15.9		UTO.01		LB4.0		LTO.4	
		Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended	Dissolved	Suspended
Se	1976	-	-	-	-	-	-	-	-	0.89	0.11	-	-
	1977	-	-	-	-	-	-	-	-	-	-	-	-
	1978	-	-	-	-	-	-	-	-	-	-	-	-
Zn	1976	-	-	-	-	-	-	-	-	-	-	-	-
	1977	0.55	0.45	-	-	-	-	-	-	0.81	0.19	-	-
	1978	0.67	0.33	0.53	0.47	0.94	0.06	-	-	0.50	0.50	0.53	0.47

form (Fe^{+2}) is oxidized to the more insoluble Fe^{+3} hydroxide. The solubility of aluminum reaches a minimum between high and low pH regions, especially if complexing species such as sulfate and silica are present (Hem 1970). This is the most likely explanation for the higher suspended aluminum fraction present at the mined and agricultural sites where pH is close to neutral. A higher dissolved fraction of aluminum was observed at the reference sites, most probably due to the much lower pH encountered there.

3. <u>Statistical Interdependence of Water Quality Parameters</u>

Pearson correlation coefficients (r) were calculated in order to explain the statistical interdependence of various water quality parameters analyzed. Calculations were made using the same SAS CORR procedure used in the overburden analysis. A list of significant correlation coefficients where $r \geq 0.5$ and $p \leq 0.001$ for Jamestown and New River area site water quality parameters is presented in tables 16 and 17.

Like the correlations between geochemical parameters, correlation coefficients between water quality parameters generally reflect similar geochemical behavior or lattice substitution by atoms or ions of similar atomic or ionic size or like ionic charge. The analyses revealed close association between the anions and cations of the common salts found in Cumberland Plateau strata. Calcium and magnesium concentrations were positively correlated with chloride, sulfate, and alkalinity. Manganese was also correlated with sulfate. Suspended solids, important in the transport of heavy metals, were correlated with the concentrations of heavy metals, notably Al, Fe, Co, and Cd at the Jamestown area sites and Cu, Fe, Ni, Pb, and Zn at the New River area sites. In addition, suspended solids were positively correlated with turbidity at the Jamestown and New River sites (r = .84 and .55, respectively). Minear and Tschantz (1976), observed that turbidity was not correlated with suspended solids and stated that turbidity measurements are unreliable as an index of suspended solids in stream water. Dissolved solids were also correlated with several metals at each site.

4. <u>Relationship of Stream Metal Concentrations to Lithology</u>

In order to compare stream and strata concentrations of metals, mean stream metal concentrations of a Jamestown and a New River mined and unmined site were plotted against overall mean strata concentrations of metals in Jamestown and New River area core samples (figure 31). Mean stream-to-strata concentrations of manganese, nickel, copper, and cadmium were higher relative to mean stream-to-strata concentrations of

TABLE 16. PEARSON CORRELATION COEFFICIENTS FOR JAMESTOWN AREA WATER QUALITY DATA ($|r| > 0.5$ $p < 0.001$)

Variable A	Variable B	r	Variable A	Variable B	r
pH	Alkalinity†	(.39)	Dissolved	Hardness	.66
	Fe(S)	(.26)	Solids	Ca(T)	.64
	Ca(T)	(.37)		Mg(T)	.58
				Al(S)	.57
Alkalinity	Cl	.68		Conductivity	.54
	Ca(T)	.65		Cl	.54
	Hardness	.64		Alkalinity	.53
	Na	.63		K	(.44)
	Total Inorganic			Fe(T)	(.35)
	Carbon	.57		Na	(.47)
	Conductivity	.56		Mn(T)	(.29)
	Dissolved Solids	.53		SO_4	(.42)
	K	(.40)		Mn(D)	(.40)
	Mg(T)	(.42)		Turbidity	(.31)
	Fe(T)	-		Suspended Solids	(.32)
	Fe(S)	(.38)		NO_2-NO_3	(.37)
	Turbidity	(.35)			
	Mn(T)	-	SO_4	Mg(T)	.77
	NO_2-NO_3	(.36)		Mn(D)	.73
				Mn(T)	.66
Acidity	Ni(S)	.69		Hardness	.61
				Al(S)	.57
Suspended	Al(S)	.93		NO_2-NO_3	.54
Solids	Turbidity	.84		Ca(T)	.52
	PO_4(T)	.81		Conductivity	.50
	Fe(S)	.80		Dissolved Solids	(.42)
	Fe(T)	.70		Mn(S)	(.44)
	Cd(D)	.70		Cl	(.39)
	Al(T)	.66		K	(.39)
	Total Organic			Zn(S)	-
	Carbon	.60		Na	(.32)
	N(Kjel.)	.59			
	Co(S)	.59	Cl	Na	.86
	K	.52		Ca(T)	.76
	Hardness	(.26)		Hardness	.75
	Ca(T)	(.26)		Conductivity	.74
	Cd(S)	(.47)		Al(S)	.73
	Conductivity	-		Alkalinity	.68
	Dissolved Solids	(.32)		Mg(T)	.57

(continued)

Table 16. (continued)

Variable A	Variable B	|r|	Variable A	Variable B	|r|
Cl (Continued)	K	.54	Fe(T)	Fe(S)	.88
	Dissolved Solids	.54		N(Kjel.)	.79
	PO_4(T)	.52		Turbidity	.77
	N(Kjel.)	.51		PO_4(T)	.74
	NO_2-NO_3	(.49)		Total Organic Carbon	.71
	Dissolved Oxygen	(-.30)		Suspended Solids	.70
	Fe(T)	(.46)		K	.68
	SO_4	(.39)		Cr(S)	.65
				Zn(S)	.63
Ca(T)	Hardness	.99		Al(S)	.60
	Cl	.76		Co(D)	.53
	Conductivity	.75		Mn(D)	.52
	Mg(T)	.72		Mn(T)	(.47)
	Na	.70		Hardness	(.37)
	Alkalinity	.65		Ca(T)	(.32)
	Dissolved Solids	.64		Dissolved Solids	(.35)
	K	.56		Mg(T)	(.45)
	SO_4	.52		Conductivity	(.34)
	Fe(T)	(.32)		Alkalinity	-
	Mn(T)	(.35)		Fe(D)	(.39)
	Mn(D)	(.32)		Al(T)	(.38)
	Al(S)	(.44)		Cl	(.46)
	Turbidity	-		NO_2-NO_3	-
	NO_2-NO_3	(.47)			
	Suspended Solids	(.26)	Fe(S)	Al(S)	.91
	Fe(S)	-		Turbidity	.89
	pH	(.37)		Fe(T)	.88
				Suspended Solids	.80
Mg(T)	Hardness	.82		CO(S)	.75
	SO_4	.77		Al(T)	.64
	Mn(D)	.75		As(D)	.62
	Mn(T)	.72		Dissolved Oxygen	-.60
	Ca(T)	.72		PO_4(T)	.55
	Conductivity	.70		Cd(S)	.53
	K	.62		K	.53
	NO_2-NO_3	.60		Pb(S)	.50
	Dissolved Solids	.58		Mn(T)	-
	Cl	.57		Total Inorganic Carbon	(.41)
	Co(T)	.51			
	Alkalinity	(.42)		Total Organic	
	Na	(.43)		Carbon	(.44)
	Fe(S)	-		Mn(D)	-
	Al(S)	-		Mg(T)	-
	Turbidity	-		Alkalinity	(.38)

(continued)

Table 16. (continued)

Variable A	Variable B	|r|
Fe(S) (Continued)	Hardness	-
	Ca(T)	-
	Cd(D)	-
	pH	-
	As(T)	(.45)
Fe(D)	Co(D)	.78
	Co(T)	.66
	Mn(T)	(.44)
	Fe(T)	.39
	Dissolved Oxygen	-
	Mn(D)	(.48)
Mn(T)	Al(S)	.99
	Mn(D)	.87
	Co(T)	.77
	Co(D)	.72
	Mg(T)	.72
	SO_4	.66
	Fe(T)	(.47)
	K	(.39)
	Conductivity	(.42)
	Fe(S)	-
	Hardness	(.45)
	Ca(T)	(.35)
	Dissolved Solids	(.29)
	NO_2-NO_3	(.44)
	Fe(D)	(.44)
	Alkalinity	-
	Turbidity	-
Mn(S)	Co(S)	.90
	Al(S)	.74
	SO_4	(.44)
	Conductivity	-
Mn(D)	Mn(T)	.87
	Zn(S)	.76
	Mg(T)	.75
	SO_4	.73
	Co(D)	.72
	Co(T)	.66
	N(Kjel.)	.64
	Fe(T)	.52
	K	.52
	Cr(S)	.51
	NO_2-NO_3	(.47)
	Conductivity	(.41)
	Hardness	(.43)

Variable A	Variable B	|r|
Mn(D) (Continued)	Ca(T)	(.32)
	Dissolved Solids	(.39)
	Fe(D)	(.48)
Total Organic Carbon	Cr(S)	.80
	PO_4(T)	.75
	Al(S)	.74
	K	.74
	N(Kjel.)	.72
	Fe(T)	.71
	Turbidity	.61
	Suspended Solids	.60
	Fe(S)	-
Total Inorganic Carbon	As(D)	.60
	As(T)	.60
	Alkalinity	.57
	Fe(S)	-
	Turbidity	-
N(Kjel.)	PO_4(T)	.87
	Fe(T)	.79
	Total Organic Carbon	.72
	Mn(D)	.64
	Co(D)	.63
	Suspended Solids	.59
	Cr(S)	.56
	K	.56
	Turbidity	.55
	Cl	.51
NO_2-NO_3	Mg(T)	.60
	Conductivity	.58
	SO_4	.54
	Hardness	.52
	Mn(D)	(.47)
	Mn(T)	(.44)
	Cl	(.49)
	Ca(T)	(.47)
	Na	(.44)
	Co(D)	-
	Dissolved Solids	(.37)
	Alkalinity	(.36)
	Fe(T)	-

(continued)

Table 16. (continued)

Variable A	Variable B	|r|	Variable A	Variable B	|r|
PO_4(T)	N(Kjel.)	.87	Co(S)	Al(S)	.78
	Suspended Solids	.81		Fe(S)	.75
	Turbidity	.78		Turbidity	.68
	Total Organic Carbon	.75		Suspended Solids	.59
	Fe(T)	.74	Co(D)	Co(T)	.92
	Cr(S)	.59		Mn(S)	.90
	Fe(S)	.55		Fe(D)	.78
	Cd(D)	.53		Mn(T)	.72
	K	.53		Mn(D)	.72
	Cl	.52		N(Kjel.)	.63
	Al(T)	(.49)		Fe(T)	.53
Al(T)	Zn(S)	.74		Total Organic Carbon	.80
	Al(S)	.72		K	.75
	Suspended Solids	.66		Fe(T)	.65
	Fe(S)	.64		PO_4(T)	.59
	Ni(S)	-.57		N(Kjel.)	.56
	Turbidity	.57		Turbidity	.53
	Cd(S)	.56		Water Temperature	(.47)
	Fe(T)	(.38)			
	PO_4(T)	(.48)			
			Ni(S)	Acidity	.69
Al(S)	Mn(T)	.99		SiO_2	.62
	Suspended Solids	.93		Se(T)	-.57
	Fe(S)	.91			
	PO_4(T)	.89	Pb(T)	Zn(S)	.85
	Turbidity	.89		Pb(D)	.76
	K	.80		Cd(S)	.58
	Co(S)	.78			
	Mn(S)	.75		Cd(T)	.74
	Total Organic Carbon	.74		Al(S)	.70
				Fe(S)	.50
	Cl	.73			
	Pb(S)	.70	Zn(S)	Pb(T)	.85
	Hg(T)	.62		Mn(D)	.76
	As(D)	.62		Al(T)	.74
	Dissolved Solids	.57		Fe(T)	.63
	Zn(S)	-		Al(S)	-
	Hardness	-		SO_4	-
	Ca(T)	-			
Co(T)	Co(D)	.92			
	Mn(T)	.77			
	Fe(D)	.66			
	Mn(D)	.66			
	Mg(T)	.51			

+T = Total; D = Dissolved; S = Suspended

TABLE 17. PEARSON CORRELATION COEFFICIENTS FOR NEW RIVER AREA WATER QUALITY DATA ($|r| > 0.5$ $p < 0.001$)

Variable A	Variable B	$\lvert r \rvert$
pH	Alkalinity	.57
	Ca(T)*	(.29)
	Ca(D)	(.29)
Alkalinity	pH	.57
	Ca(T)	(.35)
	Ca(D)	(.34)
	Mg(D)	(.33)
	Dissolved Solids	-
	SO_4	(.17)
Suspended Solids	Total Solids	.85
	Cu(T)	.82
	Fe(T)	.58
	Turbidity	.55
	Ni(T)	.53
	Pb(T)	.50
	Zn(T)	.50
Dissolved Solids	Co(D)	.72
	Total Solids	.70
	Ca(D)	(.41)
	Mg(D)	(.42)
	Ca(T)	(.40)
	SO_4	(.45)
	Mn(T)	(.47)
	Mn(D)	(.45)
	Fe(T)	(.29)
	Alkalinity	-
Turbidity	Ni(T)	.61
	Fe(T)	.60
	Suspended Solids	.55
	Cu(T)	.56
	Total Solids	.54
SO_4	Mn(D)	.92
	Ca(T)	.92
	Ca(D)	.91
	Mg(T)	.91
	Mg(D)	.90
	Mn(T)	.88
	Co(D)	.70
	Ni(D)	.66

Variable A	Variable B	$\lvert r \rvert$
Ca(T)	Ca(D)	.99
	Mg(T)	.96
	Mg(D)	.96
	SO_4	.92
	Mn(D)	.89
	Mn(T)	.84
	Co(D)	.72
	Ni(D)	.61
	Dissolved Solids	(.40)
	Alkalinity	(.35)
	Total Solids	(.18)
Ca(D)	Ca(T)	.99
	Mg(D)	.97
	Mg(T)	.97
	SO_4	.91
	Mn(D)	.89
	Mn(T)	.85
	Co(D)	.72
	Ni(D)	.63
	Dissolved Solids	(.41)
	Total Solids	(.21)
	Alkalinity	(.34)
Mg(T)	Mg(T)	.99
	Ca(D)	.97
	Ca(T)	.97
	SO_4	.91
	Mn(D)	.86
	Mn(T)	.84
	Co(D)	.67
	Ni(D)	.58
	Dissolved Solids	(.42)
	Total Solids	(.23)
	Alkalinity	(.34)
Mg(D)	Mg(T)	.99
	Ca(D)	.97
	Ca(T)	.96
	SO_4	.90
	Mn(D)	.86
	Mn(T)	.83
	Co(D)	.67

(continued)

Table 17. (continued)

Variable A	Variable B	|r|
Mg(D) (continued)	Ni(D)	.59
	Dissolved Solids	(.42)
	Total Solids	(.22)
	Alkalinity	(.33)
Fe(T)	Zn(T)	.71
	Ni(T)	.69
	Pb(T)	.63
	Mn(T)	.62
	Cu(T)	.60
	Turbidity	.60
	Co(T)	.58
	Suspended Solids	.58
	Total Solids	.58
	Mg(D)	(.33)
	Dissolved Solids	(.29)
Mn(T)	Mn(D)	.92
	SO_4	.88
	Ca(D)	.85
	Mg(T)	.84
	Ca(T)	.84
	Mg(D)	.83
	Co(D)	.72
	Ni(D)	.70
	Fe(T)	.62
	Co(T)	.53
	Total Solids	(.38)
	Dissolved Solids	(.47)
	Ni(T)	(.49)
Mn(D)	Mn(T)	.92
	SO_4	.92
	Ca(T)	.89
	Ca(D)	.89
	Mg(D)	.87
	Mg(T)	.87
	Co(D)	.80
	Ni(D)	.78
	Dissolved Solids	(.45)
	Fe(T)	(.38)
	Total Solids	(.22)
Co(T)	Ni(T)	.60
	Fe(T)	.58
	Mn(T)	.53
Co(D)	Ni(D)	.84
	Mn(D)	.80
	Dissolved Solids	.72
	Ca(T)	.72
	Mn(T)	.72
	Ca(D)	.72
	SO_4	.70
	Mg(T)	.67
	Mg(D)	.67
Cu(T)	Suspended Solids	.82
	Total Solids	.75
	Fe(T)	.60
	Turbidity	.56
	Pb(T)	.53
	Ni(T)	.52
Ni(T)	Fe(T)	.69
	Zn(T)	.62
	Turbidity	.61
	Co(T)	.60
	Total Solids	.58
	Suspended Solids	.53
	Cu(T)	.52
	Mn(T)	(.49)
Ni(D)	Co(D)	.84
	Mn(D)	.78
	Mn(T)	.70
	SO_4	.66
	Ca(D)	.63
	Ca(T)	.61
	Mg(D)	.59
	Mg(T)	.58
	Co(T)	.52
Pb(T)	Fe(T)	.63
	Zn(T)	.55
	Cu(T)	.53
	Suspended Solids	.50
Zn(T)	Fe(T)	.71
	Ni(T)	.62
	Pb(T)	.55
	Suspended Solids	.50

*T = Total; D = Dividend; S = Suspended

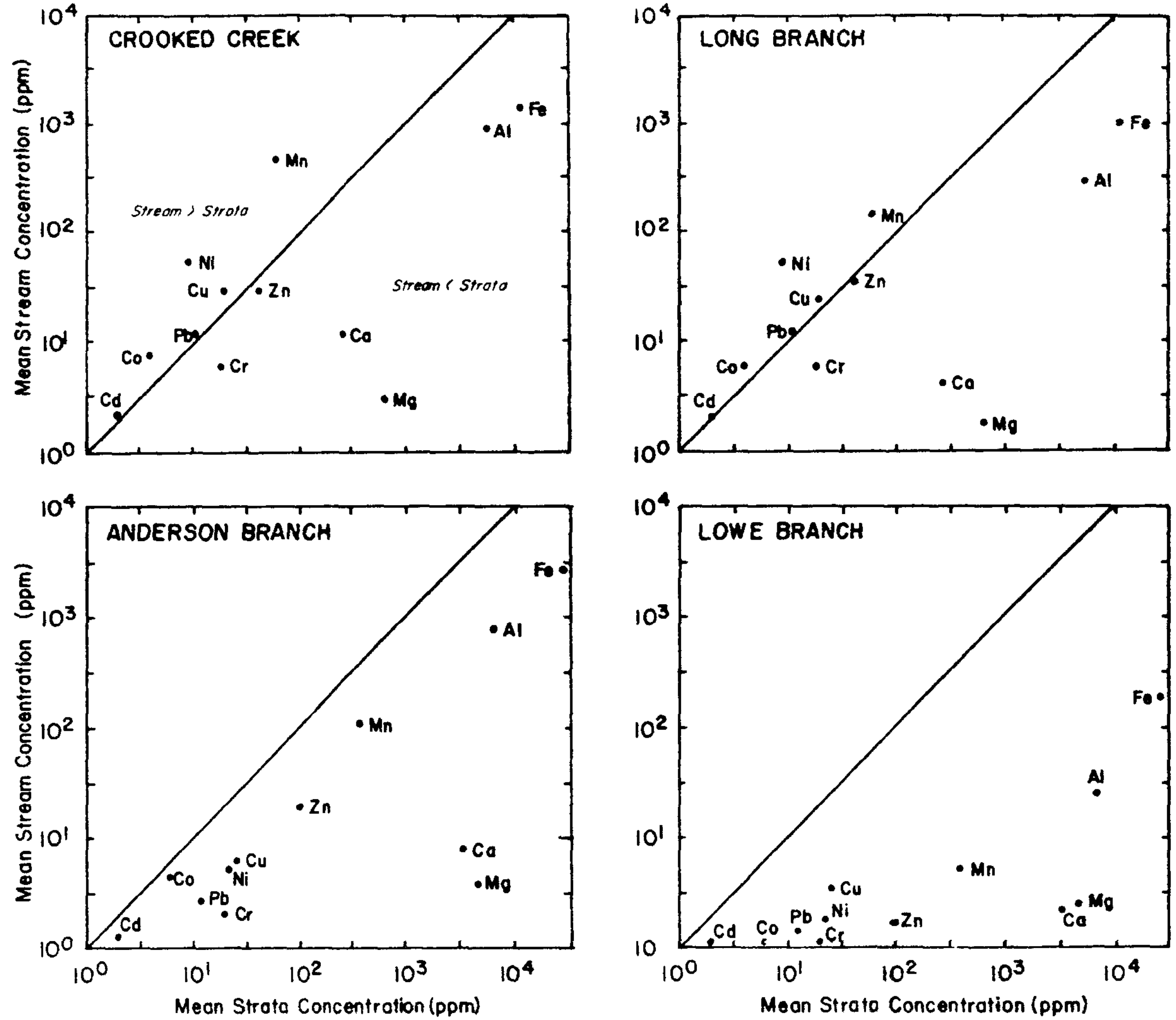

Figure 31. Plots of mean stream and mean strata concentrations of metals associated with Jamestown and New River area mined and unmined sites. Diagonal line represents points where stream concentrations equal strata concentrations.

aluminum, iron, calcium, and magnesium at all mined and unmined sites. Higher stream-to-strata concentrations for the former group of elements at Jamestown area sites are most likely due to the insensitivity of mean values in pinpointing isolated pockets of metal-producing minerals. Mean New River stream concentrations were much more depressed relative to strata concentrations than Jamestown area stream concentrations with no stream concentrations exceeding strata concentrations. Ratios of mean strata concentrations to mean stream concentrations (table 18) at mined sites were about 25 to 40 percent of the ratios of strata-to-stream concentrations of metals at unmined sites, indicating that larger quantities of metals were entering mine-impacted streams relative to uninpacted streams.

Furthermore, New River mined and unmined sites averaged 6 to 10 times the strata-to-stream ratios of Jamestown sites, indicating that proportionately greater quantities of metals were entering the water column at Jamestown sites.

Higher strata-to-stream ratios for individual elements may reflect solubility or mobility differences among the elements. A low strata-to-stream ratio would suggest a higher ion mobility or leaching rate for the element. Perhac (1974) compared the ion mobility of trace elements in the sediments and water columns of east Tennessee streams and concluded that zinc was the most mobile element followed by cobalt, iron, and manganese. The least mobile of the elements examined were copper and nickel. Akers (1978) established a scale of leaching rates based on the ratio of coal leachate metal concentrations to solid coal metal concentrations in which manganese and calcium leached the slowest. Williams (1977) studied the release of metals from Illinois-Basin coal processing wastes and observed that calcium and cobalt leached most rapidly from 4-day static leaching tests, while aluminum and lead leached the least. A comparison of the results of each of the above ion mobility and leaching rate studies to strata-to-stream concentration ratios obtained in this study are presented in table 19. Elements are listed from highest to lowest mobility or leaching rate. Study data agreed more closely with Williams' ranking, although disparity among the various analytical methods in the literature precludes any quantitative comparisons.

5. <u>Cluster Analysis</u>

Cluster analysis was performed on water quality data of Jamestown and New River area sites using the numerical taxonomic program, NT-SYS, developed by F. J. Rohlf, J. Nishpaugh, and D. Kirk. Yearly mean values of pH, alkalinity, suspended

TABLE 18. RATIOS OF MEAN STRATA TO MEAN STREAM METAL CONCENTRATIONS FROM NEW RIVER AND JAMESTOWN AREA SITES (MEAN STRATA CONCENTRATION/MEAN STREAM CONCENTRATION)

Jamestown Area

Metal	Mean Strata Conc. (ppm)	Mean Stream Conc. (ppm.)-CC15.9	Ratio	Mean Stream Conc. (ppm)-LB4.0	Ratio
Mn	56	447.0	0.12	143.2	0.39
Ni	8	50.0	0.16	50.0	0.16
Co	3	6.8	0.44	5.0	0.60
Cu	18	28.7	0.63	22.4	0.80
Cd	1	1.1	0.90	1.0	1.0
Pb	10	10.7	0.93	10.6	0.94
Zn	38	30.0	1.3	33.1	1.1
Cr	17	5.1	3.3	5.0	3.4
Al	5644	898.0	6.3	514.4	11.0
Fe	11037	1454.1	7.6	1024.4	10.8
Ca	272	10.4	26.2	3.0	90.7
Mg	651	2.0	325.5	0.8	814.0

New River Area

Metal	Mean Strata Conc. (ppm)	Mean Stream Conc. (ppm) Anderson Branch	Ratio	Mean Stream Conc. (ppm) Lowe Branch	Ratio
Co	5	3.2	1.6	0.02	250.0
Mn	388	99.0	3.9	4.1	96.6
Ni	21	4.5	4.7	0.7	30.0
Cu	24	4.8	5.0	2.4	10.0
Cd	1	0.2	5.0	0.1	10.0
Zn	98	17.8	5.5	0.7	140.0
Pb	11	1.6	6.9	0.4	27.5
Al	6724	783.0	8.6	23.9	281.3
Fe	30513	2552.4	12.0	188.8	2542.8
Cr	19	1.0	19.0	0.1	190.0
Ca	3418	6.2	551.3	1.2	2848.3
Mg	4570	2.8	1632.1	1.5	3046.7

TABLE 19. COMPARISON OF VARIOUS ION MOBILITY AND LEACHING RATE STUDIES FOUND IN THE LITERATURE TO STUDY DATA. ELEMENTS LISTED FROM HIGHEST TO LOWEST OBSERVED ION MOBILITY OR LEACHING RATE. ELEMENTS LISTED FOR THIS STUDY ARE FROM LOWEST TO HIGHEST STRATA TO MINED STREAM CONCENTRATION RATIOS

Literature				This study	
Hem (1970)	Williams (1977)	Akers (1978)	Perhac (1974)	Jamestown area	New River area
Na	Ca	Mn	Zn	Mn	Co
Mg	Co	Ca	Co	Ni	Mn
K	Ni	Mg	Fe	Co	Ni
Ca	Zn	Zn	Mn	Cu	Cu
Cd	Cd	Pb	Cu	Cd	Cd
Zn	Mn	Fe	Ni	Pb	Zn
Cu	Fe	Ni		Zn	Pb
Hg	Mg	Cu		Cr	Al
Co	Cu	Co		Al	Fe
Ni	Na	Al		Fe	Cr
Pb	Cr			Ca	Ca
Mn	Al			Mg	Mg
Cr	Pb				
Fe	K				
Al					

solids, dissolved solids, sulfate, total iron, total manganese, total calcium, total magnesium, total aluminum, dissolved cobalt, total copper, and total zinc were used to generate an unweighted pair-group arithmetic average (UPGMA) cluster of cophenetic correlations. The resultant UPGMA phenograms for Jamestown and New River area sites are presented in figures 32 and 33.

The Jamestown area sites were divided into two distinct groups, one containing all reference sites except for LB4.0 for 1978 and the other containing the heavily mined site UT0.01 for 1976 and 1977 and the agricultural site for all years sampled. Of the mined sites present in the first group, most represented the 1978 sampling year. Conversely, most of the mined sites in the second group represented the 1976 sampling year. Perhaps the second group represents immediate post-mining water quality conditions since mining at all Jamestown area-mined sites ceased in September of 1976. LB4.0 in 1978 would fit this group because of the mining taking place in the watershed beginning in June of 1978. Continuous runoff from the agricultural watershed possibly caused water quality conditions at CC18.5 to mimic post-mining water conditions.

New River area sites were grouped into three distinct groups again, depending on the year sampled and the presence of mining activity. The first group was dominated by the unmined sites and by Anderson Branch sampled in 1975 and 1976. Anderson Branch was, however, not affected by mining until early 1976 and so was most like the reference sites prior to this time. Bills and Green Branches for the 1975 sampling year were also in this group, but a reasonable explanation for their water qualities to reference sites cannot be offered. Most of the sites in the second group were mined sites sampled between 1977 and 1979, in addition to the Bowling Branch reference site sampled in 1978 and 1979. The third group consisted entirely of the Indian Fork site for all years sampled. Although most of the mined sites were present in the second and third groups, little distinction was evident between the degree of mining in the watershed. Much closer correlation was observed between sampling years for each site than for percent-mined watershed. For instance, Bills and Green Branches for sampling year 1979 were closely correlated despite their 9 and 24 respective percent-mined character. Bills and Green Branches were also correlated in decreasing magnitude for the 1975, 1978, 1976, and 1977 sampling years.

D. WATER QUALITY SUMMARY

A wide variety of physical and chemical parameters were measured at each of the Jamestown and New River sites to characterize water

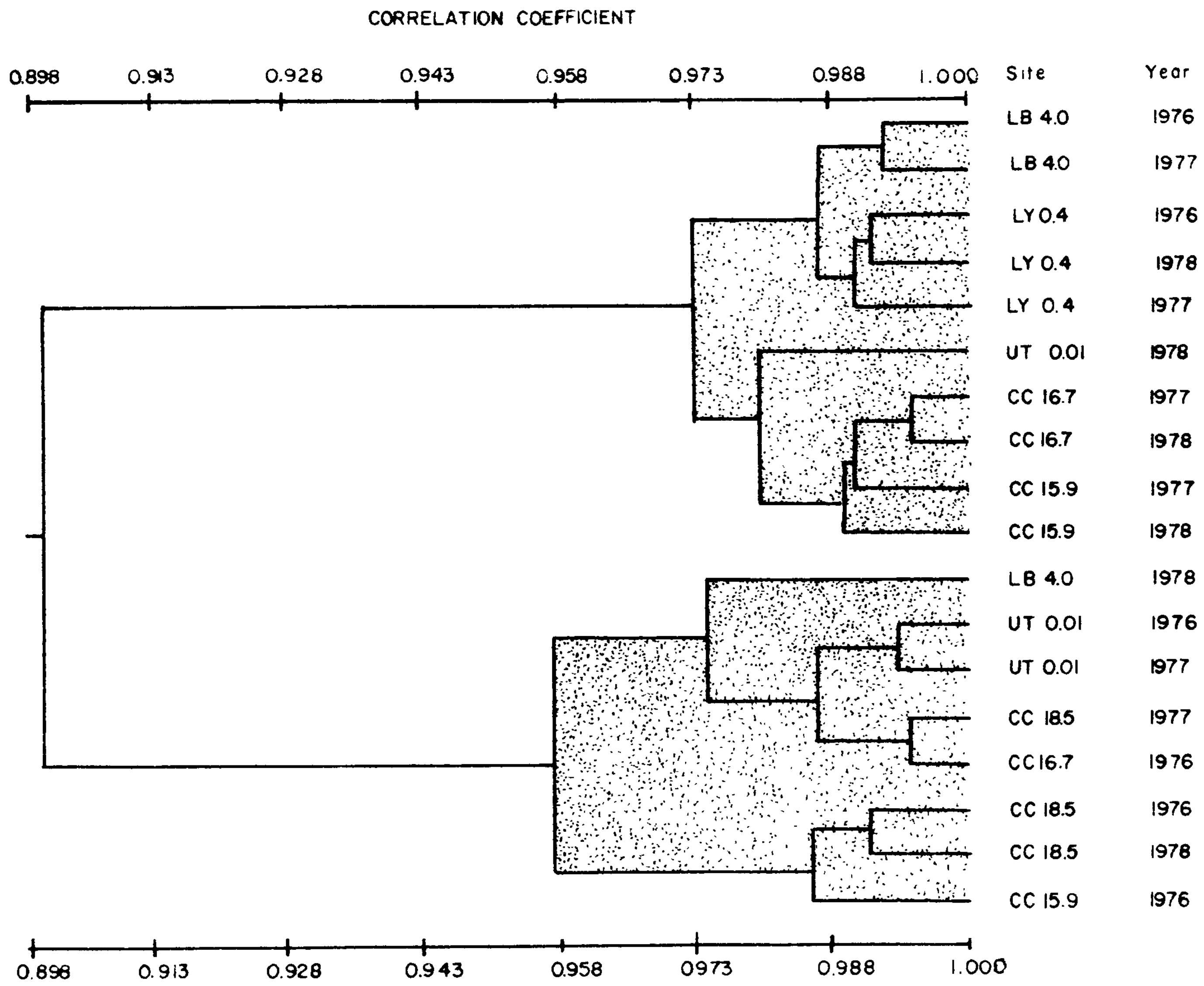

Figure 32 . Phenogram of UPGMA clustering of Jamestown area water quality data. Shaded areas are groups of closely related sites.

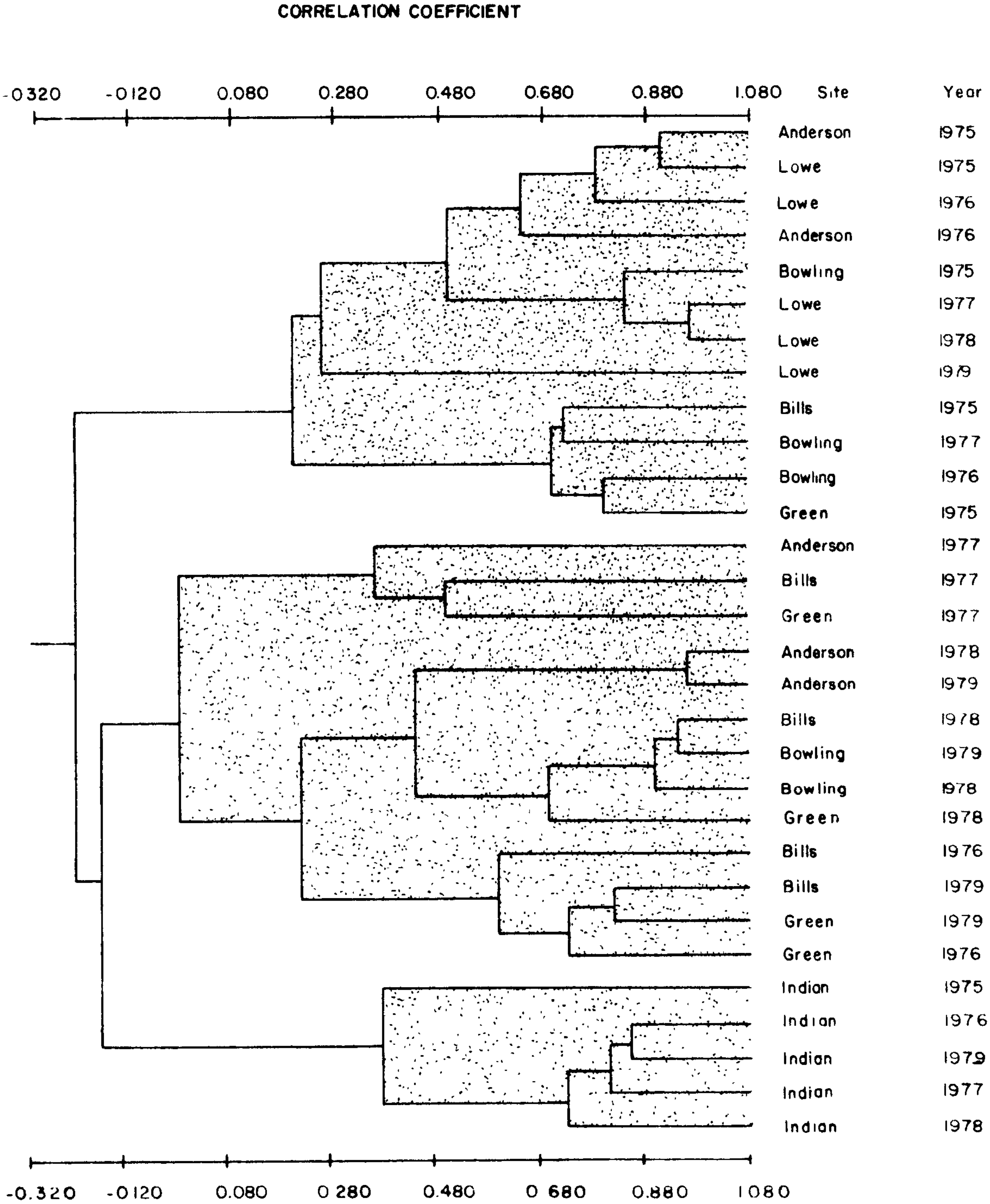

Figure 33. Phenogram of UPGMA clustering of New River area water quality data. Shaded areas are groups of closely related sites.

quality conditions unique to each site and to identify significant surface mining impacts. Values for pH and alkalinity confirmed earlier reports of the alkaline nature of the drainage in mined areas with average pH ranging from 6.2 to 7.0 Reference site mean pH values ranged from 4.4 to 6.2. Sixty-three percent of the monthly pH values at LB4.0, a reference site, were below the lower affluent limit of pH = 6 established by the Surface Mine Control and Reclamation Act of 1977 (SMCRA).

Mean alkalinity ranged from 11.5 mg/l $CaCO_3$ to 31.0 mg/l $CaCO_3$ at the mine sites, approximately three times higher than reference site alkalinity values.

Sulfate and iron concentrations were typically low at all sites except at Indian Fork, a New River site, where sulfate usually exceeded 250 mg/l. Total iron rarely exceeded the maximum effluent limit of 7 mg/l established under the SMCRA. Approximately 44 percent of the total iron values at Indian Fork, however, exceeded this limit. Manganese was also low at all sites ranging from 0.0 mg/l to 1.1 mg/l. These values are significantly lower than the 4.0 mg/l effluent limit established by the SMCRA.

Suspended solids were significantly higher at the mined sites. Mean values ranged from 23.9 to 32.5 mg/l at the area-mined sites and from 111.9 to 774.3 mg/l at the contour-mined sites. A value of 29,500 mg/l was recorded at the contour-mined site, Green Branch, the highest value observed during the study. Dissolved solids were also higher at mined sites in both areas, mean values ranged from 62.0 to 74.1 mg/l at the area-mined sites, while contour-mined sites ranged from 100 to 1221.2 mg/l dissolved solids. Eighty-two to ninety-six percent of the dissolved solids at the Jamestown sites were comprised of the four cations (Ca^{+2}, Mg^{+2}, Na^{+1}, and K^{+1}), three anions (HCO_3^-, SO_4^{-2}, and Cl^{-1}), and dissolved silica. Significant differences in the concentrations of these ions were observed between mined and reference sites.

Significant differences in mean metal concentrations between mined and reference sites were observed only for aluminum, cobalt, iron, and manganese in the Jamestown area, whereas significant differences were observed for all metals at the New River sites except for cadmium and chromium. Most mean metal concentrations were, however, well below safe drinking water standards established by EPA at all sites.

An analysis of the dissolved and suspended metal concentrations in Jamestown area streams revealed that the greatest quantity of each element occurred in the dissolved state. Aluminum and iron were the only exceptions, each occurring most abundantly in the suspended fraction.

Significant correlation was observed between the anions and cations of common salts found in Cumberland Plateau strata. Suspended solids were correlated with concentrations of Al, Fe, Co, and Cd at the Jamestown area sites and Cu, Fe, Ni, Pd, and Zn at New River sites.

Stream metal concentrations were compared to strata concentrations. Mean stream-to-strata concentrations of manganese, nickel, copper, and cadmium were higher relative to mean stream-to-strata concentrations of aluminum, iron, calcium, and magnesium at all mined and unmined sites. The analysis indicated that greater quantities of metals are entering mine-impacted streams especially area-mined sites.

Cluster analysis divided area- and contour-mined sites into distinct groups which generally represented either mined or unmined conditions. In addition, mined sites were correlated more by sampling year than by the degree of mining in the watershed.

CHAPTER V

HYDROLOGIC DATA

A. INTRODUCTION

A total of nine basins were gaged with streamflow and rainfall monitoring systems as a part of this study. Daily tabulations of these data are presented in appendix A. The hydrologic data are summarized and discussed in this section.

Rather than simply presenting the data, both the validity of the records and the extent to which the data are representative of the actual hydrologic processes will be evaluated. Because there is a paucity of relatively long-term continuous hydrologic information collected at mined watersheds, it may be assumed that these data will find use beyond this research project. Considering the current uncertainties regarding some of the impacts of mining, these data may be useful to researchers and decisionmakers in further evaluating the impacts of mining on the hydrologic balance. Since any conclusions which are drawn from an evaluation of these data could have far-reaching implications, it is important that all circumstances surrounding the collection and verification of these data be reported.

In addition, these data will be used in a later report to validate hydrologic models developed for land use planning (Betson et al. 1980). Model validation using data of questionable validity or which may be unrepresentative could lead to erroneous conclusions. The validity and representativeness of the data will be addressed in this section also.

Finally, considerable effort and expense are currently being expended on the collection of hydrologic data both at mine plan areas and throughout the coal provinces of the United States. The experiences encountered in the collection of these data and the extent to which the data have proven useful and have found application may be valuable in evaluating some of the current data collection activities.

B. NEW RIVER BASIN SITES

All six of the study streams listed in table 1 as contour-mined study sites were instrumented for hydrologic data collection. Figure 34 shows the location of these gaging stations within the New River Basin.

The U.S. Geological Survey (USGS) operated all of the hydrologic gaging stations in the New River Basin as part of a cooperative agreement between the USGS, TVA, and the University of Tennessee.

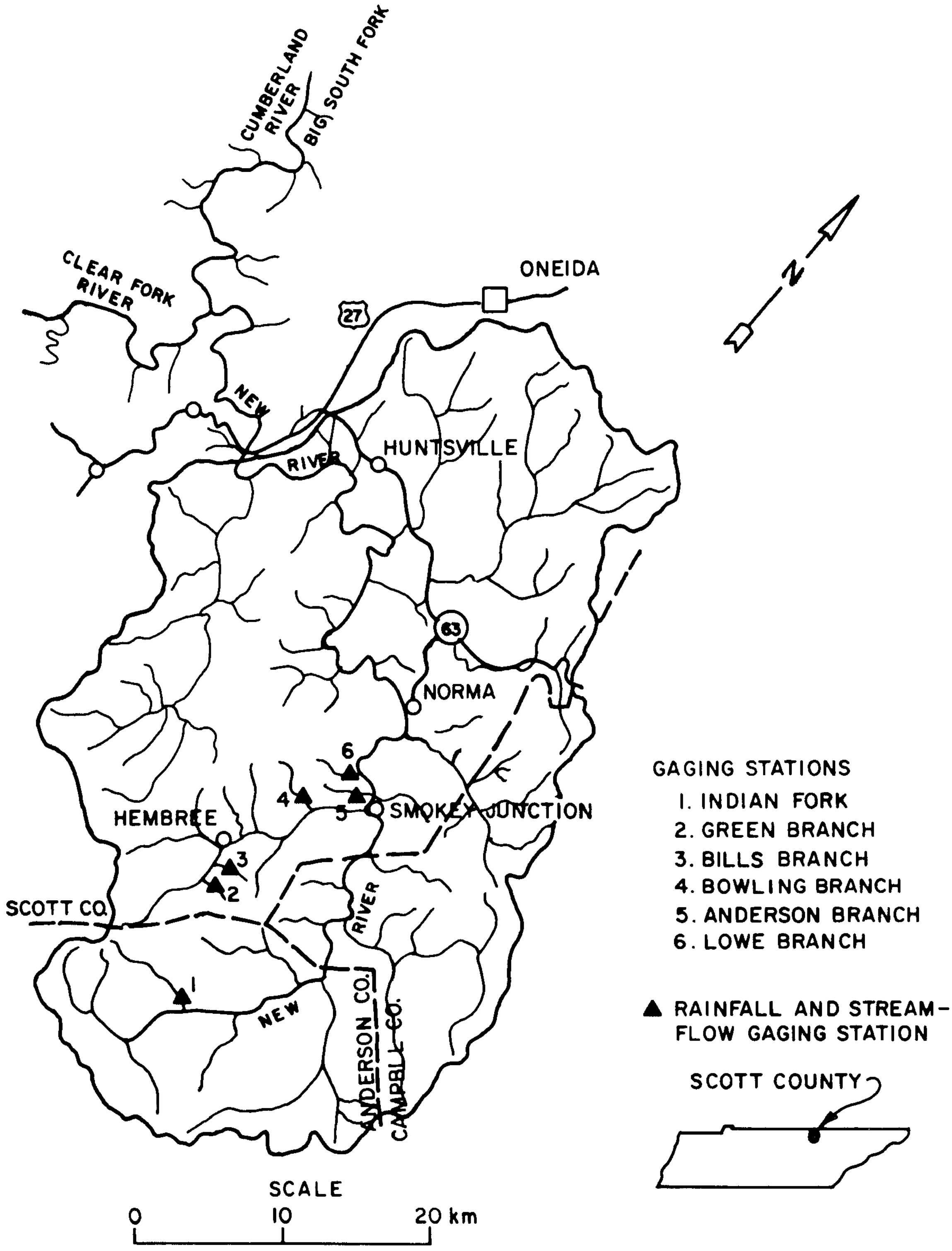

Figure 34: Contour–Mined Hydrologic Gaging Stations -- New River Basin

Each gaging station consisted of a stream control structure, a continuous stage recording device, and a continuous recording raingage. Table 20 presents a summary of the gaging station characteristics along with information about the extent of mining in the basin. Data collection began at each of the sites sometime during calendar year 1975. Figures 35 through 38 indicate the available project data for the period of study for both the New River Basin and the Fentress County sites.

Daily rainfall volumes in inches and mean daily flows in cubic feet per second (cfs) are presented in tables A-1 through A-36 in appendix A for each of the six stations. These data were obtained directly from the USGS or from USGS publications (USGS, 1978). An "e" associated with a tabulated value indicates that the number represents an estimated, or in some cases, an adjusted value. Cubic feet per second per square mile is abbreviated cfsm.

1. Rainfall Data Summary

Table 21 presents a summary of monthly rainfall volumes for water years 1976-1978 for the New River Basin sites. Long-term average rainfall in this area is about 55 inches (TVA 1969). Thus, of the three years of data, 1977 apparently represented a relatively dry year, while 1976 and 1978 appear to have represented near-average rainfall conditions.

Although the maximum distance between any of the gaging stations is only about 10 miles (from Lowe Branch to Indian Fork) the observed rainfall was found to vary considerably among stations as shown by the standard deviation values and comparison of the means presented in table 21. Some consistent patterns of the rainfall variation were fairly evident, however. Table 22 presents a comparison of basin aspect, gage elevation, and the percent of months of observed rainfall with monthly volumes less than the 6-station average. Basin aspect was fairly consistent and well defined for the smaller watersheds of Lowe, Anderson, Green, and Bills. Because of the size of the basins, however, aspect for Bowling and Indian represents more of an average than a true value.

From table 22 there is some indication that gage elevation may have influenced the rainfall catch. Average basin rainfall appears to have increased with increasing gage elevation. This would agree with other studies which have shown that average basin rainfall depths calculated from observations made at a single raingage located near the basin outlet regularly underestimate the actual basin rainfall (Eagleson 1970, p 195). It also appears that the measured rainfall

TABLE 20. SUMMARY OF GAGING STATION AND SITE MINING INFORMATION*, NEW RIVER BASIN SITES

Site	Latitude	Longitude	Drainage area (sq. mi.)	Gage elev. (ft. msl)	% mined	Dates of mining
Anderson Br.	36°18'34"	84°23'14"	0.81**	1240	7.5	3/76-3/77
Bills Br.	36°12'39"	84°24'19"	.67	1530	9.0	12/74-9/75
Bowling Br.	36°16'14"	84°24'17"	2.19	1350	0	Unmined
Green Br.	36°12'09"	84°24'59"	1.38	1440	24.1	72-9/75
Indian Fork	36°09'37"	84°23'15"	4.32	1460	18.9	52-present
Lowe Br.	36°19'04"	84°23'07"	.92	1250	0	Unmined

*Gaging station data from USGS, 1978.
**Presented as 0.69 sq. mi. in USGS, 1978; but as 0.81 in Minear, et al., 1978; 0.81 will be used in this report.

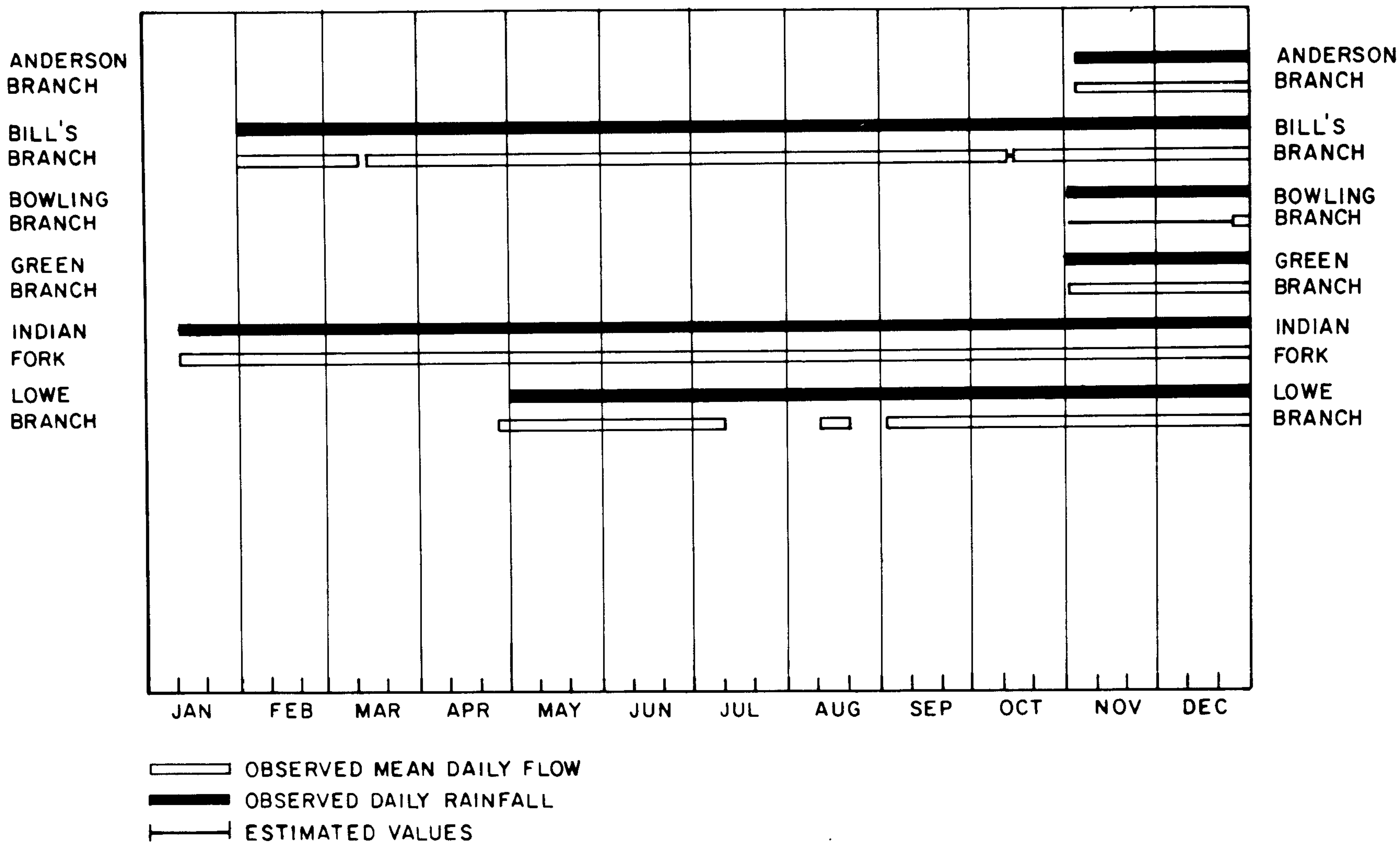

Figure [illegible] : Available Project Data for Calendar Year 1975

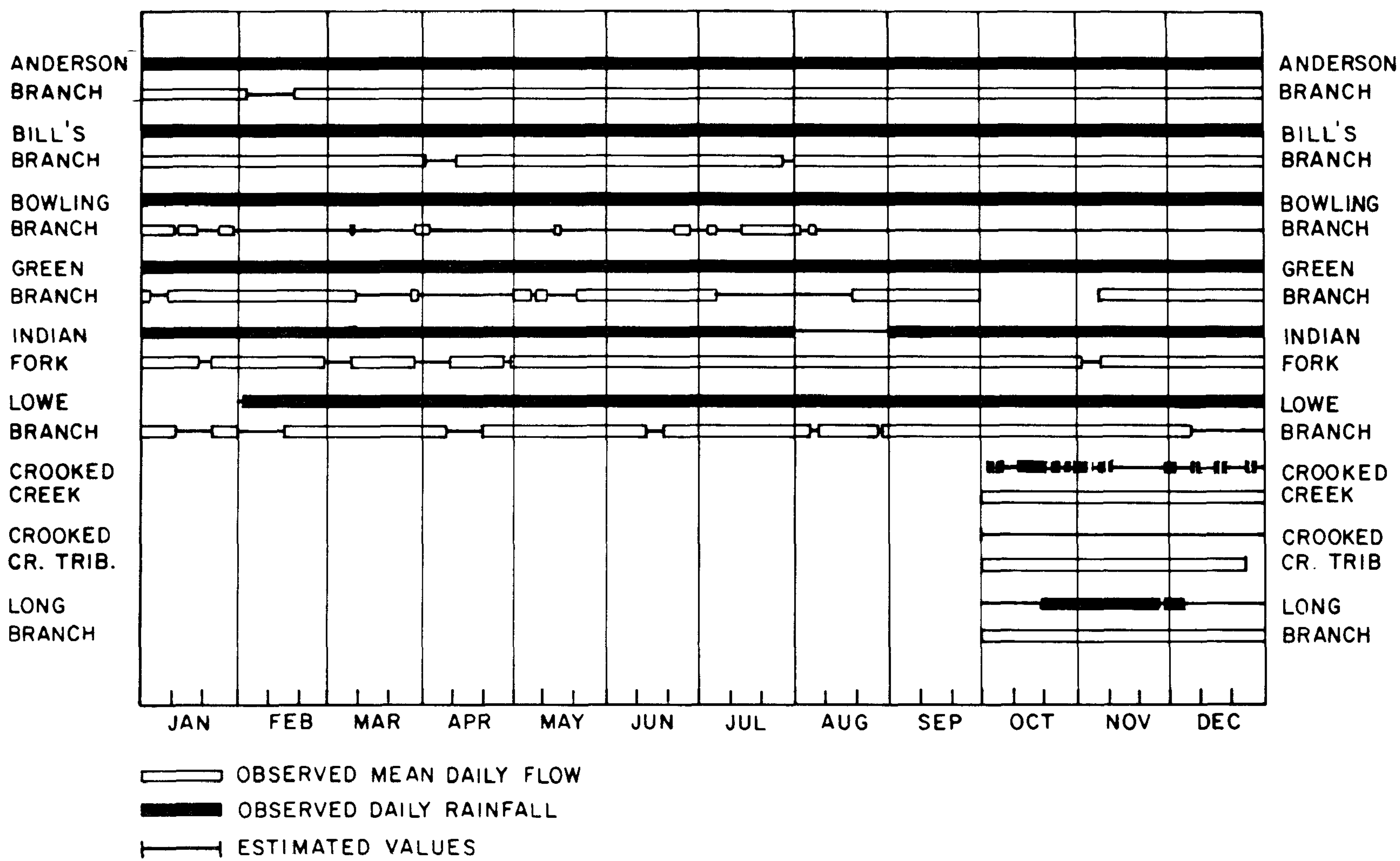

Figure : Available Project Data for Calendar Year 1976

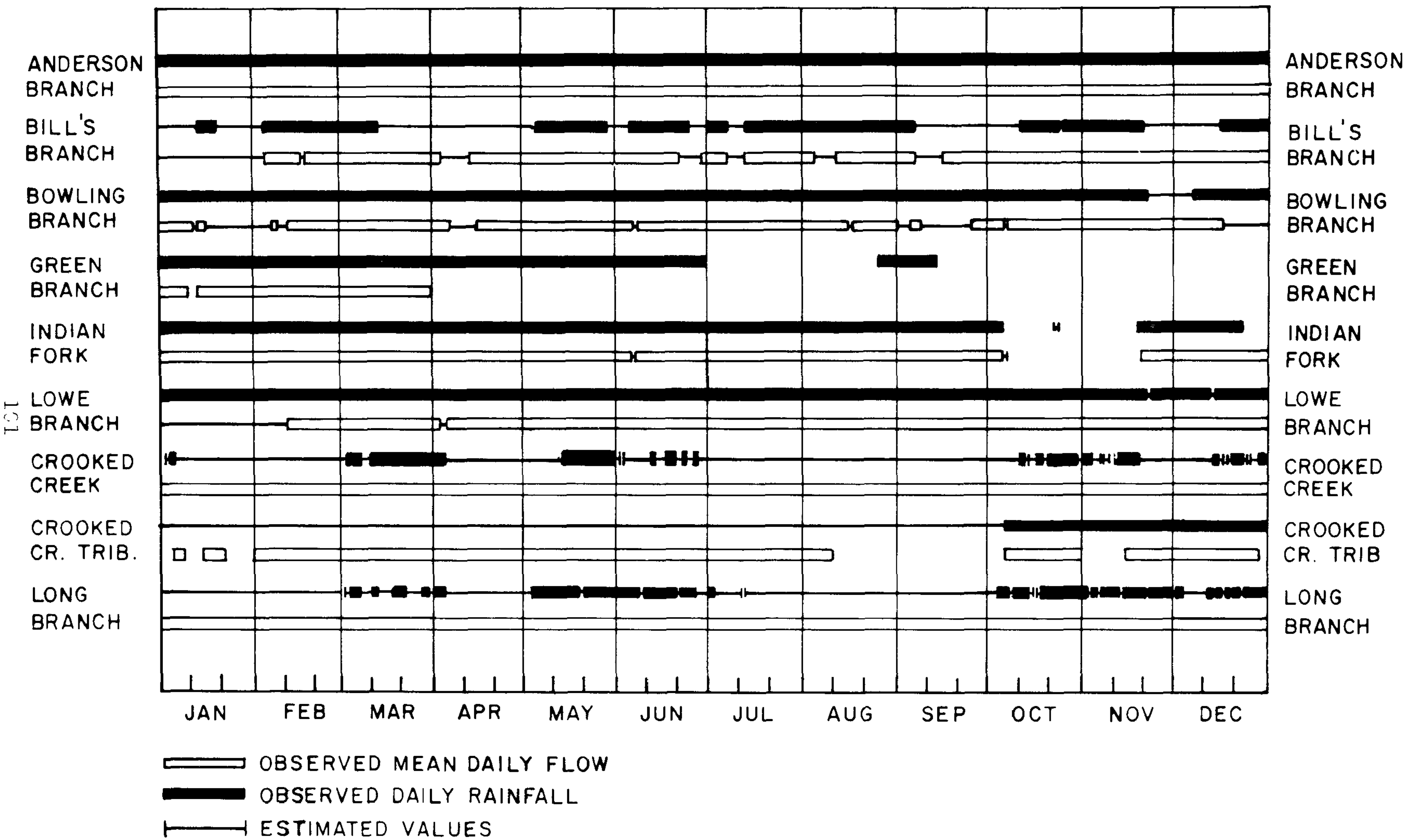

Figure : Available Project Data for Calendar Year 1977

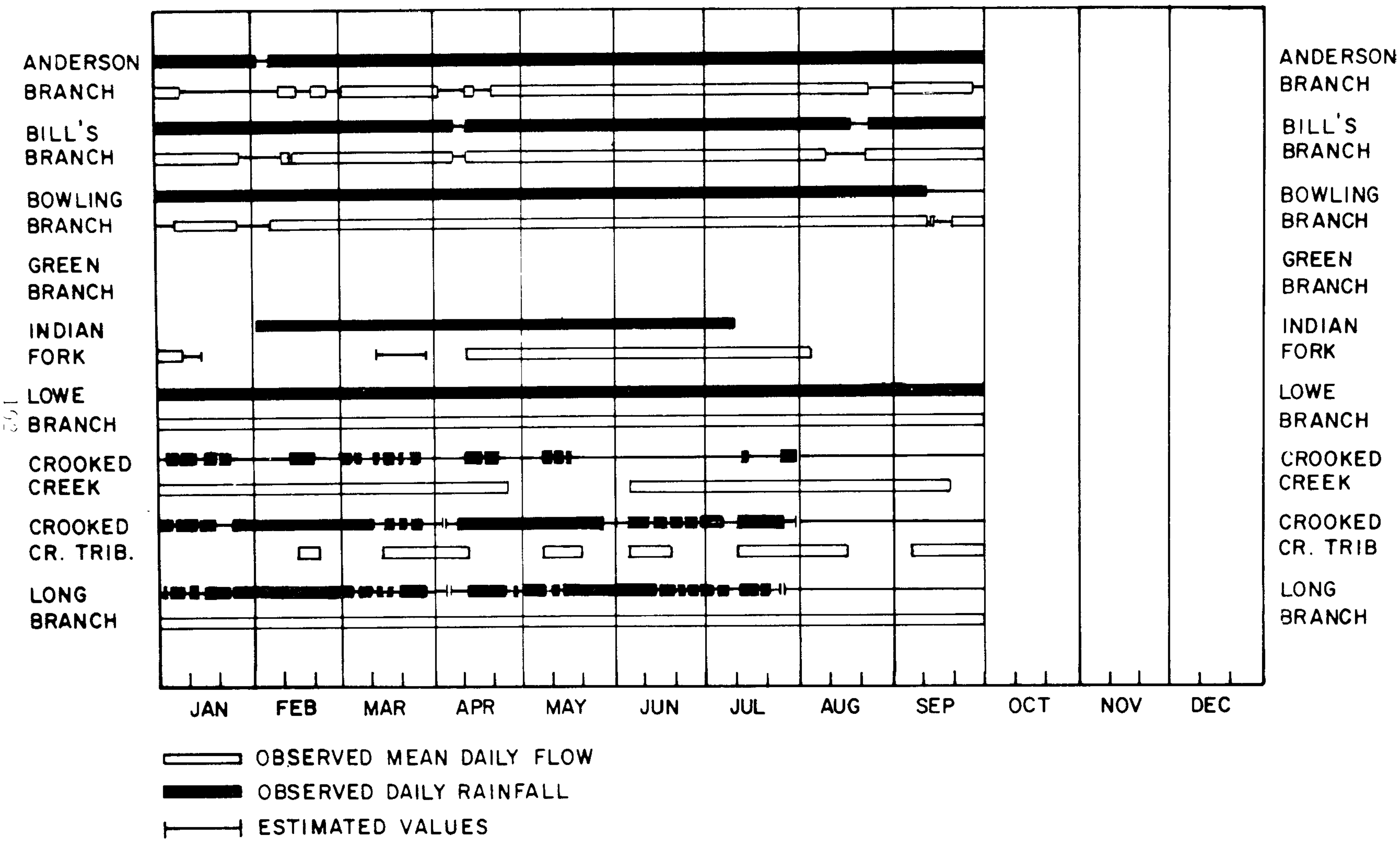

Figure 38: Available Project Data for Calendar Year 1978

TABLE 21. MONTHLY RAINFALL IN INCHES, WATER YEARS 1976-1978, NEW RIVER BASINS

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
					Water Year 1976								
Bowling	-	-	4.85	4.26	2.68	7.44	1.16	7.21	6.23	5.30	2.47	5.00	-
Lowe	4.35	4.33	3.48	3.88	2.74	6.23	1.17	5.70	5.73	4.81	1.50	3.99	47.64
Anderson	-	-	4.07	3.73	2.79	7.20	1.32	6.59	5.25	4.97	1.85	4.24	-
Bills	4.80	4.69	4.45	4.26	3.02	8.04	1.43	7.10	4.50	5.83	2.67	4.09	54.88
Indian	4.62	4.90	4.64	5.34	3.73	8.60	2.05	6.51	3.66	5.08	2.56	3.70	55.39
Green	-	-	4.29	5.00	3.05	8.08	1.33	7.60	4.13	6.59	2.89	3.06	-
Mean	4.59	4.64	4.30	4.41	3.00	7.60	1.41	6.78	4.92	5.43	2.32	4.01	52.64
Std. Dev.	.23	.29	.38	.63	.39	.84	.33	.67	.99	.67	.53	.64	4.33
					Water Year 1977								
Bowling	5.61	1.39	3.50	2.07	2.46	4.43	9.52	2.41	2.10	2.43	0.78	6.81	43.51
Lowe	4.41	1.06	3.55	1.43	1.93	3.00	6.89	2.09	6.16	1.77	2.61	5.47	40.37
Anderson	5.01	1.17	3.41	1.39	1.99	3.88	6.66	2.48	5.59	2.10	2.30	6.48	42.46
Bills	5.64	1.30	3.09	2.51	2.44	4.78	10.00	1.29	3.97	2.86	3.24	7.89	49.01
Indian	7.78	1.64	4.22	2.54	1.98	5.17	9.70	1.65	7.44	2.32	3.07	6.15	53.66
Green	6.19	1.85	3.45	3.01	2.49	5.71	10.71	1.89	3.70	-	-	-	-
Mean	5.77	1.40	3.54	2.16	2.21	4.50	8.91	1.97	4.83	2.30	2.40	6.56	45.80
Std. Dev.	1.16	.30	.37	.65	.27	.96	1.71	.46	1.93	.40	.98	.89	5.43
					Water Year 1978								
Bowling	5.35	9.05	4.10	5.27	1.53	3.74	4.08	5.01	3.72	5.32	6.97	1.20	55.34
Lowe	5.01	6.37	2.69	4.68	1.46	5.30	5.00	4.80	3.11	6.38	5.15	1.28	51.23
Anderson	5.64	7.70	3.08	5.08	1.51	3.73	3.44	5.97	3.93	7.86	6.30	0	54.25
Bills	5.30	9.36	4.67	4.14	.71	3.94	4.07	4.74	3.99	7.35	3.09	1.62	52.98
Indian	-	-	-	-	-	4.15	3.51	5.84	3.66	-	-	-	-
Mean	5.32	8.12	3.64	4.79	1.30	4.17	4.02	5.27	3.68	6.72	5.38	1.02	53.45
Std. Dev.	.26	1.37	.91	.50	.40	.65	.62	.59	.35	1.12	1.70	.71	1.77

TABLE 22. VARIATION OF MONTHLY RAINFALL, NEW RIVER BASIN SITES

Basin	Basin aspect	Gage elev.	Max basin elev.	Latitude	Percent*
Lowe	East	1250	2620	36°19'04"	78
Anderson	East-southeast	1240	2640	36°18'34"	68
Bowling	East	1350	2600	36°16'14"	44
Green	West-northwest	1440	3080	36°12'09"	37
Indian	South-southeast	1460	3260	36°09'37"	36
Bills	West-northwest	1530	3040	36°12'39"	36

*Percent of months of observed rainfall with monthly volumes less than the 6-station average.

generally increased from the northernmost (Lowe) to the southernmost basin (Indian).

Overall, it seems that the variation in rainfall amounts from station to station were larger than would be expected or could reasonably be attributed to real variations in the rainfall distribution. The difference in observed volumes between adjacent watersheds (Lowe-Anderson and Bills-Green) is particularly large for some months (March 1977) while for other months is quite close (February 1976). This only serves to emphasize the extreme difficulty in obtaining representative rainfall amounts from a single raingage located at the basin outlet of a mountainous watershed. As indicated by the amount of missing and estimated data shown in figures 35 through 38, occasionally it is difficult even to obtain any record of rainfall at all, other than from "nearby" gages which may be many miles away.

2. Flow Data Summary

Table 23 presents the observed monthly runoff volumes in inches for each of the six basins for water years 1976-1978. Basin yield in percent, (runoff/rainfall) x 100, is presented in table 24.

One of the most apparent conclusions which can be drawn from figures 35 through 38 and the data in tables A-1 through A-36 is that continuous flow record is very difficult to maintain. Figures 35 through 38 show several periods of missing data and indicate that much of the data is estimated or adjusted. Reasons for the missing and estimated data range from the mechanical or electrical failure of the stage recording device to sedimentation problems upstream of the control structure, to the formation of ice in the weir pool.

Evaluation of only the monthly runoff volumes in table 24 indicates for the most part, little that can be questioned. Two notable exceptions to this are the volumes recorded for Lowe and Indian in April 1977--these two observed volumes are quite obviously in error. One other unexpected result which is less apparent concerns the monthly runoff volumes for Bills. The sustained high volumes in the late summer and fall months indicate that either there may be some problems in the data or that something quite unusual is occurring on that watershed relative to the other basins. The considerable range among basins in annual totals for a given year also provides some indication that some of the observed runoff may not be representative.

TABLE 23. MONTHLY RUNOFF IN INCHES, WATER YEARS 1976-1978, NEW RIVER BASINS

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
					Water Year 1976								
Bowling	-	-	-	5.65	1.96	4.61	1.15	2.27	2.41	1.45	.07	.10	-
Lowe	-	3.06	2.38	2.87	1.59	3.94	.92	.95	1.20	-	-	.02	-
Mean	-	3.06	2.38	4.26	1.78	4.28	1.03	1.61	1.80	1.45	.07	.06	-
Anderson	-	-	-	3.86	2.16	5.18	1.19	1.79	1.75	1.65	.16	.16	-
Bills	2.61	4.46	4.35	7.34	4.01	7.54	1.62	3.03	1.21	3.18	1.14	.30	40.79
Indian	-	-	-	4.99	3.13	4.22	1.15	3.51	2.12	2.40	.37	.61	-
Green	4.33	4.24	4.05	5.37	2.81	5.33	1.30	2.47	1.70	2.07	.47	.31	39.88
Mean	3.47	4.35	4.20	5.39	3.03	5.57	1.32	2.77	1.70	2.32	.42	.46	40.33
					Water Year 1977								
Bowling	1.09	.49	2.64	1.83	2.05	3.38	4.78	.54	.50	.09	.05	.48	17.92
Lowe	.28	.16	1.87	1.38	1.16	1.89	15.02	1.73	.35	.01	.01	.14	24.00
Mean	.68	.32	2.26	1.60	1.60	2.63	9.90	1.14	.42	.05	.03	.31	20.96
Anderson	1.46	.60	2.21	1.53	1.52	2.68	7.85	.67	.71	.12	.11	.56	20.02
Bills	2.33	.76	2.77	1.37	2.25	3.72	8.70	.77	2.24	.29	.78	3.30	29.28
Indian	3.54	1.36	3.72	-	-	3.82	26.44	-	-	.48	-	-	-
Green	-	-	3.16	-	1.58	11.14	-	-	-	-	-	-	-
Mean	2.44	.91	2.96	1.45	1.78	5.34	14.33	.72	1.47	.30	.44	1.93	24.65
					Water Year 1978								
Bowling	1.87	8.62	3.44	5.70	1.13	3.95	1.93	2.85	.82	.28	.73	.07	31.38
Lowe	.62	3.90	1.81	3.39	.47	2.65	.86	1.65	.34	.07	1.14	.02	16.92
Mean	1.24	6.26	2.62	4.54	.80	3.30	1.40	2.25	.58	.17	.94	.04	24.15
Anderson	1.17	5.34	2.65	5.36	1.59	4.53	1.70	3.08	.94	.60	1.62	.06	28.64
Bills	4.66	8.01	4.60	11.23	1.49	6.46	2.06	1.79	.37	.32	1.41	.14	42.54
Indian	-	-	3.22	-	-	-	-	5.76	2.74	1.77	-	-	-
Mean	2.91	6.68	3.49	8.30	1.54	5.50	1.88	3.54	1.35	.90	1.52	.10	35.59

TABLE 24. PERCENT YIELD, WATER YEARS 1976-1978, NEW RIVER BASIN SITES

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
					Water Year 1976								
Bowling	-	-	-	133	73	62	99	31	39	27	3	2	-
Lowe	-	71	68	74	58	63	79	17	21	-	-	1	-
Mean	-	71	68	103	66	62	89	24	30	27	3	2	-
Anderson	-	-	-	103	77	72	90	27	33	33	9	4	-
Bills	54	95	98	172	133	94	113	43	27	54	43	7	74
Green	-	-	-	90	103	52	86	46	51	36	13	20	-
Indian	37	106	117	141	108	76	88	50	41	32	24	18	72
Mean	45	100	108	126	105	74	94	41	38	39	22	12	73
					Water Year 1977								
Bowling	19	35	75	88	83	76	50	22	24	4	6	7	41
Lowe	6	15	53	96	60	63	218	83	6	1	1	3	59
Mean	13	25	64	92	72	70	134	52	15	3	4	5	50
Anderson	29	51	65	110	76	69	118	27	126	6	5	8	47
Bills	41	58	90	54	92	78	87	60	56	10	24	42	60
Green	-	-	91	-	63	195	-	-	-	-	-	-	-
Indian	46	83	88	-	-	74	273	-	-	2	-	-	-
Mean	39	64	84	82	77	104	159	44	91	12	15	25	54
					Water Year 1978								
Bowling	35	95	84	108	27	106	47	57	22	5	10	5	57
Lowe	12	61	67	72	32	50	17	34	11	1	22	2	33
Mean	24	78	70	90	27	78	32	46	17	3	16	3	45
Anderson	22	26	86	106	106	122	49	52	24	8	26	85	53
Bills	88	86	98	271	210	164	51	38	9	4	46	9	80
Indian	-	-	-	-	-	-	-	99	75	-	-	-	-
Mean	55	56	92	188	155	143	50	63	36	6	36	47	66

If the monthly volumes for the unmined basins (Bowling and Lowe) are compared with the corresponding monthly averages for the mined basins (Anderson, Bills, Indian, and Green), superficially it might appear that surface mining dramatically increased the runoff. Table 23 indicates that the average runoff from the unmined watersheds was exceeded by the average runoff from the mined basins for 32 of the 35 months. Since rainfall also tended to be higher on the mined watersheds, however, the yield of runoff may be a better indicator of whether mining has had any real effects.

Monthly basin yields are summarized in table 24 and do indicate an apparent difference between the basin responses of the mined and unmined watersheds. But while the yield for the mined basins usually exceeded that for the unmined basins, the mined watershed yield often also exceeded 100 percent (runoff exceeded rainfall). While single months of greater than 100 percent yield do occur occasionally during winter months, consecutive months of greater than 100 percent yield are impossible in natural basins where snowmelt effects are insignificant. In addition, other months with unexpectedly high monthly yields were observed throughout the period of record at the mined watersheds. This includes the high yields observed at several basins for the late summer and fall months, particularly during the dry year of 1977.

An additional consideration in evaluating these data involves comparison of the expected and observed losses for these basins. It has been observed (Betson, et al., 1980) that the long-term average annual loss (rainfall minus runoff) in the region of this study is about 29 inches. Although in any given year the observed loss could be more or less because of differences in soil moisture storage; a comparison of the annual rainfall totals in table 22 and the annual runoff in table 23 indicates that most of the basin losses are much less than the expected 29 inches (Lowe 1978, is an exception). At all other basins, mined and unmined, the losses were between 3 and 19 inches less than the expected.

Although the losses for any basin during any given year cannot be compared directly with the 29-inch value, these consistently low-loss values in watersheds with forest cover and during years of fairly high rainfall indicate that the data may not be representative. Measured rainfall may be low or runoff volumes too high, or both. In any case, however, it would be difficult to attribute the high yields experienced at Bills Branch to mining on only 10 percent of the watershed since the remainder of the basin was unaffected by the mining.

In summary, there are several indications that at least some of the data are in error and that there may also be unrepresentative data included in the observations. Among the indications of possible problems are: (1) consecutive months of greater than 100 percent basin yield; (2) unrealistically high values of basin yield during typically dry months; (3) relatively high yields during the dry year of 1977; (4) a significant difference between the observed and the long-term average annual losses; and (5) the fact that many of the rainfall and streamflow values were estimated or adjusted. Consequently, any future use and interpretation of these data must be done with caution.

C. FENTRESS COUNTY SITES

Of the six area-mined sites listed in table 1, only three were instrumented for hydrologic data collection: Long Branch (LB4.0), Crooked Creek (CC15.9), and Crooked Creek Tributary (or Unnamed Tributary-UT0.01). These sites are shown in figure 39.

Gaging stations in Fentress County were also operated by the USGS and were similar to the stations in the New River Basin. Table 25 presents a summary of gaging station chracteristics along with information about the extent of mining in the basin. Available project data collected at the gaging stations are presented in tables A-37 through A-48. These data were obtained directly from the USGS or from published sources (USGS 1978).

1. Rainfall Data Summary

As shown in figures 35 through 38, almost all of the rainfall data for these three sites was estimated from nearby gages. Thus, any real variation in rainfall among the three stations cannot be realistically determined. Table 26 presents monthly summaries of the rainfall at the three stations for water years 1977 and 1978. The fact that most of the data were estimated is reflected in the small variation in the monthly totals among the three stations. Average annual rainfall for this region is also about 55 inches (TVA 1969).

2. Flow Data Summary

Monthly runoff volumes for the three Fentress County sites are given in table 27 and percent yields are summarized in table 28. There was no complete month of observed data at Crooked Creek Tributary for water year 1978, thus its omission from the table. Figures 35 through 38 show that the flow record at the Fentress County sites was fairly continuous, with the exception of the Crooked Creek Tributary site.

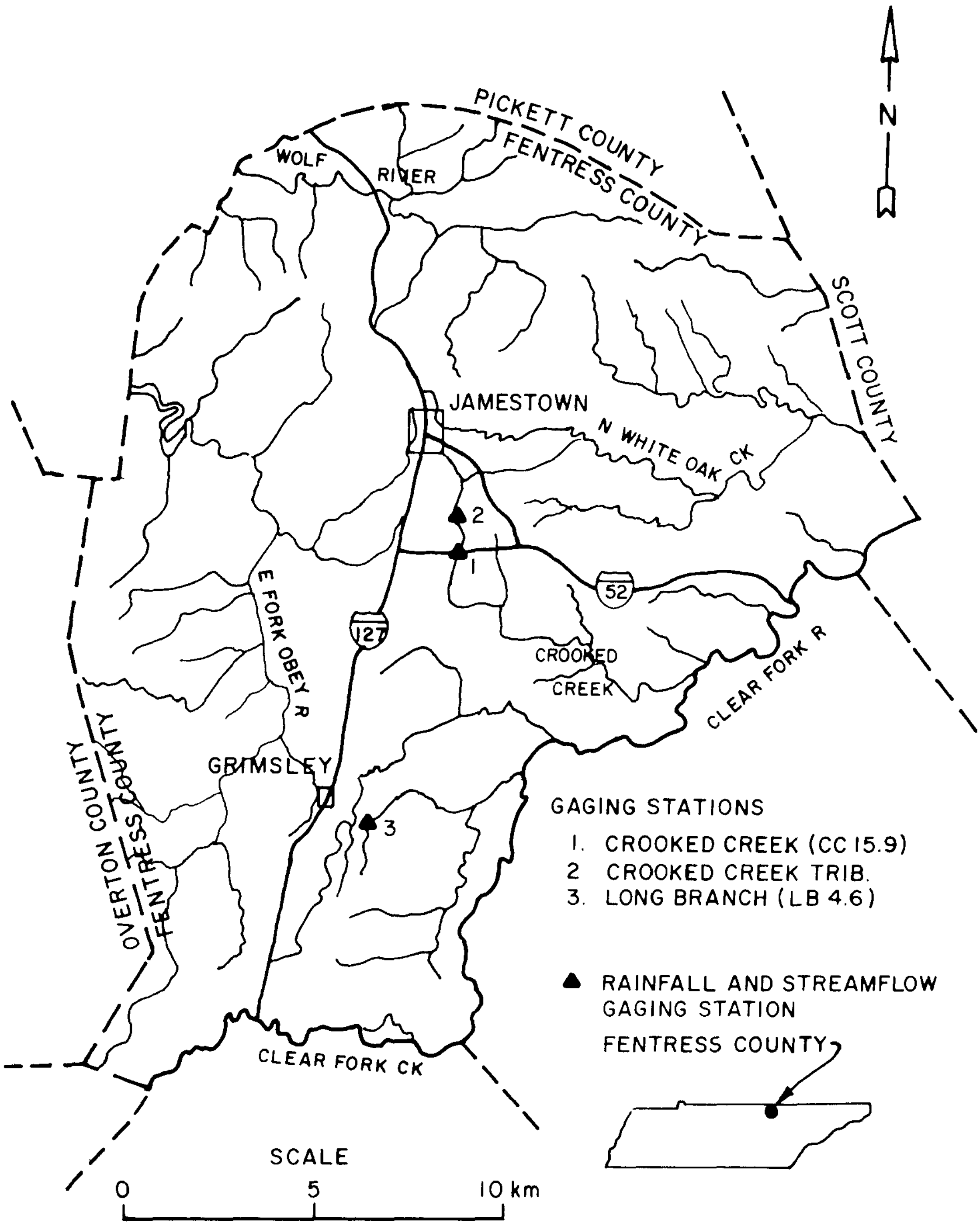

Figure 39 Area-Mined Gaging Stations--Fentress County, TN

TABLE 25. SUMMARY OF GAGING STATION AND SITE MINING INFORMATION*, FENTRESS COUNTY SITES

Site	Latitude	Longitude	Drainage area (sq. mi.)	(ft. msl)	% mined	Dates of mining
Crooked Cr. (RM 15.9)	36°22'59"	84°54'50"	3.62	1600	13	4/75-9/76
Crooked Cr. Trib	36°23'30"	84°54'43"	.25	1630	43	9/75-9/76
Long Branch	36°15'32"	84°57'40"	1.11	1670	0	Unmined

*Gaging station data from USGS, 1978.

TABLE 26. MONTHLY RAINFALL IN INCHES, WATER YEARS 1977-1978, FENTRESS COUNTY SITES

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
						Water Year 1977							
Long	5.82	1.53	2.97	2.54	1.95	4.59	8.94	2.05	6.45	4.51	4.10	6.65	52.10
Crooked	7.37	1.55	3.10	2.86	2.16	5.24	9.48	1.99	6.46	4.38	3.99	6.88	55.46
Crooked Trib	7.13	1.41	2.69	2.77	2.12	4.86	9.29	2.03	6.42	4.58	3.97	7.20	54.47
Mean	6.77	1.50	2.92	2.72	2.08	4.90	9.24	2.02	6.44	4.49	4.02	6.91	54.01
Std. Dev.	.83	.08	.21	.16	.11	.33	.27	.03	.02	.10	.07	.28	1.73
						Water Year 1978							
Long	4.08	6.55	3.74	5.43	1.72	3.86	3.14	4.27	3.14	8.37	3.40	2.24	49.94
Crooked	3.62	6.86	3.76	5.28	2.22	4.33	3.46	4.39	3.05	8.30	3.40	2.19	50.86
Crooked Trib	3.97	6.03	3.62	5.43	1.84	4.17	2.94	4.11	3.96	8.99	3.25	2.23	50.54
Mean	3.89	6.48	3.71	5.38	1.93	4.12	3.18	4.26	3.38	8.55	3.35	2.22	50.45
Std. Dev.	.24	.42	.08	.09	.26	.24	.26	.14	.50	.38	.09	.03	.47

TABLE 27. MONTHLY RUNOFF IN INCHES, WATER YEARS 1977-1978, FENTRESS COUNTY SITES

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
						Water Year 1977							
Long	0.27	.33	1.56	2.15	1.15	4.26	7.21	0.83	0.47	0.06	0.00	1.04	19.33
Crooked	1.87	.60	1.32	1.29	1.24	2.93	5.83	.67	1.26	.72	.40	2.03	20.16
Crooked Trib	1.80	.91	-	-	2.51	2.60	4.90	1.15	1.52	1.52	-	-	-
Mean	1.84	.76	1.32	1.29	1.88	2.76	5.36	.91	1.39	1.12	.40	2.03	20.16
						Water Year 1978							
Long	2.75	3.88	3.11	3.59	1.62	3.16	.92	2.63	.42	.50	.24	.06	22.88
Crooked	1.99	4.17	3.09	3.74	1.74	3.84	-	-	-	2.46	.66	-	-

TABLE 28. PERCENT YIELD, WATER YEARS 1977-1978, FENTRESS COUNTY SITES

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
						Water Year 1977							
Long	5	22	52	85	59	93	81	40	7	1	0	16	37
Crooked	25	39	42	57	56	61	34	20	16	10	30	36	
Crooked Trib	25	64	-	-	118	53	53	57	24	33	-	-	-
Mean*	25	52	42	45	88	54	57	46	22	24	10	30	36
						Water Year 1978							
Long	67	59	83	66	94	82	29	62	13	6	7	3	46
Crooked	55	61	82	71	78	87	-	-	-	30	19	-	-

*Mean is for mined basins, Crooked and Crooked Trib.

Evaluation of the data in tables 27 and 28 indicates no distinct difference between the mined and unmined sites. There is no apparent consistent pattern of higher runoff volumes or yields at the mined or unmined stations. The existence of missing or estimated data complicates the problem of analysis. It does appear, however, that in contrast with the New River Basin sites, these flow data are more nearly what would be expected. The problems of excessive runoff volumes and yields, and of lower than expected losses are not present in these data.

D. SUMMARY

The difficulty in obtaining continuous, representative hydrologic data in remote areas cannot be overemphasized. The hydrologic data gathered throughout this study were collected by the USGS, the largest and most experienced hydrologic data collection organization in the nation. Yet for a variety of reasons there are numerous instance of either missing or estimated records.

Several factors contributed to the problem of collecting continuous and representative data. Because these study sites were remote, access was difficult, time consuming, and costly. As a result, automatic data recorders were used and gaging equipment was only serviced on approximately a monthly basis. Thus if the equipment should malfunction, as much as a complete month of record could be lost. The harshness of the environment also caused problems. The formation of ice in the weir pool was a persistent problem in the winter, the high runoff season. The ice then prevented the stage recorder float from operating properly. High loads of sediment and other debris also caused problems. Sedimentation upstream of the control structure affected the stage-discharge rating while the impact of stones, tree limbs, and other debris affected the integrity of the control structure. While more frequent servicing of the equipment would not have eliminated these problems, the long periods of missing or questionable records may have been avoided.

As was shown in the analysis of the New River Basin data, an evaluation of the relationship between rainfall and streamflow is a prerequisite to evaluating and interpreting the streamflow data. The flow data collected throughout this study were published in the usual manner of tabular values of mean daily flow without any presentation of associated rainfall. If these published data were to be interpreted in the absence of the unpublished rainfall data, some dramatic but quite unsound conclusions might be reached regarding the effects of mining on runoff volumes. Rainfall data collected within the basin are a necessity when evaluating the effects of land-use change on the hydrologic balance in basins with relatively small drainage areas. In systems terminology, the output from a system tells nothing about the operation of the system unless the system input is known.

Under PL 95-87, increasing amount of hydrologic data are being collected both for permit applications and to assess the cumulative impacts of mining in a region. From the experiences of this study, it may be anticipated that these data will be very difficult to interpret and evaluate for two reasons. First, it can be assumed that many of these data, particularly those for permit applications, will be collected with less-than-adequate quality control. As was shown here, it is difficult to ensure the adequacy of data collected even under research conditions. Secondly, the basin response can only be evaluated to the extent that it is represented in the data, i.e., extrapolation of the data to conditions other than those under which the data were collected will be very difficult. Thus if the data were used in an evaluation of the probable hydrologic impacts of mining on the hydrologic balance of a basin, the analysis would be based on only a very small sample of the complete hydrologic regime of the watershed. The use of hydrologic models in conjunction with available data would seem to offer some advantage over a simple analysis and interpretation of the data.

Hydrologic models can be used to stimulate continuous long-term hydrologic information for a variety of land-use conditions. Only a small amount of site-specific data is required to calibrate and verify hydrologic models, which can then be used to simulate with a fair amount of confidence. Because models can be used to simulate the basin hydrology under any number of land-use conditions, the simulation results may be used both to understand the basin response and to predict the probable hydrologic consequences of a proposed land-use change.

It seems, then, that while the collection of continuous long-term streamflow is certainly a necessity, greater emphasis should be placed on the collection and publication of streamflow and associated rainfall records. This is particularly true for short-term stations so that data can be used for model development and calibration to better assess the effects of land use change. Data collection is becoming increasingly expensive, while at the same time cost-effective means for maintaining environmental quality are increasingly emphasized. The use of hydrologic models to help determine the impacts of land-use change can significantly aid in the cost-effective management of the Nation's resources.

CHAPTER VI

BENTHOS

A. INTRODUCTION

According to Hynes (1970), it is now extremely difficult and probably quite impossible to find any stream which has not been altered in some way by human activity. The streams in the Cumberland Plateau are no exception. Since the days of the early settlers, Cumberland Plateau streams have been subject to increasing human pressures.

Coal mining, as was mentioned previously, began early in the history of the region. It has only been during the latter half of this century that surface mining has had a significant impact to the environment, most notably because of the tremendous increase in land area affected.

More mining means that more stream habitats will be affected. Siltation, acid or alkaline mine drainage, increased flow rates, and reduced canopy are only a few of the changes which are sited as significant impacts due to surface mining.

In order to record changes in stream habitats as well as the benthic community, a one-year study was undertaken at the Jamestown sampling sites. Emphasis was placed on quantitative as well as qualitative differences between mined and unmined sites.

B. ANALYTICAL PROCEDURES AND EXPERIMENTAL DESIGN

Benthic data were collected at monthly intervals from all Jamestown sites beginning in April 1976. Sampling was completed in March 1977. A hard freeze prohibited sampling at all sites during January and February 1977.

Four sampling methods were used in the study. Quantitative sampling was accomplished by using a Surber sampler and a drift net, while a kick net and an artificial substrate device was used to collect qualitative data.

Three Surber samples were collected at each site using a 0.09-m^2 Surber sampler with a 1-mm^2 mesh net. The substrate was disturbed to an approximate depth of 5 cm. Care was taken so that all benthos within the sampling area would be collected. Three artificial substrate samples were positioned at each site and sampled monthly. The artificial substrate sampling device was designed to simulate leaves, small sticks, and twigs, and consisted of conservation webbing material and concrete blocks with a surface area of 0.9 m^2. The conservation webbing and concrete blocks, placed in 35-cm by 125-cm barbeque baskets, were carefully retrieved from each site, picked of organisms, and returned to the site.

Drifting organisms were collected using a number 45 mesh (363 micron) drift net which was placed in the stream for four 6-hour photo periods per day so that time of day drift patterns could be observed. Flow measurements were taken at the beginning of drift sampling and not again until a sufficient amount of rainfall during the four photo periods.

Qualitative kick net samples were also taken at each site. A "D" shaped dip net 30 cm across was used to collect organisms inhabiting a wide variety of habitats.

All samples were preserved in the field and returned to the lab where organisms were picked from the organic matter and separated into insect and noninsect groups, weighed, and identified. Once identified to genus or in some cases to species, the organisms were grouped into one of four trophic levels for modeling purposes. Trophic level designations were derived from Merritt and Cummins (1978) and included carnivores, collectors herbivores, and shredders.

C. RESULTS

Composition of Taxa Collected--

A total of 163 identifiable taxa were collected from all sites during the study (table 29). An additional 23 taxa were collected which could not be identified and, therefore, not included in the taxonomic tabulations. Of the 163 taxa, 52 and 55 percent were found at the reference sites LB4.0 and LY0.4, respectively. Only 49 taxa (30 percent) were common to each reference site. Fifty-two and fifty-six percent of the total identifiable taxa were collected at CC15.9 and CC16.7, respectively. Sixty taxa (37 percent) were common to these mined sites. A total of 61 taxa (37 percent) were collected from the agricultural site, CC18.5, while only 18 taxa (11 percent) were collected from the heavily mined site UT0.01.

Collectors were the most numerous group of organisms collected, representing between 28 and 51 percent of the taxa collected at each site. Dipterans were the most numerous order followed by ephemeropterans and trichopterans. Chironomids were the most numerous family in the collector group. Collectors were also slightly more numerous at the mined sites CC16.7 and CC15.9 than at the reference sites.

Carnivores followed collectors in numbers of taxa collected, representing between 24 and 39 percent of the total taxa collected at each site. Coleopterans were the most common carnivore order sampled followed by odonates and hemipterans. Slight differences were observed between total numbers of carnivore taxa found at mined sites CC15.9 and CC16.7 and the reference sites.

Shredders represented 15 to 33 percent of the total taxa collected at each site. Again, slight differences in numbers were observed between mined sites CC16.7 and CC15.9 and the reference sites.

TABLE 29. THE INVERTEBRATE FAUNA OF THE JAMESTOWN AREA SAMPLING STATIONS FROM APRIL 1976 TO MARCH 1977 ARRANGED BY TROPHIC LEVEL

Trophic level			Stations CC18.5	CC16.7	CC15.9	UTO.01	LB4.0	LYO.4
Carnivore								
Coleoptera								
	Currulionidae	Phycoetes sp		x				
	Dryopidae	Helichus sp.	x	x	x	x	x	x
		Pelonomus obscurus					x	
	Dytiscidae							
		Derovatellus sp.			x			
	Elmidae	Dubiraphia sp.					x	
		Gonielmis sp.			x		x	
		Gonielmis dietrichi		x				
		Optioservus sp.			x			x
		Oulimnius sp.			x			
		Oulimnius latisculus					x	
		Promoresia sp.		x				x
		Promoresia elegans		x	x			
		Stenelmis sp.						x
	Gyrinidae	Gyrinus sp.	x		x			
	Haliplidae	Peltodytes sp.	x		x			
	Hydrophilidae							
		Berosus sp.			x			
	Staphylinidae							
	Psephenidae	Ectoparia sp.		x				x
Diptera								
	Dolichopodidae							
	Emphididae	Hemerodromia sp		x	x			x
	Rhagionidae	Atherix variegata						x
	Tabanidae							
		Chrysops sp		x				x
		Tabanus sp.	x		x	x	x	x
Hemiptera								
	Corixidae							
		Arctocorixa sp.					x	
	Gerridae	Gerris sp.	x	x		x	x	x
		Rheumatobates sp.	x		x			
		Trepobates sp.		x			x	
	Hydrometridae	Hydrometra sp.			x			
	Notonectidae	Notonecta sp.					x	
	Veliidae	Microvelia sp.	x	x	x		x	x
		Rhagovelia sp.	x	x	x	x	x	x
Megaloptera								
	Corydalidae	Corydalus cornutus			x			x
		Nigronia sp.	x	x	x	x	x	x
	Sialidae	Sialis sp.	x	x	x		x	x

(continued)

TABLE 29. (continued)

Trophic level		Stations					
		CC18.5	CC16.7	CC15.9	UTO.01	LB4.0	LYO.4
Carnivore							
Odonata							
Aeshinidae	*Aeshna* sp.					x	
	Boyeria sp.	x	x	x		x	x
Calopterygidae	*Calopteryx* sp.	x	x	x		x	x
	Hetaerina sp.	x					
Cordulegasteridae							
	Cordulegaster sp.		x	x	x	x	x
Gomphidae	*Dromogomphus* sp.		x	x			
	Gomphus sp.	x	x	x	x		x
Lestidae	*Lestes* sp.	x					
Libellulidae	*Plathemis* sp.	x					
Plecoptera							
Perlidae	*Acronueria* sp.	x	x	x		x	x
Perlodidae	*Hydroperla* sp.					x	
	Isoperla sp.	x	x	x		x	x
Rhynchobdellida							
Glossiphoniidae							
	Placobdella sp.	x					
Trichoptera							
Rhyacophilidae	*Rhyacophilia* sp.		x			x	x
Total Carnivore Taxa/		19	22	25	7	22	22
Percent		31.1	23.9	29.4	38.9	25.9	24.7
Collectors							
Basommatophona							
Planorbidae	*Gyraulus* sp.	x					
Collembola							
Isotomidae	*Isotoma* sp.		x	x		x	
Diptera							
Ceratopogonidae							
	Bezzia sp.	x					
	Palpomyia sp.		x	x			
Chaoboridae	*Chaoborus* sp.			x			
Chironomidae							
Chironomini							
	Brundinia sp.						x
	Chironomus sp.	x	x	x		x	x
	Cryptotendipes sp.		x				
	Dicrotendipes sp.	x	x			x	
	Einfeldia sp.	x					
	Endochironomus sp.	x	x				x
	Glyptotendipes sp.					x	x
	Hetero-trissocladius sp.		x	x	x	x	x
	Kiefferulus sp.			x			

(continued)

TABLE 29. (continued)

Trophic level		CC18.5	CC16.7	CC15.9	UTO.01	LB4.0	LYO.4
		Stations					
Collectors							
Diptera							
Chronomidae							
Chronomini (continued)							
	Microtendipes sp.	x	x	x		x	x
	Natarsia sp.	x	x	x			x
	Paraphaenocladius sp.						x
	Paratendipes sp.		x		x		x
	Phaenopsectra sp.		x	x		x	
	Polypedilum sp.	x	x	x	x	x	x
	Polypedilum fallax		x				
	Potthastia sp.	x	x	x			x
	Stenochironomus sp.		x			x	
	Stictochironomus sp.		x	x	x		
	Tribelos sp.		x			x	x
Tanytarsini	Paratanytarsus sp.		x			x	
	Rheotanytarsus sp.		x			x	
Orthocladiinae							
	Cardiocladius sp.			x			
	Cricotopus sp.		x	x		x	
	Epoicocladius sp.			x			x
	Eukiefferiella sp.		x	x		x	x
	Orthocladius sp.			x	x		
	Parametriocnemus sp.		x	x		x	x
	Psectrocladius sp.	x	x	x		x	
	Smittia sp.					x	
	Trichocladius sp.		x	x			x
	Trissocladius sp.					x	
Tanypodinae							
	Ablabesmyia sp.		x	x		x	
	Ablabesmyia tarella					x	
	Clinotanypus sp.	x				x	
	Conchapelopia sp.	x	x	x		x	x
	Pentaneura sp.		x	x		x	x
	Procladius sp.		x	x		x	x
	Psectrotanypus sp.			x			
	Zavrelimyia sp.		x			x	x
Culicidae							
	Culex sp.					x	
Dixidae	Dixa sp.	x	x	x			x
Simuliidae							
	Prosimulium sp.	x	x	x			
	Simulium sp.	x	x	x		x	x

(continued)

TABLE 29. (continued)

Trophic Level			CC18.5	CC16.7	CC15.9	UT0.01	LB4.0	LY0.4
			Stations					
Collectors								
Ephemeroptera								
Baetidae								
		Baetis sp.	x	x	x		x	x
		Centraptilum sp.		x	x			x
		Neocloeon sp.	x					
		Paracloeodes sp.					x	
Caenidae		*Caenis* sp.			x			
Ephemerellidae								
		Ephemerella sp.	x	x	x		x	x
		Ephemerella lutulenta		x		x	x	
		Ephemerella simplex		x				
Ephemeridae		*Ephemera* sp.		x	x		x	x
		Hexagenia sp.	x		x			x
		Litobrancha sp.		x				x
Heptageniidae								
		Rhithrogena sp.						x
		Stenacron sp.	x	x	x		x	x
		Stenonema sp.	x	x	x		x	x
Leptophlebiidae								
		Habrophlebia sp.			x			x
		Habrophlebiodes sp.					x	x
		Paraleptophlebia sp.						x
Siphlornuridae								
		Ameletus sp.					x	x
		Siphlonurus sp.	x					
Heterodontida								
Sphaeriidae		*Psidium* sp.	x	x	x		x	
		Sphaerium sp.	x	x			x	x
Trichoptera								
Hydropsychidae								
		Cheumatopsyche sp.	x	x	x		x	x
		Diplectrona sp.		x	x		x	x
		Hydropsyche sp.	x	x	x		x	x
Philopotamidae								
		Wormaldia sp.						x
Psychomyiidae		*Cyrnellus fraternus*		x	x			
		Lype sp.					x	x
		Lype diversa			x			
		Phylocentropus sp.						x
		Psychomyia sp.						x
	Total Collector Taxa/		27	47	43	5	42	43
		Percent	44.3	51.1	50.6	27.8	49.4	48.3

(continued)

TABLE 29. (continued)

Trophic level			Stations CC18.5	CC16.7	CC15.9	UT0.01	LB4.0	LY0.4
Herbivores								
Amphipoda								
	Talitridae	Hyalella azteca		x	x			
Basommatophora								
	Lymnaeidae	Lymnaea sp.	x	x				
	Physidae	Physa sp.	x	x				
	Planorbidae	Helisoma sp.	x					
		Helisoma anceps	x	x				
		Helisoma trivolis	x					
		Menetus sp.	x					
Plecoptera								
	Chloroperlidae							
		Hastaperla sp.						x
	Taeniopterygidae							
		Strophopteryx sp.			x		x	
Trichoptera								
	Hydroptilidae	Oxyethira sp.						x
	Molannidae	Molanna sp.						x
	Total Herbivore Taxa/		6	4	2	0	1	3
		Percent	9.8	4.3	2.4	0	1.2	3.4
Shredder								
Amphipoda								
	Gammaridae	Crangonyx sp.		x			x	
Decapoda								
	Astacidae	Cambarus sp.	x	x	x	x	x	x
Diptera								
	Tipulidae							
		Antocha sp.		x	x		x	x
		Dicranota sp.			x			x
		Eriocera sp.					x	x
		Hexatoma sp.		x	x		x	x
		Limnophila sp.		x	x	x		x
		Limonia sp.						x
		Ormosia sp.		x		x		
		Paradelphamyia sp.					x	x
		Pilaria sp.				x		
		Tipula sp.	x	x	x	x	x	x
Isopoda								
	Asellidae	Asellus sp.	x	x				
		Lirceus sp.		x				
Lepidoptera								
	Pyralidae	Nymphula sp.		x		x		

(continued)

TABLE 29. (continued)

Trophic level		CC18.5	CC16.7	CC15.9	UTG.01	LB4.0	LYO.4
Shredder							
Plecoptera							
Capniidae	Allocapnia sp.		x				
Leuctridae	Leuctra sp.	x	x	x		x	x
	Paraleuctra sp.	x	x	x		x	x
Nemouridae	Nemoura sp.	x	x	x		x	x
Taeniopterygidae							
	Taeniopteryx sp.	x	x	x		x	x
Trichoptera							
Lepidostomatidae							
	Lepidostoma sp.	x	x	x		x	x
Limnephiloidae							
	Banksiola sp.		x				
	Frenesia sp.			x			x
	Limnephilus sp.					x	x
	Neophylax sp.		x	x		x	x
	Pycnopsyche sp.		x	x		x	x
Phryganeidae	Ptilostomis sp.	x		x			
Total Shredder Taxa		9	19	15	6	15	18
	Percent	14.8	20.7	17.6	33.3	17.6	20.2
Total Taxa		61	92	85	18	85	89
Percent of Total Taxa Collected		37.4	56.4	52.1	11.0	52.1	54.6

However, only nine shredder taxa (15 percent) were collected at the agricultural site CC18.5, while six shredder taxa (33 percent) were collected at the heavily mined site, UT0.01. Most of the shredder taxa collected were tipulids.

Herbivores were the least abundant group collected, representing 1.2 to 9.8 percent of the total taxa collected at each site. Not surprising was the fact that a greater percentage was observed at the agricultural site where canopy was at a minimum. Six out of a total of ten herbivores collected at all sites were found at this site.

Mean Numbers of Organisms Collected--

The mean numbers of organisms collected by each sampling method are presented in tables 30, 31, and 32. Dipterans were generally the most abundant group sampled, ranging from 16 per m^2 at UT0.01 to 664 per m^2 at CC18.5. Reference sites LY0.04 and LB4.0 had 172 and 52 dipterans per m^2, respectively. Overall, there were between 21 total organisms collected per m^2 at UT0.01 and 1410 oganisms per m^2 at CC18.5. Greatest numbers occurred in May and December.

Dipterans were also in greatest numbers in the drift with mean numbers ranging from 14 organisms per 1000 m^3 at CC16.7 to 58 organisms at LB4.0. Overall, mean numbers were greatest at the reference site LB4.0 (73 organisms per 1000 m^3) and lowest at CC16.7 (31 organisms per 1000 m^3). No drift samples were collected at UT0.01. Highest concentrations of drift occurred in the summer months, possibly due to the more active nature of the organisms during this time and/or lower flow rates. Drift was lowest almost without exception during the month of October. Drift was lowest during September only at LB4.0.

Dipterans dominated artificial substrates only at the agricultural site and mined sites, while ephemeropterans were dominant at the reference sites. Mean numbers of dipterans ranged from 24 to 261 colonizing organisms per m^2 at CC16.7 and CC18.5, respectively. Mean numbers of ephemeropterans ranged from 28 to 32 organisms per m^2 at LB4.0 and LY0.4, respectively. Mean numbers of total organisms collected ranged from 50 per m^2 at CC16.7 to 419 per m^2 at CC18.5.

Total number of organisms collected by one sweep of a kick net at the mined and reference sites ranged from 622 at LY0.4 to 852 at CC16.7 (table 33). Ephemeroptera dominated the samples collected at CC16.7, while diptera was dominant at CC15.9 and LY0.4. Plecoptera was the dominant order at LB4.0. Greatest numbers were usually collected in late spring and early summer. Lower numbers were found in September and October.

Species Diversity--

To compare sites for differences in species composition, species diversity indices were calculated for Surber and drift data. The

TABLE 30. MEAN NUMBER OF ORGANISMS PER M^2 COLLECTED IN THE MONTHLY SURBER SAMPLES BETWEEN APRIL 1976 AND MARCH 1977 IN THE JAMESTOWN AREA

Stations	Order	1976 April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 March	Mean for sample period	Percent
CC18.5	Coleoptera	x	x	x	x	22	7	4	-	-	-	6	0.4
	Diptera	x	x	x	x	758	248	75	1096	1416	396	664	47
	Ephemeroptera	x	x	x	x	19	4	4	-	4	-	5	0.4
	Hemiptera	x	x	x	x	7	7	-	4	-	-	4	0.3
	Odonata	x	x	x	x	4	11	-	-	-	-	3	0.2
	Plecoptera	x	x	x	x	-	-	-	30	19	4	9	1
	Trichoptera	x	x	x	x	1907	377	100	59	19	66	421	30
	Other	x	x	x	x	207	715	274	370	200	22	298	21
	Total					2924	1369	457	1566	1658	485	1410	100
CC16.7	Coleoptera	23	7	4	11	-	-	-	-	-	-	5	4
	Diptera	61	460	8	8	11	27	8	252	63	15	91	69
	Ephemeroptera	59	52	-	30	-	-	-	-	-	4	15	11
	Hemiptera	-	-	-	-	4	4	-	-	-	-	1	1
	Odonata	8	8	-	-	-	-	-	-	-	-	2	2
	Plecoptera	7	-	-	-	-	-	-	15	-	4	3	2
	Trichoptera	56	33	-	-	4	-	-	4	-	-	10	8
	Other	11	-	-	12	7	8	-	4	-	-	4	3
	Total	225	560	12	61	26	39	8	275	63	23	131	100
UTO.01	Diptera	19	38	8	-	x	x	x	x	x	x	16	76
	Odonata	8	-	-	-	x	x	x	x	x	x	2	10
	Other	12	-	-	-	x	x	x	x	x	x	[illegible]	14
	Total	39	38	8	0							21	100

(continued)

TABLE 30. (continued)

Stations	Order	1976 April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 March	Mean for sample period	Percent
CC15.9	Coleoptera	-	-	8	-	-	-	-	4	4	22	4	1
	Diptera	78	182	7	8	29	19	4	266	593	478	166	50
	Ephemeroptera	44	196	15	19	-	-	-	7	-	11	29	9
	Hemiptera	-	-	-	-	4	-	-	-	-	-	0.4	0.1
	Odonata	-	81	-	-	-	-	-	-	-	-	8	
	Plecoptera	4	82	-	-	-	-	-	192	411	178	87	26
	Trichoptera	4	-	-	-	-	-	22	70	74	45	22	7
	Other	11	-	8	26	19	-	7	15	23	26	14	7
	Total	141	541	38	53	52	19	33	554	1105	760	330	100
LY0.4	Coleoptera	30	-	4	4	-	-	-	-	7	-	5	1
	Diptera	172	569	95	49	96	29	4	137	515	56	172	55
	Ephemeroptera	34	60	4	85	7	4	19	4	19	4	24	8
	Hemiptera	-	-	-	-	19	-	-	-	-	-	2	1
	Odonata	-	4	11	-	-	-	-	-	4	4	2	1
	Plecoptera	89	100	-	285	-	4	-	41	104	37	66	21
	Trichoptera	123	55	-	11	-	-	4	37	52	41	32	10
	Other	12	-	4	33	11	4	18	4	4	4	9	3
	Total	460	788	118	467	133	41	45	223	705	146	312	100

(continued)

TABLE 30. (continued)

Stations	Order	1976 April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 March	Mean for sample period	Percent
LB4.0	Coleoptera	4	8	15	-	-	-	-	11	4	11	5	2
	Diptera	33	104	189	4	45	-	4	19	46	71	52	8
	Ephemeroptera	15	18	7	22	22	85	41	7	30	15	26	9
	Hemiptera	-	-	-	-	4	-	-	7	-	-	1	0.4
	Odonata	-	-	-	-	4	4	-	-	-	-	1	
	Plecoptera	363	563	204	11	-	-	-	41	66	152	140	48
	Trichoptera	44	26	-	152	7	-	4	44	82	11	37	13
	Other	33	12	8	4	45	33	15	53	77	37	32	11
	Total	492	731	423	193	127	122	64	182	305	297	294	100
	TOTAL	1357	2658	599	774	3262	1590	607	2800	3836	1711		

x No samples collected.

- No organisms found in sample.

TABLE 31. MEAN NUMBER OF ORGANISMS PER 1000 M^3 COLLECTED BY DRIFT SAMPLING FROM MAY 1976 TO MARCH 1977 AT THE JAMESTOWN AREA SITES

Station	Order	1976 May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 Mar.	Mean for sample period	Percent
CC18.5	Basommatophora	x	x	x	(365)[o]	(8)	(1)	-	(1)	-	(375)	
	Coleoptera	x	x	x	19	-	-	13	1	-	6	9
	Diptera	x	x	x	-	10	1	26	98	15	25	38
	Ephemeroptera	x	x	x	38	-	-	-	1	-	7	11
	Hemiptera	x	x	x	95	8	-	2	1	-	18	28
	Plecoptera	x	x	x	-	-	-	2	2	4	1	2
	Trichoptera	x	x	x	19	2	1	-	-	-	4	6
	Other	x	x	x	19	-	-	2	-	-	4	6
	Total				190	20	2	45	103	19	65	100
CC16.7	Coleoptera	-	2	1	3	2	1	8	2	-	2	6
	Diptera	60	7	7	-	-	-	39	10	1	14	45
	Ephemeroptera	-	2	2	11	2	-	1	4	1	3	10
	Hemiptera	-	6	1	14	12	-	1	-	-	4	13
	Plecoptera	-	3	-	-	-	-	9	28	4	5	16
	Trichoptera	-	-	6	11	2	1	1	1	-	2	6
	Other	-	2	5	-	-	-	2	-	-	1	3
	Total	60	22	22	39	18	2	61	45	6	31	100
CC15.9	Coleoptera	-	1	2	14	-	-	12	1	0.2	3	4
	Diptera	133	29	77	16	14	1	9	33	47	40	56
	Ephemeroptera	-	2	3	9	-	1	3	1	-	2	3
	Hemiptera	-	4	1	4	-	1	-	-	-	1	1
	Plecoptera	-	-	-	-	-	-	26	11	11	5	7
	Trichoptera	-	1	5	32	130	-	1	-	2	19	27
	Other	-	1	4	6	-	-	2	-	-	1	1
	Total	133	38	92	81	144	3	53	46	60	71	100

(continued)

TABLE 31. (continued)

Station	Order	1976 May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 Mar.	Mean for sample period	Percent
LY0.4	Coleoptera	-	1	1	-	1	-	-	-	-	0.3	1
	Diptera	19	132	8	-	-	5	2	1	-	19	42
	Ephemeroptera	-	19	7	6	-	2	3	3	2	5	11
	Hemiptera	-	4	-	3	-	-	-	-	-	1	2
	Plecoptera	-	49	57	38	-	-	5	5	1	17	38
	Trichoptera	-	10	-	3	-	3	-	1	1	2	4
	Other	-	-	1	3	-	-	2	1	-	1	2
	Total	19	215	74	53	1	10	12	11	4	45	100
LB4.0	Coleoptera	-	-	-	-		-	3	0.3	-	0.3	0.4
	Diptera	13	23	465	1	5	1	3	9	4	58	79
	Ephemeroptera	-	-	-	-	1	-	-	2	1	0.4	1
	Hemiptera	-	4	-	-	8	-	-	-	-	1	1
	Plecoptera	-	8	22	-	-	-	6	21	31	10	14
	Trichoptera	-	1	22	1	-	-	-	-	1	3	4
	Other	-	3	-	-	-	-	-	8	-	1	1
	Total	13	39	509	2	14	1	12	40	37	73	100

x No samples collected.

- No organisms found in sample.

o Not included in total number.

TABLE 32. MEAN NUMBER OF ORGANISMS PER M^2 COLLECTED BY ARTIFICIAL SUBSTRATE SAMPLING FROM MAY 1976 TO MARCH 1977 IN THE JAMESTOWN AREA

Stations	Order	1976 May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 Mar.	Mean for sample period	Percent
CC18.5	Basommatophora	x	x	x	15	7	33	30	15	104	34	8
	Coleoptera	x	x	x	-	-	-	-	15	-	3	1
	Decapoda	x	x	x	4	4	7	4	-	-	3	1
	Diptera	x	x	x	4	33	-	163	1337	30	261	62
	Ephemeroptera	x	x	x	-	11	-	11	7	-	5	1
	Rhynchobdellida	x	x	x	604	4	-	-	-	-	101	24
	Heterondontida	x	x	x	-	-	-	11	-	-	2	0.5
	Megaloptera	x	x	x	-	-	11	15	15	7	8	2
	Plecoptera	x	x	x	-	-	-	-	4	-	1	0.2
	Trichoptera	x	x	x	-	-	-	4	4	-	1	0.2
	Other	x	x	x	-	-	-	-	-	-	-	-
	Total				627	59	51	238	1397	141	419	100
CC16.7	Coleoptera	7	-	-	-	-	-	-	7	-	2	4
	Diptera	19	-	41	-	-	-	4	144	7	24	48
	Ephemeroptera	-	-	7	19	15	11	11	33	7	11	22
	Plecoptera	-	-	-	-	-	-	33	81	4	13	26
	Trichoptera	-	-	-	-	-	-	-	-	4	0.4	1
	Other	-	-	-	-	-	-	-	-	-	-	-
	Total	16	0	48	19	15	11	48	265	22	50	100
CC15.9	Coleoptera	*	-	-	-	*	*	11	*	-	2	1
	Diptera	*	-	7	-	*	*	89	*	422	102	71
	Ephemeroptera	*	-	4	4	*	*	-	*	7	3	2
	Megaloptera	*	-	-	4	*	*	-	*	-	1	1
	Oligochaeta	*	-	-	-	*	*	-	*	-	1	1
	Plecoptera	*	-	-	-	*	*	89	*	63	30	21
	Trichoptera	*	-	-	-	*	*	11	*	7	4	3
	Other	*	-	-	-	*	*	-	*	-	-	-
	Total	*	0	11	12	-	-	200	-	499	143	100

(continued)

TABLE 32. (continued)

Stations	Order	1976 May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 Mar.	Mean for sample period	Percent
LYO.4	Coleoptera	-	-	7	-	-	-	-	-	-	1	2
	Decapoda	-	-	4	4	4	4	15	-	-	3	5
	Diptera	-	-	7	-	-	56	-	-	26	10	16
	Ephemeroptera	26	28	63	33	19	35	37	11	33	32	52
	Megaloptera	-	-	4	-	4	4	7	-	7	3	5
	Plecoptera	4	4	-	7	-	-	15	7	22	7	11
	Trichoptera	-	4	4	-	-	-	22	4	15	6	10
	Other	-	-	-	-	-	-	-	-	-	-	-
	Total	30	36	89	44	31	99	96	22	103	62	100
LB4.0	Coleoptera	-	-	-	-	-	-	70	-	4	8	12
	Decapoda	-	-	4	-	-	-	11	4	4	3	5
	Diptera	-	-	70	-	-	-	7	11	-	10	15
	Ephemeroptera	-	4	-	19	96	67	33	22	7	28	42
	Hemiptera	-	-	-	-	7	-	-	-	-	1	2
	Heterondontida	-	-	-	-	-	-	4	-	-	0.4	1
	Megaloptera	-	-	-	-	4	-	15	4	11	4	6
	Plecoptera	11	4	-	-	-	-	-	19	44	9	14
	Trichoptera	-	4	15	4	-	-	-	-	-	3	5
	Other	-	-	-	-	-	-	-	-	-	-	-
	Total	11	12	89	23	107	67	140	60	70	66	100
		57	48	237	725	212	228	722	1744	835		

x No samples collected.

- No organism found in sample.

* Station vandalized.

TABLE 33. TOTAL NUMBER OF ORGANISMS PER SWEEP COLLECTED BY KICK NET SAMPLING FROM APRIL 1976 TO MARCH 1977 IN THE JAMESTOWN AREA

Station	Order	1976 April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec	1977 March	Total No	Percent
CC18 9													
	Basommatophora	x	x	x	x	21	10	10	3	1	1	46	11%
	Coleoptera	x	x	x	x	-	20	1	-	-	2	23	6
	Decapoda	x	x	x	x	9	10	3	1	-	-	23	6
	Diptera	x	x	x	x	42	11	3	45	36	29	166	41
	Ephemeroptera	x	x	x	x	2	20	-	-	1	-	23	6
	Hemiptera	x	x	x	x	3	23	1	-	-	-	27	7
	Heterondontida	x	x	x	x	5	-	-	11	-	2	18	4
	Megaloptera	x	x	x	x	8	11	8	4	6	3	40	10
	Odonata	x	x	x	x	3	8	1	-	-	-	12	3
	Trichoptera	x	x	x	x	-	-	5	4	3	11	23	6
	Other	x	x	x	x	1	-	-	-	-	-	1	0.2
	Total					94	113	32	68	47	48	402	100%
CC16.7													
	Basommatophora	-	1	-	-	-	-	-	-	-	-	1	0.1%
	Coleoptera	13	4	6	1	9	2	-	1	-	-	36	4
	Decapoda	6	1	2	27	3	5	-	-	-	-	44	5
	Diptera	26	20	1	66	1	2	-	8	28	-	152	18
	Ephemeroptera	181	1	44	15	33	15	1	4	5	-	299	35
	Hemiptera	2	-	6	-	1	-	-	-	-	-	9	1
	Megloptera	7	-	4	2	7	2	1	1	4	-	28	3
	Odonata	5	-	2	-	3	-	-	-	-	-	10	1
	Plectoptera	96	6	3	1	1	1	-	7	20	-	135	16
	Trichoptera	60	2	27	7	12	5	14	2	2	-	131	15
	Other	1	3	1	-	-	-	-	1	1	-	6	1
		397	38	96	119	70	32	16	24	60	0	852	100%

(continued)

TABLE 33. (continued)

Station	Order	1976 April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 March	Total No.	Percent
UTO.01													
	Coleoptera	1	-	-	-	x	x	x	x	x	x	1	4%
	Decapoda	-	-	2	-	x	x	x	x	x	x	2	7
	Diptera	2	18	-	-	x	x	x	x	x	x	20	71
	Ephemeroptera	-	1	-	-	x	x	x	x	x	x	1	4
	Hemiptera	-	1	1	-	x	x	x	x	x	x	2	7
	Trichoptera	-	-	2	-	x	x	x	x	x	x	2	7
	Total	3	20	5	0							28	100%
CC15.9													
	Coleoptera	4	9	2	2	-	-	-	-	2	3	22	3%
	Decapoda	1	1	1	13	8	3	-	-	-	-	27	3
	Diptera	3	133	-	3	3	-	-	34	80	56	312	37
	Ephemeroptera	8	27	-	3	-	8	-	-	3	-	49	6
	Hemiptera	-	-	3	-	1	-	2	-	-	-	6	1
	Heterondontida	-	-	6	-	-	-	-	-	3	-	9	1
	Megaloptera	5	1	2	5	8	-	-	-	7	6	34	4
	Odonata	1	-	2	1	-	2	2	-	-	-	8	1
	Oligochaeta	-	-	-	10	-	-	-	-	-	-	10	1
	Plectoptera	3	76	-	-	-	-	-	36	159	25	299	35
	Trichoptera	2	19	1	2	1	-	-	8	28	4	65	8
	Other	1	1	-	-	-	-	-	-	-	-	2	0.2
	Total	28	267	17	39	21	13	4	78	282	94	843	100%

(continued)

TABLE 33. (continued)

Station	Order	1976 April	May	June	July	Aug.	Sept	Oct	Nov.	Dec.	1977 March	Total No.	Percent
LYO 4													
	Coleoptera	5	2	-	10	5	1	-	-	-	-	23	4%
	Decapoda	6	-	-	2	11	8	5	4	-	-	36	6
	Diptera	36	70	6	78	34	-	1	9	33	2	269	43
	Ephemeroptera	14	11	11	6	4	7	4	4	4	3	68	11
	Hemiptera	-	2	-	-	1	-	-	-	-	-	3	0.5
	Megaloptera	1	-	-	-	-	2	-	-	-	-	3	0.5
	Odonata	3	-	13	3	-	2	2	4	1	-	28	5
	Plecoptera	40	-	2	73	10	2	-	5	1	-	133	22
	Trichoptera	15	4	3	3	8	8	2	1	2	5	51	8
	Other	-	6	-	-	-	-	1	-	-	-	7	1
	Total	120	95	36	175	73	30	15	27	41	10	622	100%
LB4.0													
	Coleoptera	3	1	4	-	-	-	-	-	1	-	9	1
	Decapoda	-	3	-	2	7	1	15	3	2	1	34	5
	Diptera	3	19	42	12	9	1	-	2	64	12	164	24
	Ephemeroptera	6	5	3	2	-	2	3	2	8	2	33	5
	Hemiptera	-	-	1	-	3	-	-	-	1	-	5	1
	Megaloptera	6	-	2	2	5	3	2	3	3	1	27	4
	Odonata	-	-	3	-	-	-	-	-	-	-	3	0.4
	Plecoptera	133	146	85	6	-	-	-	-	13	2	385	56
	Trichoptera	5	6	2	15	-	-	-	2	2	-	32	5
	Other	-	-	-	-	-	-	-	-	2	-	2	0.3
	Total	156	180	142	39	24	7	20	12	96	18	694	100%

x = no samples collected

- = no organisms found

Shannon-Weaver diversity index for these two sampling techniques is presented in tables 34 and 35 for each site and month. Diversity was highest at the reference sites, ranging from 4.01 at LB4.0 to 4.29 at LY0.4 for Surber samples and from 4.02 at LY0.4 to 4.28 at LB4.0 for drift samples. Diversity was also higher ($\bar{d}$ = 4.20) at CC16.7 for drift samples. Diversity was lowest at CC18.5, most likely due to the great number of Dipterans collected there relative to the total taxa collected.

Seasonally, diversity was generally highest in early summer and late fall. The highest monthly value was observed in June at LY0.4 ($\bar{d}$ = 3.86) for Surber samples and in July at CC15.9 ($\bar{d}$ = 3.88) for drift samples. Lowest diversity values usually occurred in late summer and early fall.

Lower diversity at mined sites was possibly due to the homogeneous sandy substrate originating from the mine. The substrate was also fairly homogeneous at CC18.5, composed almost entirely of fine organic matter and an ideal habitat for the numerous chironomids found there.

Biomass--

Gross insect biomass was determined from Surber, drift, and artificial substrate samples at each site monthly. Greatest biomass was observed at each reference site and at the agricultural site CC18.5. Biomass at LB4.0 and LY0.4 was 37 percent and 20 percent, respectively, of the total biomass of all organisms collected by Surber sampling (table 36). Thirty percent of the total biomass of organisms collected on artificial substrates was found at CC18.5 while 28 percent was observed at LY0.4. Organisms collected from LB4.0 comprised 32 percent of the total drift biomass, while organisms from CC18.5 contributed 24 percent. Mined sites CC15.9 and CC16.7 had significantly lower insect biomass, each representing only 15 percent of the total Surber biomass and 23 percent of the total drift biomass, respectively.

Seasonally, greater insect biomass was generally observed in the spring and fall for Surber samples and throughout the summer and fall for artificial substrate samples. Peaks in drift biomass occurred throughout the sampling period, depending on the site examined.

D. DISCUSSION AND CONCLUSION

Hynes (1970) stated in streams with clean stony runs rather than silty reaches or pools the number of species and the total biomass was greater. This was made evident by comparing low numbers of organisms at the mined sites with numbers at the reference and agricultural sites. CC16.7 and UT0.01 had the lowest biomass and number of species collected from Surber and artificial substrate sampling. CC16.7 did have high total numbers of taxa for Surber

TABLE 34. SPECIES DIVERSITY ($\bar{d}$) OF ORGANISMS COLLECTED IN THREE SURBER SAMPLES THE JAMESTOWN AREA SITES BETWEEN APRIL 1976 AND MARCH 1977. TOTAL ORGANISMS AND TAXA ARE FROM APPENDIX A

Sampling site	Parameter	1976									1977	Total for
		April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	March	Study period
CC18.5	Total Organisms	x	x	x	x	790	370	123	420	449	131	2283
	Total Taxa	x	x	x	x	21	26	11	13	13	7	40
	$\bar{d}$	-	-	-	-	2.05	2.53	2.19	1.59	1.71	1.23	3.00
CC16.7	Total Organisms	60	151	3	16	7	10	2	74	17	6	346
	Total Taxa	20	14	3	6	5	7	2	4	1	3	44
	$\bar{d}$	3.91	2.16	0.32	2.48	2.24	2.52	0.21	0.55	0.00	1.25	3.35
UT0.01	Total Organisms	10	10	2	-	x	x	x	x	x	x	22
	Total Taxa	8	6	2	-	x	x	x	x	x	x	16
	$\bar{d}$	3.12	2.37	1.00	-	-	-	-	-	-	-	3.81
CC15.9	Total Organisms	37	146	10	14	14	5	9	150	298	205	889
	Total Taxa	12	14	7	7	7	1	4	11	12	8	39
	$\bar{d}$	3.08	3.27	2.65	2.55	2.41	0.00	1.66	2.65	1.99	1.65	3.41
LY0.4	Total Organisms	123	212	31	126	36	11	12	60	190	39	840
	Total Taxa	31	23	18	18	6	6	6	7	16	13	66
	$\bar{d}$	4.51	3.48	3.86	2.39	1.65	2 41	2.28	1.71	2.03	3.27	4.29
LB4.0	Total Organisms	143	195	114	52	34	33	17	48	82	80	791
	Total Taxa	17	24	13	7	13	5	6	11	18	14	50
	$\bar{d}$	2.59	2.28	2.08	1.29	3.33	1.58	1.85	3.00	3.57	2.64	4.01

x no samples collected.

- no organism found in sample.

TABLE 35 . SPECIES DIVERSITY ($\bar{d}$) OF ORGANISMS COLLECTED IN DRIFT SAMPLES FROM THE JAMESTOWN AREA SITES FROM MAY 1976 TO MARCH 1977

Sampling site	Parameter	1976 May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 Mar.	Total
CC18.5	Organisms	x*	x	x	29	14	3	76	447	55	624
	Taxa	x	x	x	11	7	3	7	9	4	27
	($\bar{d}$)	-	-	-	2.72	2.61	1.59	2.20	0.72	1.22	1.70
CC16.7	Organisms	25	13	1	11	8	9	100	86	9	282
	Taxa	12	8	16	6	5	6	13	8	3	46
	($\bar{d}$)	35	2.78	3.79	2.41	2.16	2.42	2.75	1.95	1.22	4.20
CC15.9	Organisms	57	123	131	36	10	4	153	546	772	1832
	Taxa	9	23	29	12	3	3	10	11	12	61
	($\bar{d}$)	2.03	3.76	3.88	2.91	1.36	1.50	2.37	2.50	1.22	3.31
LYO.4	Organisms	18	23	154	17	1	6	7	9	5	460
	Taxa	7	33	13	5	1	3	5	10	4	49
	($\bar{d}$)	2.60	3.67	1.46	1.44	0.00	1.46	2.24	3.26	1.92	4.02
LB4.0	Organisms	41	139	23	9	30	4	4	149	111	542
	Taxa	5	26	13	4	5	3	3	11	10	10
	($\bar{d}$)	1.76	3.67	3.21	1.75	1.90	1.50	1.50	2.22	2.06	4.28

*x = no samples collected.

TABLE 36. JAMESTOWN AQUATIC INSECT BIOMASS FOR SURBER, ARTIFICIAL SUBSTRATE, AND DRIFT SAMPLES COLLECTED FROM APRIL 1976 AND MARCH 1977

Stations	Sample type	Units	April	May	June	July	1976 Aug.	Sept.	Oct.	Nov.	Dec.	1977 Mar.	Total (grams)
CC 18.5	Art. Sub.	mg/m^2	x	x	x	x	-	37	259	963	5333	630	7.22
	Surber	mg/m^2	x	x	x	x	5300	2200	2000	2200	2600	1500	15.80
	Drift	$mg/100m^3$	x	x	x	x	429	6	1	28	16	3	0.48
CC 16.7	Art. Sub.	mg/m^2	x	-	-	593	407	74	111	778	852	630	3.45
	Surber	mg/m^2	6100	4000	1100	1900	1500	500	100	100	100	40	15.44
	Drift	$mg/100m^3$	x	200	59	65	39	3	4	13	50	15	0.45
UT 0.01	Art. Sub.	mg/m^2	x	-	-	-	x	x	x	x	x	x	-
	Surber	mg/m^2	2500	100	800	-	x	x	x	x	x	x	3.40
	Drift	$mg/100m^3$	x	x	x	x	x	x	x	x	x	x	-
CC 15.9	Art. Sub.	mg/m^2	x	*	-	407	74	*	*	296	*	1778	2.56
	Surber	mg/m^2	1600	200	900	5200	80	-	200	2600	2100	5700	18.58
	Drift	$mg/100m^3$	x	9	13	16	37	45	1	39	17	71	0.25
LY 0.4	Art. Sub.	mg/m^2	x	519	148	778	185	556	1296	1296	370	889	6.67
	Surber	mg/m^2	5000	1600	7900	1200	700	600	400	900	2600	4600	25.50
	Drift	$mg/100m^3$	x	23	20	7	63	1	2	32	14	8	0.17
LB 4.0	Art. Sub.	mg/m^2	x	37	74	778	296	444	222	1593	111	519	4.07
	Surber	mg/m^2	16300	4700	600	8700	500	1200	500	1700	7500	5300	47.00
	Drift	$mg/100m^3$	x	53	26	522	0	2	13	5	6	13	0.64

x = no sample collected

- = no organism found

* = station vandalized

sampling but the greatest percentage was observed prior to the start of heavy siltation. Numbers decreased noticeably as the siltation continued (table 37). CC16.7 also had the lowest number of organisms for Surber, drift, and artificial substrate sampling. CC18.5, established after sampling at UT0.01, was discontinued, had the highest total number of organisms collected from Surber, and artificial substrate and second highest numbers for drift sampling although total time sampling was less by four months. CC18.5 received a great deal more sunlight resulting in the growth of aquatic and semiaquatic vegetation and had a thick organic mud substrate.

An increase in invertebrate drifting was noted by Talak (1977) in response to mining activity. This observation was also noted in this study with the highest total number of organisms and taxa collected in drift sampling at CC15.9. The organisms collected most probably represented what was drifting out of the affected strip mined watershed and into the area where the sampling for CC15.9 was conducted.

Surber sampling at the mine site CC16.7 indicated a decline in the number of organisms per m^2 and the number of taxa collected monthly. Winner (1980) hyphothesized that heavily polluted habitats are dominated by midges, moderately polluted habitats by midges and caddisflies, and minimally polluted or unpolluted habitats by caddisflies and mayflies. A lack of ephemeroptera was indicated in Surber samples at CC16.7 and CC15.9 about the time mining activity increased resulting in heavy siltation (sand) at CC16.7, increased turbidity and light silting at CC15.9. The presence of silt on stony substrate reduces and changes the fauna, and the deposition of sandy silt reduces the total number of insects emerging, especially ephemeroptera, plecoptera, and trichoptera (Hynes 1970). Diptera was the only order to be sampled consistantly at CC16.7 and CC15.9. Midges comprised 66 percent at CC16.7 and 16 percent at CC15.9 of the Dipteran population collected by Surber sampling. During the later part of the survey, midges were 100 percent of the Diptera population in November and December and 99 percent in March at CC16.7 (table 12).

Talak (1977) noted that all orders decrease initially but ephemeroptera showed the most precipitous decline with very little recovery over time, indicating that this order was most seriously affected by mining operations. Artificial substrate sampling at CC16.7 indicated that number of ephemeroptera increased just about the time it decreased in Surber samples. This observation corresponds to the increased siltation (sand) from mining operations. A similar comparison cannot be effectively made at CC15.9 due to missing data caused by the destruction of artificial substrate sampling gear by vandalism. But with what data was obtained one may speculate a similar relationship as at CC16.7. It appears as siltation covered natural habitats, the organisms were forced to congregate on the artificial substrate blocks which were repositioned on top of the accumulating sand on a monthly basis. Even though ephemeroptera was present at CC16.7, the

TABLE 37. FIELD OBSERVATIONS OF SURVEY STREAMS FROM MAY 1976 TO MARCH 1977 IN THE JAMESTOWN AREA

	1976								1977
Station	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	March
CC18.5	x	x	x	Water somewhat turbid. Very, very slow flow.	Water low. Slight turbidity.	Water slightly turbid.	Water clear.	Water clear.	Water clear.
CC16.7	Water clear.	Water muddy-siltation (sand)	Heavy siltation. New mine	Siltation (sand)	Low water. Slight turbidity. Siltation (sand)	Water clear. Good flow.	Water clear. Siltation (sand)	Water clear. Siltation (sand)	Water clear. Siltation (sand)
UT0.01	Siltation (sand)	Heavy siltation (sand)	Stream completely filled in w/sand.	x	x	x	x	x	x
CC15.9	Slightly muddy.	Water muddy. Light siltation. Building wier	Very turbid. New mine Sand deposits along banks.	Low flow. Fairly turbid. Stagnant in pools.	Low flow. Turbid.	Water cloudy. Silty as usual.	Water clear. Red-brown detritus.	Light turbidity. Reddish precipitate or growth on substrate.	Water clear. Orange color on substrate. Very little silt.
LY0.4	Water very clear.	Water very clear.	Water very clear.	Water clear. Slight brown color. Water level low.	Water low and clear.	Water clear. Light brownish color.	Water clear.	Water clear.	Water clear.

(continued)

TABLE 37. (continued)

Station	1976 May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1977 March
LB4.0	Water clear.	Water clear. Substrate covered w/detritus.	(No observations recorded.)	Water not turbid. Brownish color.	Water very, very low. Dry areas between pools. Distinct brown color.	Water clear and black. Little or no flow. Series of pools.	Water clear. Very slight brown color.	Water clear. 25% of substrate covered w/leaves.	Water slightly turbid.

x = No samples collected.

total number of organisms collected was lower than those at LY0.4 and LB4.0 for both Surber and artificial substrate sampling.

Talak also noted that trichoptera declined but recovered higher and diptera, plecoptera, and coleoptera initially declined and then recovered. Diptera was the only consistent order collected by Surber sampling at CC16.7 and CC15.9. Plecoptera and trichoptera declined at both CC16.7 and CC15.9 with a recovery at CC15.9.

Chutter (1968) noted that sedimentation could considerably reduce the density of a stream's fauna and that the summer density was lowest where there was a lot of silt and sand. Over all, the reference stations LY0.4 and LB4.0 for the months of June-August had a higher density of fauna than those stations exposed to strip mine erosion.

In the absence of any adverse water quality problems it is concluded that the most serious effect from the mining operations along Crooked Creek was the loss of habitat due to heavy siltation in the nature of sand. These same observations were made by Talak (1977), Minear (1977-78), and Mackenthum (1965).

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APPENDIX

Daily Rainfall and Streamflow Data

Contour- and Area-Mined Stream Sites, 1976-1978

TABLE A-1 ANDERSON BRANCH DAILY RAINFALL (IN) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1			--	0	.35	0	.01	.53	40	0	0	.34
2			--	.02	0	0	0	.01	51	0	0	.16
3			--	.43	.05	0	.01	0	.01	1.67	0	.16
4			--	0	.01	.01	.12	0	0	.38	0	.07
5			0	.01	.07	.60	0	0	01	.91	0	0
6			0	0	.09	.03	0	.28	0	.03	.79	0
7			.08	.48	0	0	0	.40	0	0	.01	0
8			0	.02	0	.43	0	0	0	24	0	0
9			.29	.05	.01	.59	0	0	0	.01	0	.95
10			0	0	02	01	0	0	0	0	0	.26
11			0	32	.07	0	.16	.41	0	0	0	0
12			.01	.02	0	.11	0	0	0	.49	0	0
13			0	.40	.02	0	.01	.19	0	0	0	0
14			.02	0	01	0	0	1.39	0	0	0	0
15			.65	.01	0	.01	0	.54	0	0	.14	.21
16			0	.03	0	.22	.01	.14	0	02	0	.01
17			0	0	.14	0	0	.08	0	0	.01	.01
18			0	.04	1.37	01	0	.41	0	0	0	0
19			0	0	.03	0	0	.01	.64	0	01	0
20			.01	.07	0	18	0	0	1 51	0	0	34
21			0	0	.03	.87	.56	0	54	.03	0	0
22			.03	0	0	0	.01	0	05	.90	0	0
23			0	.01	.01	0	.02	0	0	.01	0	0
24			0	.12	0	.09	0	0	01	0	0	0
25			1.38	.70	0	.27	.19	0	78	.01	0	0
26			.22	95	51	.19	.06	0	05	0	0	.12
27			.01	0	0	.07	0	.01	11	.13	0	.50
28			0	.05	0	0	0	2.02	31	.01	.89	01
29			.01	0	0	2 34	0	.16	15	01	0	70
30			.21	0	--	72	.16	01	17	.10	0	.40
31			1 15	0	--	.45	--	0	--	.02	0	--
Total			--	3 73	2.79	7.20	1.32	6.59	5 25	4 97	1.85	4.24
Total Annual		--										

TABLE A-2 ANDERSON BRANCH MEAN DAILY FLOW (CFS) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR	APR.	MAY	JUNE	JULY	AUG.	SEP.
1			--	8.2	1.5	.68	5 6	.40	1 1	68	.16	.05
2			--	3.8	1.4	.61	3.4	.38	1 5	53	.15	.15
3			--	3.6	1.2e	.58	2.3	.30	1.6	3 4	12	.10
4			--	3.2	1 2e	.53	1 9	.28	1 2	6 1	12	10
5			75	2.3	1.2e	.68	1 3	.26	93	6 7	.10	09
6			.75	1 9	1 4e	.70	1.'1	25	68	5 3	53	09
7			75	1.7	1.3e	61	.93	.53	61	2 5	.26	07
8			.68	2.0	1.2e	.68	.84	.35	53	1.6	15	07
9			.84	2.0	1.1e	3.8	.68	.30	40	1.1	12	.46
10			93	1.7	1.3e	4 1	.61	.26	35	.84	11	.44
11			.93	1.6	1 7e	2.8	58	.40	30	61	.10	15
12			.92	1.6	.85e	2.2	.53	.30	26	.84	10	12
13			.75	2.0	.76e	1 6	46	28	22	61	09	.10
14			.68	2 7	.66e	1.2	.44	30	20	46	07	.07
15			.93	2 5	.60e	1 0	.42	7.0	18	40	07	07
16			2.2	2.2	.60e	.98	.40	3.4	26	35	.06	06
17			2.3	1.7	.70e	.84	.35	2.0	22	34	06	.06
18			1.7	1 6	6.3e	.75	.34	1 9	18	30	06	05
19			1.3	1.5	4.3	.70	.32	2.2	68	.26	.06	.05
20			1.0	1.2	3.2	.68	.31	1.6	5.8	.22	.05	12
21			.93	.84	2 5	3.2	.46	1.1	5 6	.20	05	.15
22			.75	.75	2.7	3.0	.47	.84	3.8	.84	.05	.12
23			.68	68	2.2	2.2	.35	.75	2.2	46	04	.07
24			.61	.61	1.7	1 7	.30	.61	1 3	26	04	.04
25			2 8	.93	1.5	1 6	.29	.46	1.6	.22	04	.04
26			11.0	13.0	1 2	1.3	.28	.40	2.0	.18	.04	04e
27			4.5	8.4	1.0	1.3	.27	.30	1 6	17	.07	.04e
28			2.7	3.8	.93	1.2	.26	1 6	1 1	16	.35	.20e
29			1.9	2.7	.75	30.0	.25	5.8	1.0	16	.15	.15e
30			1.6	2.0	--	34.0	.22	2.8	.84	.15	.07	.23e
31			8.4	1.5	--	7.7	--	1.7	--	.18	.05	--
Total												
(cfs)			--	84.21	46.95	112.92	25.96	39.05	38 24	36.12	3.49	3.55
(in)			--	3.86	2.16	5.18	1.19	1.79	1.75	1.65	.16	.16
Avg-cfs			--	2.72	1.62	3.64	.87	1.26	1.27	1.17	.11	.12
cfsm			--	3.94	2.35	5 28	1.26	1.83	1.84	1.70	.16	.17

TABLE A-3 ANDERSON BRANCH DAILY RAINFALL (IN) - WY 1977

DAY	OCT.	NOV.	DEC	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP
1	0	.01	.04	.03	0	.01	.01	0	0	.60	.02	0
2	.01	0	.02	.01	.01	0	50	0	0	0	0	0
3	0	0	0	.08	.02	.15	30	30	0	[illegible]	0	0
4	0	.01	0	.06	0	.50	4 00	0	0	01	0	0
5	0	0	0	.10	0	0	.20	0	0	0	18	0
6	.52	0	1.07	.20	0	0	0	0	.89	0	0	.11
7	.06	.01	.44	.02	0	0	.01	.30	0	0	13	99
8	.25	0	0	02	0	0	0	.01	0	0	.11	10
9	57	01	02	.25	.02	.01	0	0	15	0	13	01
10	.01	0	02	.05	0	0	0	0	0	13	25	0
11	0	.01	.21	0	01	01	0	0	0	.06	.05	0
12	0	30	36	0	.35	1 00	0	0	.08	.24	0	0
13	0	0	0	0	0	1.00	0	0	.44	.01	.06	.48
14	0	.06	.01	10	22	0	0	0	12	0	05	59
15	0	06	.23	02	.01	.01	0	0	.02	0	13	68
16	11	0	0	0	0	0	0	0	.31	0	.03	62
17	01	0	0	0	0	0	.07	0	04	0	02	01
18	0	0	0	0	01	10	.05	0	20	0	02	0
19	.01	01	06	0	0	30	0	03	.52	0	01	08
20	58	0	.28	0	.02	.08	0	01	.29	0	01	02
21	0	0	01	0	0	.01	0	0	02	0	01	0
22	01	0	01	01	01	15	40	18	24	0	0	0
23	0	0	0	.03	.30	01	10	31	31	0	0	0
24	35	0	0	.13	.60	0	10	.02	1 05	01	1 09	0
25	1.78	01	.40	.10	0	0	01	.17	82	.99	0	64
26	0	.19	.03	.16	.01	0	0	31	08	.01	0	1.60
27	01	.01	0	02	.40	.01	0	01	0	0	0	55
28	.01	30	0	0	0	.15	50	0	.01	0	0	0
29	0	0	0	0	--	.18	.40	.62	0	.03	0	0
30	71	.18	.20	0	--	.20	.01	01	0	.01	0	0
31	01	--	0	0	--	0	--	20	--	0	0	--
Total	5.01	1 17	3.41	1.39	1.99	3 88	6.66	2.48	5.59	2 10	2.30	6 48
Total Annual		42 46										

TABLE A-4 ANDERSON BRANCH MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN	FEB	MAR.	APR.	MAY	JUNE	JULY	AUG	SEP
1	29	2.8	.40	1.0	.15	1.7	.75	1.5	.26	75	.03	05
2	16	2.2	.50	1.0	14	1.5	2.0	1 2	.18	26	02	04
3	.12	1 0	.64	.96	21	1 2	8.0	96	17	.15	02	04
4	10	.93	60	.80	.16	2 8	122	.83	15	.12	02	04
5	.08	64	.54	86	.15	3.0	12.0	.61	.10	10	01	04
6	.38	.30	2 3	1.1	.14	2 3	3 8	58	1 1	07	01	04
7	24	.27	10 0	1 5	.13	1 7	2.3	.56	30	07	01	26
8	22	23	4.2	1 3	12	1 3	1 6	54	22	07	01	15
9	2.0	21	2 0	1.5	.14	1 1	1 1	53	18	05	02	10
10	1 4	20	1 5	3.5	.13	96	93	53	15	05	03	07
11	40	18	1.2	3.8	.14	.90	75	.46	.12	10	06	07
12	35	.17	2 2	2.7	.90	6 4	61	35	12	05	12	05
13	.36	19	2 5	1.7	1.4	8 6	53	30	26	04	10	22
14	.40	31	1.9	1 5	1 3	3 2	50	.30	40	.03	09	40
15	.15	38	1 6	1.7	1 3	2 0	46	.30	.18	02	08	53
16	15	28	1.4	1 3	1 2	1 8	.40	26	18	01	07	93
17	.15	24	1.3	1 1	1 0	1.6	.35	26	15	01	07	75
18	05	.20	1 1	1.0	.86	1.5	.30	.25	15	01	06	46
19	05	18	1 0	95	.96	1.2	28	.22	30	01	05	18
20	1 3	16	1 1	90	.86	1 9	26	18	40	01	04	.10
21	1.2	.14	1 1	.61	75	1 9	.22	.18	26	01	03	10
22	1.0	.13	1.0	.31	.68	1 7	22	.18	35	01	03	10
23	.93	.12	.90	38	70	1 3	84	18	68	01	02	10
24	1 1	11	86	.35	8 0	1 2	2 0	22	1.9	01	93	10
25	2 7	11	.80	.28	4.5	1.0	1.4	18	2 5	35	15	53
26	4 1	.12	1 1	.28	3 0	.93	1 0	30	2 2	12	10	3 0
27	3 2	.17	1.0	29	2 3	.75	.95	.26	93	05	07	2 2
28	2 2	22	.90	.21	1.7	.72	.83	.18	68	04	07	93
29	1 9	40	80	21	--	68	2 7	1.5	53	03	05	35
30	2 2	46	1 0	.20	--	.84	2 1	46	30	03	05	35
31	2 8	--	.90	.17	--	.80	--	30	--	03	05	--
Total												
(cfs)	31 68	13.05	48.34	33.46	33.02	58.48	171 18	14 66	15 40	2 67	2 47	12 28
(in)	1.46	60	2.21	1.53	1.52	2.68	7.85	67	71	12	11	56
Avg-cfs	1.02	.44	1.56	1.08	1 18	1.89	5 71	.47	51	09	08	41
cfsm	1 48	.64	2.26	1.57	1 71	2.74	8 28	68	74	13	12	59

TABLE A-5 ANDERSON BRANCH DAILY RAINFALL (IN) - WY 1978

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	0	0	.05e	.03	0	.05	.03	.01	.01	.02	.02	0
2	.01	.01	0e	0	.04	.47	.03	0	.06	1.09	.01	0
3	0	.01	0e	0	.04e	.07	0	.06	18	.07	.08	0
4	.01	.19	.60e	0	.10e	0	.01	.67	.01	0	42	
5	.01	.21	.05e	.07	0e	.02	.01	.01	01	0	.70	0
6	0	1.44	.10e	.31	.03e	0	.01	.01	.03	0	.12	0
7	0	.30	0e	.03	.01	.03	01	.07	.75	0	.01	0
8	1.97	0	.10e	1.00	.01	.21	0	.50	1.74	.11	1.29	0
9	1.05	.10	.35e	0	0	.41	.02	.01	.29	.36	.19	0
10	0	.06	0e	0	0	.21	0	0	0	.74	0	0
11	.09	0	.01e	.08	0	.02	.20	0	0	.01	.26	0
12	.01	0	0e	.02	0	.12	0	.74	.69	.03	.74	0
13	0	0	0e	0	.55	.03	0	1.28	.01	.01	1.25	0
14	0	0	.14e	0	.01	.07	0	.40	0	.02	0	0
15	.27	0	0	0	.01	0	0	22	0	1.18	0	0
16	.13	.15e	0	.11	.14	.16	0	0	0	.97	.06	0
17	.01	.50e	.42	.79	0	.04	0	.01	0	0	.16	0
18	01	0e	.04	0	.03	.11	1.24	0	0	0	.01	0
19	0e	0e	.01	.20	0	.03	.04	.01	.06	0	0	0
20	0e	.10e	.05	0	0	.02	.11	0	.01	0	05	0
21	0e	.85e	0	0	.07	.33	.09	0	0	0	0	0
22	0e	1.60e	0	.27	.04	.03	0	.01	0	0	0	0
23	0e	.02e	0	.09	.05	.03	0	.90	0	0	0	0
24	0e	.02e	1.02	.67	.17	.06	0	.80	0	1.22	0	0
25	1.45e	.10e	0	1.40	0	.86	.61	.02	0	1 15	.45	0
26	.10e	0e	0	0	0	.11	.71	.01	0	.01	.03	0
27	.02e	.50e	0	.01	.01	.07	.01	.01	0	0	0	0
28	0	.05e	0	0	.20	.04	0	.01	0	.01	0	0
29	0	1.44e	0	0	--	.04	.01	.15	.07	.01	0	0
30	0	.05e	.11	0	--	04	.30	.04	.01	.01	.25	0
31	.50	--	.03	0	--	.05	--	.03	--	84	.20	--
Total	5.64	7.70	3 08	5.08	1.51	3 73	3.44	5.98	3.93	7.86	6.30	0
Total Annual	54.25											

TABLE A-6 ANDERSON BRANCH MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	.26	.30	4.3	.84	1.4e	1.3e	1.3	1.5	.46	.05	.30	15
2	.22	.40	2.7	.68	1.3e	1.3	1.1	1 2	.40	.30	.18	.14
3	.18	.53	2.0	.61	1.2e	3.0	1.0e	1.0	.40	.40	.15	.13
4	.15	.61	2.8	.53	1.1e	3.2	.93e	2 7	.35	.12	.18	.11
5	.15	.53	3.6	.53	1.0e	2.7	.93e	2 7	.30	.07	.84	.09
6	.10	11	3.4	.84	1.4e	2.2	.84e	2 0	.26	.07	.40	.07
7	.10	7 0	2.5	.75	1.5e	1.9	.84e	1.6	.53	.07	30	.05
8	1.0	3.8	2.0	5.3	1.3e	2.5	.75e	1 9	5.6	.07	3.6	.03
9	9 5	2.2	2.0	6.3e	1.2e	2.8	.75e	1 6	4 3	10	2.3	.03
10	1.7	1.6	1.6	6.0e	1.1	7.0	68e	1 3	2.0	.18	1.5	03
11	.84	1.0	1.5	6.0e	1.0	5.0	.68e	1 2	1.0	.35	1.3	.10
12	.46	.75	1.3	5.4e	.93	3.4	.53	1 2	1.0	.15	2.2	.07
13	.35	.61	1.2	1 8e	1.1	2.7	.53	8 7	.75	.10	13	04
14	.26	.53	1.0	1.5e	1.9	15	.53	7 4	.46	.10	3.4	.02
15	.26	.35	1.0	1.5e	1.6	5 8	.46e	5.6	.35	.93	1.5	.02
16	.40	.26	.84	1.4e	1.5e	3.2	.46e	4.3	.30	2.8	.84	.02
17	.26	1 2	.84	3.2e	1.5e	2.2	.40e	2.8	.22	.53	.53	.02
18	.26	1.7	1.3	4.4e	1.4e	1.7	.35e	1.9	.22	.26	.35	.02
19	.26	1.5	1.3	3.5e	1.3e	1.5	1.2e	1.3	.18	.18	.26	.02
20	.22	1.1	1.3	2.8e	1.3e	1.2	1.0e	1.0	.18	.18	.26	.02
21	.18	2.3	1.2	2.4e	1.2	1.3	.93	.84	.18	.15	.22	.02
22	.15	16	1.0	1.9e	1.2	1.5	.84	.68	.15	.12	.18	.02
23	.12	11	.93	1.7e	1.1	1.3	.75	.93	.15	.12	.15	.02
24	.12	4.1	1.6	6 0e	.93	1.3	.68	2.8	.12	.61	.12e	.02
25	1.0	2.7	4.5	17e	1.0	2.5	1.0	2.8	.12	2.3	.16e	.03
26	3.0	1.9	3.0	12e	1.0e	7.0	5.6	1.9	.10	1.2	.30e	.02
27	1.5	1.7	2.2	9.0e	.95e	4.5	5.0	1.3	.10	.46	.16e	.02e
28	.84	4.1	1.7	5.3e	1.4e	3.4	3.0	.93	.07	.30	.15e	.01e
29	.61	27	1.2	3.5e	--	2.7	2.2	.84	.07	.22	.13e	.01e
30	.53	8.7	1.0	2.5e	--	2.0	1.9	.75	.05	.22	.18e	.01e
31	.40	--	.93	1.7e	--	1.7	--	.61	--	.46	.18e	--
Total (cfs)	25.38	116.47	57.74	116.88	34.81	98 80	37.16	67.28	20.37	13.17	35.32	1.36
(in)	1.17	5.34	2.65	5.36	1.59	4.53	1.70	3.08	.94	.60	1.62	.06
Avg-cfs	.82	3.88	1.86	3.77	1.24	3.19	1.24	2.17	.68	.42	1.14	.04
cfsm	1.19	5 62	2.70	5.46	1.80	4.62	1.80	3.15	.99	.61	1.65	.07

TABLE A-7 BILL'S BRANCH DAILY RAINFALL (IN) - WY 1976

DAY	OCT	NOV.	DEC	JAN	FEB	MAR.	APR.	MAY	JUNE	JULY	AUG	SEP
1	39	0	0	0	.32	0	01	44	30	0	0	36
2	01	0	0	.06	03	0	0	01	02	0	0	21
3	0	0	0	.57	.07	0	.01	0	02	1 12	0	01
4	.01	.01	0	.01	01	0	04	0	0	39	.01	19
5	0	0	0	.08	.23	.62	.01	0	0	21	0	04
6	0	0	.36	02	12	0	0	.32	0	03	60	0
7	04	.75	08	27	0	01	0	.16	0	0	01	0
8	.97	0	0	0	0	.55	0	.01	0	.02	0	.01
9	01	.17	26	0	0	52	01	0	0	79	0	47
10	01	.13	0	0	01	.01	0	0	0	01	0	14
11	0	.01	0	50	.10	0	24	43	0	0	0	0
12	0	2.18	0	.01	0	.18	0	0	0	.61	0	.01
13	0	0	0	.70	.03	0	0	24	0	01	0	0
14	0	10	0	0	.01	0	0	1.02	0	0	0	0
15	0	0	.62	0	0	0	0	1.22	.02	.19	.66	23
16	54	0	0	.03	0	.23	0	32	0	10	0	0
17	1.83	.01	0	0	.11	0	0	10	0	0	0	.01
18	02	0	0	.06	1.50	.02	0	.38	0	0	0	01
19	07	0	0	0	.01	.01	0	0	1.58	0	0	01
20	0	.13	0	.05	0	.38	0	0	1.22	04	0	49
21	0	0	0	0	.47	89	.49	0	0	.58	0	0.
22	0	0	.02	.01	0	0	0	0	01	.48	0	0
23	0	0	0	0	0	0	.01	.01	01	01	0	0
24	0	0	0	.05	0	.18	.07	0	.01	0	0	01
25	.37	0	1.51	.74	0	.39	24	0	.70	01	0	0
26	.38	.24	.20	1.07	0	.36	.03	0	.01	0	.54	.25
27	0	11	0	0	0	.12	.01	0	.08	02	.25	.74
28	0	0	0	.01	0	01	0	2 31	0	0	53	0
29	.15	01	.07	0	0	2 33	0	.13	.29	59	.06	.58
30	0	.84	24	0	--	85	26	0	.23	.37	.01	.30
31	0	--	1.09	.02	--	.38	--	0	--	.25	0	--
Total	4.80	4.69	4.45	4.26	3 02	8.04	1 43	7 10	4 5(	5 83	2.67	4 09
Total Annual		54 88										

TABLE A-8 BILL'S BRANCH MEAN DAILY FLOW (CFS) - WY 1976

DAY	OCT	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG	SEP
1	.85	53	4 6	8.2	4 0	85	7 8	56	.88	.40e	2 0	50
2	.84	51	3 0	4.4	3.5	.77	5.0e	33	1.9	13	1.0	24
3	.73	.46	1 8	6.4	2 5	.72	3.0e	.26	2.0	1.6	90	.12
4	.70	.44	1.4	4.4	1.3	.69	2.0e	.22	.91	2.4	80	.13
5	67	.40	1 1	3.1	1.4	1.1	1.5e	.20	.73	9 0	.75	11
6	66	37	1.1	2 0	2.3	.99	1.0e	19	48	5 2	1 2	08
7	.67	2 1	1 4	2.5	2.0	.93	.90e	.42	.35	3 1	.91	.06
8	1 9	1.5	1 2	2.1	1.8	1.2	.80e	.25	.26	2 3	.82	05
9	1 3	1.3	1 4	1 7	1.5	7 7	70e	19	.22	4.3	.79	.35
10	98	1.7	1 3	1 6	1.3	5 2	.60e	18	.19	2 3	.76	28
11	91	1.5	1.2	3.4	1.2	3.1	56e	44	.15	.88	73	10
12	80e	28	1.1	3.4	98	2 3	46	.23	.12	1.8	72	.07
13	75e	7.9	1.0	7.9	.88	1 7	.42	.22	10	1.3	70	06
14	70e	3.9	.96	7.9	.80	1.3	.40	.56	.09	1 2	70	05
15	67	3 0	1.6	4.4	.73	1 2	35	14	07	1 1	1.1	07
16	76	2 4	2.5	3.0	72	1.3	32	3 9	06	1 0	.90	.06
17	16	2 1	1.9	2 0	.72	1.1	.30	2.4	06	95	.47	05
18	5 8	2.0	1.5	1 9	16	96	28	3 4	.05	.88	23	04
19	2 4	1.9	1.2	1 8	8.2	91	26	2 5	1.4	.82	23	04
20	1 2	2.7	1 2	1 4	4.0	1 0	25	1 5	4 5	79	23	.23
21	88	2 7	1 1	1 3	3.4	14	42	88	1 3	1 4	.23	10
22	73	2.2	.98	1 2	3 2	4 6	31	.76	95	1.6	.23	.06
23	.58	1.8	.91	1 1	2 2	2 9	23	61	.70	1.2	23	04
24	48	1 1	86	1 2	1 8	2 2	22	51	58	91	23	.04
25	49	.99	6.3	2.6	1.5	3.3	.30	.42	1.1	82	.23	04
26	1 0	.88	13	25	1.3	3 0	.23	35	73	88	.40	07
27	88	1.2	4 8	10	1 1	3 4	20	30	53	95	50	75
28	76	.92	3 0	5.4	1 0	2 9	14	5 0	46	1.0	.90	21
29	.79	87	1 9	4 1	.92	27	.16	9 9	46	2 0e	80	.71
30	67	3.0	2.2	3.5	--	29	18	2 7	56	2 6e	60	77
31	61	--	11	3 5	--	8 6	--	1 3	--	2 5e	30	--
Total												
(cfs)	47 16	80.37	78 51	132 4	72 25	135 92	29 29	54 68	21 89	57 31	20 59	5 48
(in)	2 61	4.46	4 35	7 34	4 01	7 54	1 62	3 03	1 21	3 18	1 14	.30
Avg-cfs	1.52	2 68	2 53	4 27	2 49	4 38	98	1 76	73	1 85	66	18
cfsm	2 27	4 00	3 78	6 37	3 72	6 54	1 46	2 63	1 09	2 76	99	27

TABLE A-9 BILL'S BRANCH DAILY RAINFALL (IN) - WY 1977

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1	0	0	0	0e	0e	0	0e	0e	0e	01	29	89
2	0	0	0	0e	0e	53	1 30e	0e	0e	0	0	0
3	01	0	0	20e	0e	02	1 10e	40e	0e	0	0	22
4	0	0	0	0e	0e	0	4 60e	0e	0e	0	0	0
5	0	0	0	10e	02	0	10e	0e	0e	0	06	0
6	71	0	1 15	40e	0	0	0e	0	73	0	0	78
7	04	0	32	0e	0	0	0e	10	0	0	0	1 20e
8	25	0	0	0e	0	0	0e	05	0	0e	1 01	0e
9	49	0	02	.70e	0	02	0e	0	0	0e	04	0e
10	0	0	0	10e	0	0	0e	0	0	0e	21	0e
11	0	0	27	0e	0	0	0e	0	0	10e	0	0e
12	01	06	33	0e	55	2 37	0e	0	20	0e	0	0e
13	0e	06	0	0e	[illegible]	01	0e	0	55	0e	32	50e
14	0e	14	0	46	06	0	0e	0	01	02	01	50e
15	0e	11	22	06	02	0	0e	0	0	0	0	70e
16	10	0	01	0	01	0	0e	0	10	0	0	60e
17	0e	0	0	05	0	0	0e	12	0	0	0	0e
18	0e	01	0	03	0	03	10e	0	04	0	0	0e
19	0	0	03	01	0	30e	0e	0	07	0	0	0e
20	25	0	34	0e	02	10e	0e	0	0	0	0	0e
21	0	0	05	0e	0	0e	0e	0	0	18	0	0e
22	0	0	0	0e	0	20e	60e	0	0	22	01	0e
23	02	0	0	0e	37	0e	1 20e	11	0	0	0	0e
24	90	0	0	10e	83	0e	10e	0	0	0	1 29	0e
25	2 41	0	14	10e	0	0e	0e	01	1 57e	2 04	0	70e
26	01	32	07	20e	0	0e	0e	0	70e	0	0	1 20e
27	0	01	0	0e	55	0e	0e	0	0e	0	0	60e
28	0	50	0	0e	0	20e	50e	0	0e	0	0	0e
29	0	06	0	0e	--	20e	40e	50e	0e	29	0	0e
30	22	03	14	0e	--	80e	0e	0e	0e	0	0	0e
31	22	--	0e	0e	--	0e	--	0e	--	0	0	--
Total	5 64	1.30	3 09	2 51	2 44	4 78	10 00	1 29	3 97	2 86	3 24	7 89
Total Annual	49 01											

TABLE A-10 BILL'S BRANCH MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1	33	1 6	92	20e	50e	1 7	3 3	1 2	31	31	14	76
2	19	1 2	72	20e	50e	1 3	4 6	92	31	25	12	23
3	14	92	66	30e	40e	1 2	12	1 3	29	23	09	22
4	11	72	61	30e	40e	4 6	100e	78	27	21	08	19
5	10	56	56	30e	37	2 9	10e	72	27	21	10e	16
6	38	51	5 7	50e	61	2 0	5 0e	61	85	19	10e	1 5
7	62	47	13	40e	72	1 5	2 0e	56	10	19	10e	4 0e
8	29	40	4 1	40e	85	1 2	1 0e	56	08	16	2 0e	1 5e
9	2 2	40e	2 3	1 0e	78	1 0	90e	47	08	10e	1 5e	1 2e
10	54	30e	1 7	90e	34	85	80e	40	06	10e	1 3e	1 0e
11	32	30e	1 4	80e	37	72	70e	37	06	10e	1 0e	80e
12	22	20e	2 6	80e	2 3	14	60e	34	31	10e	80e	70e
13	20e	20e	2 2e	70e	2 3	9 2	60e	31	85	10e	1 0e	1 0e
14	20e	30e	2 0e	1 5e	1 7	2 2	61	29	1 2	10e	90e	2 5e
15	20e	40e	2 0e	1 5e	1 5	1 5	51	29	34	06	80e	3 5e
16	20e	40e	1 5e	1 4e	1 2	1 0	47	27	40	05	70e	6 0
17	20e	30e	1 0e	1 4e	90e	92	43	25	27	05	60e	3 5
18	20e	30e	80e	1 4e	56	92	43	27	21	05	40e	2 3
19	22	20e	70e	1 3e	51	78	40	25	1 1	05	20e	1 7
20	56	20e	80e	1 2e	47	92	37	25	1 0	05	10e	1 1
21	31	20e	70e	1 0e	40	85	37	25	34	05	10e	1 0
22	27	20e	60e	90e	43	1.0	.43	23	30e	08	05	85
23	25	10e	50e	80e	66	66	1 6	31	30e	07	06	.72
24	61	10e	40e	70e	11	56	1 9	27	20e	05	1 3	61
25	18	10e	50e	70e	3 1	51	1 1	12	17e	1 1	17	2 3
26	5 4	34	40e	80e	1 9	47	85	12	10e	29	11	6 0
27	2.0	51	40e	80e	3 5	43	.72	10	2 0e	22	08	7 3
28	1 2	.43	30e	70e	2 3	.47	72	10	1 0e	18	07	3 5
29	66	.85	30e	70e	--	43	2 9	1 0	50e	23	.06	2 0
30	2.6	1 0	30e	60e	--	5 7	1 6	56	32	19	06	1 4
31	3 3	--	30e	60e	--	5 7	--	40	--	16	06	--
Total												
(cfs)	42 02	13 71	49 97	24 80	40 57	67 19	156.19	13 87	40 32	5 28	14 15	59 54
(in)	2 33	76	2 77	1 37	2 25	3 72	8 70	77	2 24	29	78	3 30
Avg-cfs	1.36	46	1 61	80	1 45	2 17	5 23	45	1 34	17	46	1 98
cfsm	2 03	69	2 40	1.19	2 16	3.24	7 81	67	2 00	25	69	2 90

TABLE A-11 BILL'S BRANCH DAILY RAINFALL (IN) - WY 1978

DAY	OCT.	NOV	DEC	JAN	FEB	MAR.	APR	MAY	JUNE	JULY	AUG	SEP
1	0e	0	10e	04	01	05	02	05	01	05	0	02
2	0e	0	0e	0	0	40	03	03	07	85	02	03
3	0e	03	0e	01	01	13	01	10	02	13	08	04
4	0e	20	1 40e	0	02	0	08	78	0	07	18	03
5	0e	.33	20e	15	0	0	02	01	01	03	0	04
6	0e	1.22	.10e	40	0	0	02	01	01	02	01	01
7	0e	14	0e	14	0	02	03	16	1 04	03	01	0
8	2 30e	0	30e	1 13	01	18	04e	75	1 20	10	0	0
9	1 10e	.17	20e	02	0	44	03e	02	04	90	01	0
10	0e	05	0e	0	0	34	03e	02	03	37	0	0
11	10e	0	0e	0	01	0	20e	02	05	03	58	47
12	0	0	0e	0	0	20	02	48	56	04	66	02
13	0	0	0e	0	.29	0	05	1 13	04	03	15	0
14	0	0	0e	0	0	08	06	50	06	04	05	02
15	23	0	0e	0	0	0	03	23	05	1 89	03	09
16	04	77	02	0	11	08	05	0	04	88	10	0
17	0	45	48	0	0	03	04	0	05	02	02	0
18	0	0	04	01	0	11	1 35	0	06	03	0e	0
19	0	18	0	01	0	04	07	0	04	02	0e	0
20	0	.42	02	0	0	02	04	0	06	02	05e	0
21	0	1 00e	0	0	.01	42	12	0	04	02	0e	0
22	0	1 50e	0	0	01	02	03	0	05	04	0e	0
23	0	10e	01	03	.01	02	04	13	06	04	0e	0
24	0	0e	1 62	84	0	12	08	29	06	20	02	04
25	1 50e	0e	0	1.36	.08	97	62	02	05	58	26	0
26	0	0e	0	0	0	10	51	0	06	01	04	0
27	0	70e	0	0	0	07	02	0	05	02	04	0
28	0	.50e	0	0	14	02	03	0	04	01	04	0
29	0	1.50e	0	0	--	03	.07	0	10	01	05	0
30	0	10e	16	0	--	02	.33	0	04	01	62	81
31	03	--	02	0	--	03	--	01	--	86	07	--
Total	5 30	9 36	4 67	4 14	0.71	3 94	4 07	4 74	3 99	7 35	3 09	1 62
Total Annual	52 98											

TABLE A-12 BILL'S BRANCH MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1	1 6	92	6 4	85	62e	1 2	1 4	92	21	09	27	27
2	1 4	78	3 7	66	47e	1.3	1 3	78	21	10	23	27
3	1 2	72	2 6	56	37e	3 3	1 1	72	23	21	21	27
4	1 0	78	5.4	56	.31e	2 3	1 0	1 9	21	12	31	25
5	85	72	7 3	56	27e	2 0	92	1 6	21	10	72	23
6	72	13	4 1	1 2	23e	1 7	82	1 2	21	10	61	10
7	66	5.4	2.5	1 1	86e	1 7	78	1 1	34	09	40	04
8	5 7	3 1	1 9	22	23e	3 9	41e	2 8	1 4	09	34	04
9	33	2 2	2 2	11	19e	4 4	31e	2 6	43	08	34	02
10	3.7	1 7	1 4	8 5	61e	11	29e	1 4	31	12	96e	02
11	2 0	1 3	1 3	8 5	61	4 4	37e	1 3	25	09	96e	07
12	1 3	1 1	1.2	8 5	55	3 3	1 5	1 4	25	06	1 6e	04
13	92	92	1 2	7 8	70	2 5	1 4	3 9	23	05	6 2e	04
14	85	85	1.3	8 2	1 4e	14	1 4	3 7	19	05	2 4e	04
15	78	72	92	8 5	1 3	4 6	1 4	1 9	19	56	1 9e	04
16	85	1 0	85	8 5	1 4	3 9	1 4	72	19	1 5	1 4e	04
17	66	7 3	92	12	1 5	4 1	1 4	51	19	27	40e	04
18	61	2 9	1.9	4 1	1 5	3 7	3 5	40	16	21	28e	04
19	56	2 0	1 5	2 9	1 4	3 3	1 9	34	14	16	23e	04
20	51	1 5	1 4	2 2	1 7	2 9	1 3	31	14	14	16e	.04
21	47	3.5	1.2	1 6	1 3	3 5	1 1	29	14	14	16e	04
22	47	22	92	1 4	1 4	3 5	92	27	12	12	10e	04
23	.47	11	85	1.3	1 2	3 3	85	27	12	12	09	04
24	47	4 1	8 5	12	1 1	3.1	85	.29	10	12	29	04
25	6 7	2 6	11	43	1 2	5 7	92	27	10	19	29	04
26	7 3	1 7	3 7	15	1 2	6 4	2 6	25	10	16	3 1	04
27	3 3	2 8	2 2	3 5	2 0	3 3	2 3	25	09	12	29	06
28	2 0	6 4	1 4	2 9	1 2	2 5	1 5	24	09	12	27	07
29	1 6	33	1 1	1 5e	--	2 2	1 2	23	09	10	25	07
30	1 3	8 5	1 1	1 4e	--	1 9	1 1	23	09	10	37	07
31	1 1	--	1 0	70e	--	1 6	--	22	--	37	29	--
Total (cfs)	84 05	144 51	82 96	202 49	26 82	116 5	37 24	32 31	6 73	5 85	25 42	2 45
(in)	4 66	8 01	4 60	11 23	1 49	6 46	2 06	1 79	37	32	1 41	14
Avg-cfs	2 71	4 82	2 68	6 53	96	3.76	1 24	1 04	22	19	82	08
cfsm	4 05	7 19	4 00	9 75	1 43	5 61	1 85	1 55	33	28	1 22	12

TABLE A-13 BOWLING BRANCH DAILY RAINFALL (IN.) - WY 1976

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1			--	0	35	0	0	46	67	0	0	39
2			0	07	07	0	0	01	61	0	0	10
3			0	52	08	0	0	0	01	1 29	0	0
4			0	0	0	0	06	0	01	39	0	17
5			0	01	13	59	0	0	0	64	0	01
6			35	39	12	0	0	27	0	0	55	0
7			07	04	0	0	0	28	0	0	.01	0
8			0	03	0	50	0	01	0	10	0	0
9			30	0	0	52	0	0	0	37	0	1 16
10			0	0	0	0	0	0	0	0	0	.28
11			01	25	11	0	17	85	0	0	0	0
12			0	0	0	23	0	0	0	60	0	0
13			0	62	02	0	0	17	0	.02	0	0
14			0	0	.01	0	0	79	0	0	0	0
15			81	0	0	01	0	1.19	0	0	.16	.21
16			01	03	0	11	0	13	30	03	0	0
17			01	0	0	02	0	.08	0	0	0	0
18			0	.10	1.34	01	0	55	0	0	0	0
19			01	0	0	0	0	01	1 25	0	0	0
20			0	.07	0	.25	0	0	1 59	0	0	.43
21			0	0	41	75	40	0	34	05	0	01
22			03	0	.01	0	01	0	01	1 01	0	0
23			01	0	0	0	0	0	0	01	0	0
24			0	.01	0	11	.03	0	0	0	0	0
25			1 50	93	02	33	24	0	84	01	0	0
26			26	1 07	.01	28	04	0	0	0	14	05
27			01	0	0	.09	0	03	20	27	15	1 00
28			.01	.12	0	0	0	2 22	12	01	1 46	01
29			05	0	0	2 75	0	15	13	25	0	76
30			21	0	--	48	21	01	15	10	0	42
31			1 20	0	--	.41	--	0	--	15	0	--
Total			--	4.26	2 68	7 44	1 16	7 21	6 23	5.30	2 47	5 00
Total Annual	--											

TABLE A-14 BOWLING BRANCH MEAN DAILY FLOW (CFS) - WY 1976

DAY	OCT.	NOV.	DEC	JAN	FEB.	MAR	APR	MAY	JUNE	JULY	AUG.	SEP
1			--	26	3.0e	2 1e	17	.73e	3 5e	2 0e	29	09e
2			5.2e	13	2.5e	1.8e	10	.73e	5.9e	1.3e	20e	14e
3			3 7e	14	2 1e	1.7e	6 2e	59e	8 6e	4.8e	18e	09e
4			2 4e	13	1 9e	1 7e	4.8e	.52e	6 2e	16	16e	09e
5			1 6e	8.6	1.7e	2 0e	3.7e	46e	4 2e	19	15e	12e
6			1 3e	6.6	1 6e	2 1e	3 1e	40e	2 6e	13	50	09e
7			1.5e	5.8	1 5e	2.0e	2 4e	73e	1 7e	5 4e	51	.07e
8			1 4e	6.6	1 4e	2 1e	2.0e	66e	1 3e	3 1e	25e	07e
9			2 1e	6 2	1 3e	14	1.8e	52e	1 1e	3 1e	18e	46e
10			2 7e	5.9	1.2e	12e	1 4e	.59e	91e	2 0e	12e	1 0e
11			2.6e	4.6e	2 0e	8 0e	1 3e	1 8e	73e	1 3e	09e	25e
12			1.9e	4.4e	1 8e	5 9e	1.2e	1 2e	.59e	1 8e	05e	14e
13			1 4e	63	1 6e	5 6e	1.1e	91e	52e	1 4e	05e	12e
14			1 1e	12	1.5e	3 3e	1 0e	1.0e	46e	1 0e	04e	09e
15			1 5e	8.7	1 3e	2 7e	91e	30	40e	95	03e	07e
16			6 5e	6 9	1 1e	2 6e	.82e	12	40e	82	03e	07e
17			6 0e	5 6	1 0e	2 0e	73e	6 2e	52e	71	03e	07e
18			3 7e	5.1	18e	1 7e	73e	9 0e	34e	56	03e	07e
19			3.2e	4.2e	20e	1 7e	73e	9 3e	1 7	44	02e	05e
20			3.9e	2 7e	8 0e	1.7e	66e	5 6e	28	27	02e	14e
21			2 6e	2 1e	6.5e	8 3e	73e	3 7e	19	12	02e	18e
22			2 1e	1 8e	7.7e	8 0e	1 1e	2 4e	14	1 8	02e	12e
23			2 1e	2.1e	5.9e	5 9e	.66e	1 7e	5 9e	1 5	02e	07e
24			2.0e	1.8e	4 6e	4.8e	59e	1 3e	3 7e	67	01e	07e
25			12	2.8e	4 2e	4 8e	59e	1 1e	5 1e	39	01e	05e
26			39	46	4.0e	4.6e	59e	.82e	8 3e	26	02e	05e
27			17	26	3 3e	5 1e	52e	66e	6 2e	14	03e	05e
28			11	11	2.7e	5 1e	46e	3 3e	4 4e	20	52e	59e
29			8.5	7.4	2 3e	66	.40e	22e	3 3e	26	25e	46e
30			7.6	5 4	--	59	40e	9 0e	2 6e	42	12e	73e
31			29	3.7e	--	23	--	4 8e	--	44	07e	--
Total												
(cfs)	--	--	--	333 0	115.7	271 3	67 62	133 72	142 17	85 15	4 02	5 66
(in)	--	--	--	5.65	1.96	4.61	1 15	2 27	2.41	1.45	07	10
Avg-cfs	--	--	--	10.7	3.99	8.75	2 25	4.31	4.71	2 75	13	19
cfsm	--	--	--	4.89	1 82	4 00	1.03	1 97	2 16	1 26	06	09

TABLE A-15 BOWLING BRANCH DAILY RAINFALL (IN.) - WY 1977

DAY	OCT.	NOV	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	0	.01	.01	.01	0	.01	.01	.01	0	.01	0	.51
2	0	0	.02	.02	0	.01	1.07	0	0	01	0	.01
3	0	0	0	.19	.07	.21	1.08	35	0	.02	0	0
4	0	0	0	.03	.02	.63	4.16	.02	0	01	0	0
5	0	0	0	.14	0	0	.12	0	0	0	0	0
6	.60	0	1.03	.27	0	0	0	.20	.33	0	0	.63
7	.05	0	.43	.02	0	0	0	.13	0	0	0	.98
8	.27	0	0	0	0	0	0	0	0	0	0	0
9	.50	.01	.04	.50	0	.04	0	0	.13	0	.01	0
10	0	0	.01	.07	0	0	0	0	0	.09	0	0
11	0	0	.25	0	0	.04	0	0	0	.07	.01	0
12	0	.29	.36	0	.46	1.69	0	0	.07	0	.01	0
13	0	.02	0	.01	0	.02	0	0	.13	.04	0	48
14	0	.06	.01	.40	.14	0	0	0	.76	.05	0	.49
15	0	.04	.24	0	.02	.01	0	0	0	0	0	.66
16	.10	0	0	0	0	0	0	0	.01	0	0	.56
17	0	0	0	0	0	.01	0	0	.12	0	28	.01
18	0	0	0	0	.03	.28	.11	0	.02	0	0	0
19	0	0	.06	0	0	.33	.02	.19	.01	0	0	.03
20	.50	0	.26	0	.01	.09	0	0	07	0	0	0
21	0	0	0	.02	0	.02	0	0	02	.18e	0	0
22	0	0	.03	.02	.01	.21	.48	.04	02	.20e	0	0
23	01	0	0	.01	.41	0	1.36	.83	.03	0e	0	0
24	.50	0	0	.12	.77	0	.12	0	.02	0e	.47	0
25	2.32	.01	41	.16	0	.01	.01	.08	.03	1.5e	0	.81
26	0	.32	.04	.07	.01	0	0	.16	.02	0e	0	.99
27	.01	0	.01	.01	.51	0	0	0	.05	0e	0	.65
28	0	40	0	0	0	.18	.46	0	.22	0e	0	0
29	0	0	0	0	--	.20	.48	.37	0	25e	0	0
30	.75	.23	.29	0	--	.44	.04	0	.04	0	0	0
31	0	--	0	0	--	0	--	.03	--	0		--
Total	5.61	1.39	3.50	2.07	2.46	4.43	9.52	2.41	2.10	2.43	0.78	6.81
Total Annual		43.51										

TABLE A-16 BOWLING BRANCH MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	.91	4.1	1.4	3.1	.48e	7.7	4.2	4.7	.29	.80	03	.30e
2	.51	2.9	1.6	3.1	.44e	6.3	6.0	3.6	.21	59	02	.29e
3	.38	2.0	2.0	3.0	1.1e	5.3	24	3.0	.15	.35	02	.28e
4	.27	1 6	2.0	2.5	1.0e	11	102	2.6	.11	.25	02	.27e
5	.25	1 2	1.7	2.7	.98e	12	13	1.9	09	.19	.01	1 1
6	1.2e	.95	7.3	3 3	.96e	8.3	13	1 8	15	18	01	3.0
7	.74	.83	32	4.7	.95	6.5	7.3e	1.4	14e	15	.01	1.8
8	.47	.73	13	4 7	.93	5.4	5.2e	1 3	.10	.13	.01	.21
9	2.9	.66	6.4	4.7	.91e	4.5	4.2e	1.1	.07	.11	07	.18e
10	1 5	.65	4.8	11	.89e	4.0	3.4e	.88	06	08	.07	.12e
11	.98	55	3.9	12	87e	2.8	2.8e	.73	.04	.07	11	05e
12	.63	.52	6.8	8.5e	2.8	20	2.4e	.66	.03	.14	29	02e
13	.48	.60e	7.9	5 3	4 4	27	2.1e	.53	.07	.20	.29	.25e
14	.40e	.96e	6.0	4.6	4.1	10	1.9e	.45	.75	.10	.25	34e
15	.36	1 2e	5.1	5.2	4.1	6.3	1.6e	.40	.20	.07	.23	59e
16	.34	.88e	4.5	4.2e	3.7	4.9	1 5	.34	.12	.06	.22e	.52e
17	.34	.74e	4.2	3.4e	3.7	4.0	1.3	30	12	.04	.21	1.2e
18	.34	.64e	3.5	4.1e	2.7	4.1	1.2	.25	.10	04	.21	.73e
19	.32	.56e	3.1	3.7e	3.0	3.5	1.1	.24	.28	03	.20	46e
20	.52	.50e	3.3	3.4e	2.7	4.5	1.0	.23	.25	02	.17	30e
21	.57	.45e	3.5	1.9e	2.3	4.7	.99	.21	.21	.02	13	.18e
22	.43	.41e	3.5	.96e	2.2	5.3	.91	.18	.61	.02	09	.12e
23	.37	.38	3.1	1.2e	2.3	4.7	10	.39	1.4	.02	.07	.07e
24	.35	.34	2.7	1.1e	31	4.2	17	.64	2.6	.04	.08	.04e
25	22	.34	2.5	.89e	14	3.7	7.6	32	7.7	85	.09	.09e
26	11	.37	3 3	.89e	8.3	3.1	4 7	.22	7.8	.41	.09	5.1
27	4.1	.52	3.4	.92e	10	2.7	3 4	.21	2 9	.16	.08	2.9
28	2.3	.68	3.5	.68e	10	2.4	2 6	21	1.5	08	.05	3 1
29	1.6	1.4	3.4	.68e	--	2.2	8.5	1.4	.79	.05	.04	2.7
30	2.0	1.4	3.2	.66e	--	3.6	6.6	.95	.52	05	.03	2.1
31	5.4	--	3.1	.53e	--	4.2	--	.42	--	.04	.02	--
Total (cfs)	63.96	29.06	155 7	107.61	120 81	198 9	281.5	31.56	29.36	5.34	3.22	28.41
(in)	1.09	.49	2.64	1.83	2.05	3.38	4.78	.54	50	.09	.05	.48
Avg-cfs	2 06	97	5.02	3 47	4.31	6 42	9 38	1.02	98	.17	.10	.95
cfsm	.94	44	2.29	1 58	1 97	2.93	4.28	.47	45	.08	05	.43

TABLE A-17 BOWLING BRANCH DAILY RAINFALL (IN) - WY 1978

DAY	OCT.	NOV.	DEC	JAN.	FEB	MAR	APR	MAY	JUNE	JULY	AUG.	SEP.
1	0	0	.15e	.02	.02	05	05	01	0	02	0	0
2	.01	0	0e	0	0	47	04	0	.06	1.28	.01	.01
3	0	.01	.05e	0	01	07	.04	03	14	.07	.09	0
4	0	.32	1.40e	0	.20	0	04	65	0	0	.33	.01
5	0	11	15e	.04	0	.02	.03	0	0	0	.49	.01
6	.01	1.36	.10e	.29	.01	.01	.03	0	0	0	.21	0
7	0	.42	0e	05	0	03	03	10	81	0	.29	.01
8	1.97	0	.07	1.19	0	.21	06	.66	2 15	06	1.85	0
9	1.16	0	23	0	0	.41	.04	02	.04	.54	.24	0
10	0	.17	0	01	0	21	.04	.01	0	.06	0	0
11	.04	0	0	.04	0	.02	29	0	0	.01	.35	.64
12	.03	0	0	.09	0	12	0	.54	42	0	.60	0e
13	0	0	0	0	.47	03	0	1 28	0	0	1 00	0e
14	0	0	.16	0	0	.07	0	40	0	0	24	0e
15	.10	0	.06	.07	.01	0	0	.21	0	1 20	0	0e
16	.20	.28	.01	.01	.13	.16	0	0	0	.50	16	0e
17	.01	.70	.37	.75	0	04	0	0	0	0	01	0e
18	0	0	05	01	.02	.11	1 21	0	0	0	0	0e
19	0	0	0	.22	0	.03	05	0	02	0	0	0e
20	0	.25	.06	0	.01	.02	.10	0	0	0	.08	0e
21	0	.68	0	0	.01	.33	.05	0	0	0	0	0
22	0	1.80e	0	.33	.19	.03	.01	0	0	0	0	0
23	0	07e	.01	0	.08	.03	0	.29	0	0	0	0
24	0	.03e	1.07	.80	.12	.06	.04	74	0	.18	0	0
25	1.35	.02e	0	1 27	.01	.86	90	.05	0	1.15	.44	0
26	.14	0e	0	0	0	.11	.50	.01	0	.01	.03	0
27	0	.58e	0	.07	.01	.07	.01	0	0	0	01	0
28	0	.70e	.01	0	.23	04	0	0	0	0	0	0
29	0	1 50e	0	0	--	.04	.01	0	08	0	0	0
30	0	05e	.12	.01	--	.04	.51	0	0	0	.33	52
31	.33	--	.03	0	--	.05	--	.01	--	.24	.21	--
Total	5.35	9.05	4.10	5.27	1.53	3.74	4.08	5 01	3 72	5 32	6 97	1.20
Total Annual	55.34											

TABLE A-18 BOWLING BRANCH MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	1.3	2.4	12	2.7e	2.1e	3.4	3.6	5.3	40	.05	59	.25
2	1.0	1.9	7 7	1.9e	1.6e	3.9	3.0	4.6	34	.40	59	.21
3	.73	1.9	5.9	1.4e	1.2e	5.4	2.4	4.0	34	1.0	59	.18
4	1.4	1.9	8.6	1.3e	1.0e	6.2	2.2	8.4	34	.18	.59	14
5	1.1	2.1	16	1.3e	.92e	5.7	2 1	8 8	30	12	59	12
6	.56e	46	11	3.4e	.72e	4.6	1.9	6.0	25	07	59	.12
7	.14	32	8.3	2.3	1.8	4.2	1.8	4.6	73	07	59	.09
8	.14	22	7.7	16	1.8	5 6	1.6	5.9	18	07	5 9	07
9	38	15	7.1	20	1.9	7.3	1.5	7 0	12	.21	1 9	.05
10	7.4	12	6.8	19	2.0	19	1.4	5.6	5 1	.18	.26	05
11	4.2	9 3	6 5	19	2 0	12	1.4	4.3	2 6	07	2 7	14
12	2.6	8 6	5.9	17	1.8	7.8	1.4	4 1	1 9	.05	4 4	.28e
13	1.8	7.7	5.6	3.1	2.3	5.8	1.3	26	1 6	.05	9 3	23
14	1.6	7.1	5.4	4.8	3.3	29	1.1	19	91	05	2 4	23e
15	1.4	6.5	4.5e	4.8	3.1	15	1.0	15	66	1 8	1 6	25e
16	1.7	6.2	1.6e	4.4	3.3	7.0	.97	10	52	2 1	.91	.23e
17	1.3	14	1.7e	10	3.2	5.6	.84	6 8	.46	59	1.3	.21e
18	1.2	14	4.5e	14	3.1	4.3	5.7	4.2	30	46	91	19e
19	1 0	12	3 6e	11	3.1	3.9	6.0	3.1	25	40	73	.17e
20	.91	11	3.3e	9 0	3.0	3.4	4.4	2 3	25	40	.52	.04
21	.82	16	2 5e	7 7	2 8	3 4	3 7	1 7	21	.40	52	.04
22	.73	51	1.8e	6.1	2.7	3.7	3.1	1.3	18	.40	.34	.04
23	.66	38	1.5e	5.4	2.7	3.7	2.5	1.3	.18	.34	30	.04
24	.66	21	10e	19	2 3	3.6	2.2	1 9	12	.52	21	04
25	5.1	15	22e	55	2.6	6.1	3.2	1 8	12	2.4	21	.04
26	13	14	10e	38	3 3	19	20	1.2	09	82	.73	.04
27	7.1	15	7.0e	19	3.3	12	15	1 0	.07	66	30	.04
28	4.6	24	4.5e	7 2e	3.8	7.8	8.3	.82	.07	.66	.25	.03
29	3.3	55	3 4e	4.9e	--	6.0	5 2	73	.07	.59	.18	03
30	2 6	25	3 2e	4.9e	--	4.6	5.0	.59	.05	59	.34	.03
31	2 1	--	3 0e	2 3e	--	3.9	--	.52	--	.59	34	--
Total												
(cfs)	110 15	507 6	202.6	335 9	66 74	232 9	113 81	167.86	48 41	16 29	43 02	3 62
(in)	1.87	8.62	3 44	5 70	1.13	3 95	1 93	2 85	82	28	73	.06
Avg-cfs	3 55	16 9	6 54	10.8	2.38	7.51	3 79	5 41	1 61	53	1 39	12
cfsm	1 62	7 72	2 99	4 93	1 09	3 43	1 73	2 47	74	24	64	06

TABLE A-19 GREEN BRANCH DAILY RAINFALL (IN) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1			--	.02	.42	0	.02	.43	91	0	.01	35
2			0	.11	.03	.01	.01	.04	.03	0	0	20
3			0	.55	.06	0	.01	0	.03	1 07	0	01
4			0	.01	0	.01	.06	0	.01	38	02	15
5			0	0	.12	.59	.01	0	.01	43	0	03
6			07	0	.11	.02	0	.26	0	.06	.44	01
7			.01	.40	.03	.01	0	.22	0	.02	.03	0
8			.26	0	0	.42	0	0	0	.05	0	0
9			0	.01	.01	.53	0	.01	0	.75	0	.62
10			.04	0	.02	.04	0	0	0	.01	0	.12
11			0	.64	.08	.01	.15	.44	0	0	0	0
12			0	.02	.02	.15	.03	.01	0	.40	0	0
13			0	.83	0	.01	0	.20	0	0	0	0
14			.01	.01	.03	0	0	1.07	0	.01	0	0
15			.57	0	0	.01	0	1.29	0	0	1.10	.20
16			0	.03	0	.26	.01	.33	.02	.06	0	.03
17			0	.01	.10	.03	0	11	.01	02	02	0
18			0	.06	1.49	.03	0	40	.01	0	0	0
19			.01	0	.02	0	0	01	63	0	01	0
20			01	.03	0	.26	0	.01	.94	.11	0	.41
21			0	01	.47	1.04	.51	.08	02	.91	0	.03
22			01	.01	0	0	.02	.02	.01	85	0	0
23			0	0	.02	0	0	0	0	03	0	0
24			0	.09	.01	.16	.03	0	.01	.01	0	0
25			1.50	.84	01	.46	.25	0	80	01	0	0
26			.20	1.28	0	.36	.03	0	.02	0	.50	0
27			0	.02	0	.14	.01	0	.03	0	.20	0
28			.01	.02	0	0	0	2.44	.12	01	.50	0
29			.05	0	0	2.31	0	.21	.25	88	.05	60
30			.28	0	--	.87	.18	.02	.27	25	.01	.30
31			1.26	0	--	.35	--	0	--	.27	0	--
Total			4.29	5 00	3.05	8.08	1.33	7 60	4.13	6.59	2.89	3.06
Total Annual	--											

TABLE A-20 GREEN BRANCH MEAN DAILY FLOW (CFS) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP
1			--	9.7	4.8	1.8	6.7e	1.3	2.2	3.0	79e	.85
2			3.7	5.4	3.7	1.7	4.6e	.70	4 6	4.0	65e	.90
3			3.1	9.1	3.3	1.6	3.5e	.53	4 4	4 7	.50e	65
4			2.6	5.3e	3.3	1.6	2 7e	.48	2.5	2 0	.38e	43
5			2.1	4.6e	3.5	2.4	2.3e	47	1.8	17	.32e	.50
6			2 2	3.5e	4 5	2.0	2.0e	.43	1.4	11	1.2e	.38
7			2.9	2.9e	3.3	1 7	1.7e	94e	1.2	6.1e	49e	.32
8			2.4	2.6e	3.1	2.0	1 3e	67	1.0	4 8e	.38e	28
9			2.9	2.3e	2.7	8.2	1 1e	.60	.86	5 8e	.32e	1.0
10			2.4	2.0	2.7	5.8e	1.1e	.53	.74	2 4e	28e	1.2
11			2 2	5 1	2 7	4.1e	1 2e	1 5	.67	1.5e	24e	2.0
12			2.0	4.5	2.1	3 7e	1.1e	85e	.60	2 1e	.20e	1 6
13			1.7	11	1.8	2.9e	1 0e	.85e	.55	1.7e	.20e	1 2
14			1.6	8.8	1.7	2.4e	94e	2.1e	.53	94e	.17e	1 0
15			3.1	6.1	1.6	2.4e	.77e	27	.47	1.3e	2 9e	1.2
16			4.8	4.8	1.6	2 6e	.77e	9 6e	.46	1 1e	.49e	94
17			3.5	3.5	1.5	2 1e	69e	7 0e	47	.77e	.20e	.77
18			2.7	3.3	16	1.8e	.69e	8.9e	42	62e	.09e	.69
19			2.6	3.2	9.9	1.8e	.69e	7 0e	4.9	.55e	.07e	.62
20			2.4	2.4	6.3	2.0e	69e	5.3e	10	69e	.07	70
21			1.8	2.1	6.6	16	1 3e	3.7e	6.0	2 7e	.06	.77
22			1.7	1.8	6.3	6.4e	1.0e	2.7	4.3	2.9e	.06	.62
23			1.7	1.8	5.0	4 1e	.69e	2.7	3 7	1.5e	.05	.62
24			1.6	2.0	4.3	3.1e	.62e	2 6	3.4	94e	.05	.55
25			8.9	5.5	3.4	2.6e	1.0e	2 2	4.8	77e	.05	.49
26			14	23	3.1	4.3e	.77e	1.9	4 1	.62e	.08	40
27			5.9	10	2.9	4.8e	.62e	1.6	3 2	.55e	69	.30
28			3.8	7.2	2.4	3.9e	43e	12	2 9	49e	1 1	.20
29			3.0	5.3	2.2	23	.43e	16	3.4	3.4e	.90	.70
30			4.0	4.3	--	24	.43e	5 1	3 3	2 0e	.60	.75
31			14	3.5	--	10e	--	3 0	--	1.5e	.30	--
Total												
(cfs)			--	166.6	116.3	156 8	42.83	130.25	78.87	89 44	13.88	22.63
(in)			--	4.49	3.13	4 22	1 15	3.51	2 12	2.41	.37	61
Avg-cfs			--	5.37	4.01	5 06	1 43	4.20	2 63	2.89	.45	.75
cfsm			--	3.89	2.91	3 67	1 04	3 04	1 91	2.09	33	54

TABLE A-21 GREEN BRANCH DAILY RAINFALL (IN) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN.	FEB	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP
1	0	02	.01	.02	0	06	.01	0	0	--	--	1.20
2	0	01	.01	0	0	03	1.48	0	0	--	--	0
3	0	0	0	.18	0	.29	1.13	.44	0	--	--	0
4	0	0	0	.04	0	.65	5.09	.01	0	--	--	.01
5	.01	0	0	12	0	0	.14	0	0	--	--	0
6	.76	.26	1.12	.42	0	.02	.01	0	.50	--	--	.42
7	.06	.01	.34	.02	0	0	0	.05	0	--	--	1.31
8	.34	.05	0	.02	0	.01	0	0	0	--	--	.01
9	.54	.02	.04	.95	0	.03	0	0	0	--	--	0
10	.01	0	0	.14	0	0	0	0	0	--	--	0
11	0	0	.27	.04	0	0	.03	0	0	--	--	0
12	.01	.25	.35	0	.53	2.32	0	0	.25	--	--	0
13	0	.01	.01	07	01	.02	0	0	.50	--	--	.52
14	0	.04	0	.48	.07	0	0	0	.10	--	--	--
15	0	.05	.22	.02	0	0	0	0	0	--	--	--
16	.10	.03	.02	0	.01	0	0	0	.10	--	--	--
17	0	0	.01	0	.01	0	0	32	0	--	--	--
18	0	0	0	0	.02	.05	0	0	.05	--	--	--
19	0	0	.01	0	0	.34	0	0	.10	--	--	--
20	.40	0	.27	0	0	.11	0	0	0	--	--	--
21	.02	0	0	0	.01	0	0	0	0	--	--	--
22	.01	0	.01	.04	.03	.21	.80	.06	0	--	--	--
23	0	0	0	.01	.83	.01	1.03	.34	0	--	--	--
24	.91	0	.01	.02	.45	0	.08	0	0	--	--	--
25	2.56	0	.25	.07	.02	.01	0	.07	1.60	--	--	--
26	.01	.35	.07	.32	.10	0	0	.04	.50	--	0	--
27	.02	.03	.01	.03	.40	.01	01	0	0	--	0	--
28	0	.52	0	0	0	.23	.49	.01	0	--	0	--
29	0	.01	.01	0	--	.22	.40	.55	0	--	0	--
30	.42	.19	.41	0	--	1.09	.01	0	0	--	0	--
31	.01	--	0	0	--	0	--	0	--	--	0	--
Total	6.19	1.85	3.45	3.01	2.49	5.71	10.71	1.89	3.70	--	--	--
Total Annual	--											

TABLE A-22 GREEN BRANCH MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1		--	2.0	5.5	.93	1.0						
2		--	1.4	5.5	.93	.84						
3		--	1.2	4.5	.79	1.1						
4		--	1.1	2.6	.67	3.3						
5		--	.98	3.4	.59	.70						
6		--	7.5	2.8	.74	.37						
7		--	15	3.4	.48	.19						
8		.76	6.4	3.2	.48	.08						
9		.79	4.1	4.7	.48	.06						
10		.76	3.0	--	.48	.03						
11		.78	2.6	--	.55	.84						
12		.70	6.1	--	4.7	41						
13		.57	4.5	2.5	3.0	38						
14		.63	3.7	6.6	1.9	23						
15		.80	3.7	5.4	1.7	20						
16		.65	3.1	3.9	1.4	18						
17		.60	2.7	6.1	1 6	17						
18		.57	2.4	5.8	1.4	16						
19		.53	2.1	5.8	1.3	16						
20		.51	2.9	5.1	1.1	18						
21		.50	2.6	2.9	.94	16						
22		.46	2.6	.90	.96	17						
23		.43	2.2	.83	1 7	16						
24		.45	1.6	.85	17	16						
25		.45	4.8	.85	4 6	16						
26		.86	6.6	.85	3.0	16						
27		.97	4.3	.88	3.7	15						
28		2.9	4.0	.90	1.6	16						
29		3.3	3.2	.93	--	16						
30		2.4	3.3	1.1	--	31						
31		--	5.7	.93	--	23						
Total (cfs)		--	117.38	--	58.72	413.51						
(in)		--	3.16	--	1.58	11.14						
Avg-cfs		--	3.79	--	2.10	13.3						
cfsm		--	2.75	--	1 52	9.64						

TABLE A-23 INDIAN FORK DAILY RAINFALL (IN) - WY 1975

DAY	OCT	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1				--	.63	.18	0	28	03	0	0	0
2				--	.45	.03	.04	0	01	34	0	0
3				--	0	0	14	04	03	0	0	--
4				--	0	0	0	0	0	1 68	04	--
5				--	0	0	0	0	53	0	37	--
6				--	0	1 14	0	.12	06	19	0	--
7				--	0	.01	0	26	0	03	0	--
8				--	0	0	04	47	0	17	08	--
9				--	0	74	06	0	37	0	30	--
10				--	0	09	.03	0	.30	0	2 01	--
11				--	0	2.08	0	0	30	0	14	--
12				0	0	2 61	0	06	.67	.30	0	--
13				0	0	1.66	0	.04	0	30	0	--
14				0	0	.15	65	0	0	.03	.05	--
15				0	0	0	.01	2 15	62	.12	58	--
16				.99	.54	.16	0	.10	0	0	14	--
17				0	.85	.03	0	43	0	0	.24	--
18				.11	.03	0	0	01	0	0	88	--
19				1.10	0	.31	1 11	0	0	.07	1.35	--
20				05	0	.01	0	02	0	04	0	--
21				.12	0	0	0	0	0	0	0	--
22				0	.16	.62	0	0	07	0	0	--
23				0	88	0	.13	0	0	0	.01	--
24				.22	.01	1.64	.03	0	0	.31	01	--
25				1.42	0	0	51	0	1.22	0	01	--
26				.01	0	0	0	.03	.25	0	0	--
27				0	0	02	0	.01	.08	0	0	--
28				0	.08	0	0	0	.17	0	0	--
29				.11	--	3.61	.06	77	0	0	0	--
30				0	--	.43	.08	.09	0	.35	0	--
31				.02	--	0	--	0	--	01	0	--
Total	--	--	--	--	3.63	15 52	2.89	4 88	4 71	3.94	6.21	--
Total Annual	--											

TABLE A-24 INDIAN FORK MEAN DAILY FLOW (CFS) - WY 1975

DAY	OCT.	NOV	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG	SEP
1				--	2.7	3.0	10	6.1	2.1e	2 8	1 6	90e
2				--	26	1 9	8 0	4.7	1 6e	3 7	1 5	85e
3				--	16	1.7	11	4 3	1 8e	2 7	1.5	79
4				--	39	1.8	9 7	4.0	1 8e	14	1.5	79
5				--	28	1.6	8.0	3 4	3 0e	12	2 1	76
6				--	19	8.4	7 0	4.1	2.2e	5 7	1 8	1 2
7				--	12	24	6.4	4.1	1.8e	4.2	1 5	.94
8				--	6.5	9.6	5.9	5.4	1.7e	10	1.5	.86
9				--	4.2	9.0	5.4	5 1	2.3e	6.1	1.5	80
10				--	3.1	19	5.1	3 5	2 5e	4 1	8.4	.80
11				--	5.9	41	4.5	3.1	3.0e	3 3	1.9	.82
12				11	35	155	4.1	3.0	5.0e	2 8	1.5	1.0
13				8.7	17	171	3.8	2.8	35e	5.5	1 3	.92
14				8 1	8.0	61	5 8	2.5	24	2.8	1.3e	80
15				8 2	3.9	37	9.3	33	21	3.7	2.5e	.80
16				6.5	5.2	34	5 7	19e	23	2 6	2.4e	80
17				2.1	19	34	5 3	25e	12	2 3	2.3e	4.6
18				5.6	8.8	34	5.0	11e	7 5	2.1	5 0e	11
19				42	4.9	34	28	7.5e	5 5	2.1	8.0e	1.4
20				29	3 4	25	22	4 7e	4 0	2.1	3.0e	1 2
21				13	2.6	13	14	3 7e	2.5	2 2	2.6e	1 0
22				6.2	2 6	24	10	3 5e	2 3	2 0	2.3e	8.1
23				4.1	24	21	8 8	2 3e	2 0	2 0	2 0e	18
24				3 4	17	71	7 7	1 9e	1 8	5.0	1 7e	6.0e
25				52	7.3	35	14	1 5e	12	2 3	1 5e	3 0e
26				15	4.4	21	9 4	2.0e	6 6	1 9	1 4e	2 0e
27				7 4	3 2	13	8 1	1 9e	7 0	1 8	1 3e	1 5e
28				4 4	2 7	11	7 3	1 8e	7 4	1.7	1 2e	1 2e
29				3 5	--	92	6.5	6.0e	4 6	1 6	1 1e	1 0e
30				2 4	--	26	6 1	3 0e	3 3	1 7	1.0e	.90e
31				2 1	--	15	--	2 3e	--	1 8	95e	--
Total (cfs)	--	--	--	--	331 4	1048 0	261 9	186 2	210 3	118.6	69.15	74.73
(in)	--	--	--	--	2 85	9 02	2.25	1 60	1 81	1 02	.60	.64
Avg-cfs	--	--	--	--	11 8	33.8	8.73	6 01	7 01	3 83	2 23	2.49
cfsm	--	--	--	--	2 73	7.82	2 02	1.39	1 62	89	.52	58

TABLE A-25 INDIAN FORK DAILY RAINFALL (IN) - WY 1976

DAY	OCT.	NOV	DEC.	JAN.	FEB.	MAR.	APR	MAY	JUNE	JULY	AUG.	SEP.
1	35e	0e	0	0	.42	0	0	02	.18	0	0e	30
2	0e	0e	0	24	.01	0	0	01	67	0	0e	12
3	0e	0e	0	60	.18	0	0	0	08	1.05	0e	0
4	01e	0e	01	0	0	0	.04	0	0	.36	.01e	.05
5	0e	0e	0	0	.38	.68	0	0	0	.06	0e	.04
6	0e	0e	.42	0	.05	0	0	29	0	.09	.55e	0
7	.02e	.75e	.06	.46	.01	0	0	.32	0	0	0e	0
8	.95e	0e	0	.01	0	53	0	0	0	0	0e	0
9	.01e	.15e	.29	0	0	.51	0	0	0	.01	0e	.65
10	0e	.15e	01	.01	.03	0	0	0	0	0	0e	.13
11	0e	0e	0	.56	.14	0	.32	.45	0	0	0e	0
12	0e	2.30e	0	0	0	.18	0	0	0	89	0e	0
13	0e	0e	0	.90	.02	0	0	.31	0	0	0e	0
14	0e	.10e	0	0	.01	0	0	.87	0	0	0e	0
15	0	0e	.69	0	0	.02	0	1.17	0	15	.70e	.17
16	.34	0e	0	.05	0	.34	0	26	09	10	0e	0
17	1 64	0e	0	0	.08	0	0	.02	.01	0	0e	0
18	.01	0e	0	0	1.79	.08	0	.30	0	0	0e	0
19	.38	0e	0	0	0	0	0	0	.94	0	0e	0
20	.01	.15e	0	.09	0	.72	0	0	.20	.05	0e	.27
21	0	0e	0	.26	.54	1 19	.86	0	0	.60	0e	.05
22	0e	0	.01	0	.01	0	0	0	06	50	0e	0
23	0e	0	0	0	0	0	0	.09	0	.01	0e	0
24	0e	0	.02	.14	0	.21	.11	0	0	0	0e	0
25	.40e	0	1.27	.68	0	.39	.44	0	.47	0	0e	0
26	.35e	.20	.10	1.31	.05	.33	.02	0	.01	0	.50e	.57
27	0e	.09	.01	.02	0	.12	01e	01	0	.01	.20e	.87
28	0e	0	0	0	.01	0	0e	2.22	.05	0	.50e	.01
29	.15e	.04	05	0	0	2.04	0	.17	.54	.60	.10e	.47
30	0e	97	.53	.01	--	.88	.25	0	.36	.40	0e	0
31	0e	--	1.17	0	--	.38	--	0	--	.20	0e	--
Total	4.62	4.90	4.64	5.34	3 73	8.60	2.05	6 51	3 66	5.08	2.56	3.70
Total Annual	55.39											

TABLE A-26 INDIAN FORK MEAN DAILY FLOW (CFS) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	1.6e	3.6e	44	56	24	6.4e	39	7 1	7.7	5.0	3.2	2.0
2	2.5e	3.2e	29	38	17	5.9e	26e	4.6	18	3.2	2.4	2.0
3	2.2e	2.8e	19	55	17	5.5e	16e	3.8	20	20	2.2	1.7
4	1.9e	2.6e	14	41	17	5.0e	10e	3.5	11	27	2.0	1.7
5	1.8e	2.3e	12	30	21	8.8e	7.7e	3.2	7.1	17	1.9	1.6
6	1.9e	2.1e	13	18	35	7.7e	7.1e	2 9	5.5	11	5.5	1.5
7	2.0e	11e	15	22	27	6.6e	6.0e	7.7	4.2	7.1	2.7	1.5
8	13e	8.0e	12	19	22	7.1	5.5e	3.5	3.8	4.6	2.0	1.4
9	8.8e	10e	16	17	17	31	5.0e	3.2	3.2	4.5	1.8	5.5
10	6.2e	9.4e	13	15	11	28	4.6	2 9	2.9	3.2	1.7	3.2
11	4.5e	8.7e	12	22	8.0	17	5.5	7 1	2 7	2 7	1.6	1.7
12	3.5e	220e	11	28	5.8	13	4.6	3.5	2.4	6.0	1.5	1.5
13	2.8e	62e	11	40	5.4	9.4	4.2	3.8	2.2	3.5	1.5	1.4
14	2.2e	36e	11	48	5.0	7.0	3.8	10	2 0	2.4	1.4	1 4
15	1.8	25e	17	36	4.6	6.3	3.5	72	2.0	9.2	8.4	1.5
16	2.5	20e	26	28	4.6	11	3.4	32	2.0	4.6	2.2	1.4
17	46	16e	20	19	4.6	7.5	3.2	20	2.0	3.2	1.8	1.4
18	29	14e	13	16	44	6.7	3.0	21	1.8	2.4	1.7	1.3
19	9.0	15e	11	14e	39	5.9	2.9	14	13	2.2	1.5	1.3
20	6.2e	16e	10	12e	23	7.4	2.8	10	11	3.5	1.4	1.7
21	5.0e	17e	9.1	11e	22	64	7.7	7.1	4 6	5.0	1.4	1.6
22	4.1e	14e	7.8	10e	26	31	5.0	5 5	3.2	4.8	1.3	1.3
23	3.5e	12e	8.0	9.4e	17	17	3.5	5.4	2.4	3.5	1.3	1.3
24	3.1e	8.0e	8.5	9.0e	12	11	3.2	4.2	2.2	2.4	1.3	1.3
25	2.8e	7.0e	27	28	10e	20	7.8	3.5	5.5	2.2	1.2	1.3
26	6.8e	8.0e	56	78	8.8e	17	4.6	3.2	3 5	2.0	1.5	3.5
27	5.8e	8.9e	37	54	7 8e	22	4.0e	2.9	2.4	1.9	2.7	14
28	5.0e	8.0e	25	36	7.0e	17	3.5e	27	2.2	1.8	6.0	3.5
29	5.4e	7.1e	18	27	6.7e	102e	3.3	50	7.7	15	2.2	6.0
30	4.5e	27	32	20	--	151e	3.2	23	15	6.5	1.7	5.9
31	4.0e	--	73	16	--	100e	--	11	--	4.2	1.5	--
Total (cfs)	199.4	604.7	630.4	872.4	469.3	755.2	209.6	378.6	173.2	191.6	70.5	76.4
(in)	1.72	5.21	5.43	7.51	4.04	6.50	1.80	3.26	1 49	1.65	.61	.66
Avg-cfs	6.43	20.2	20.3	28.1	16.2	24.4	6.99	12.2	5.77	6.18	2.27	2.55
cfsm	1.49	4.68	4.70	6.51	3.75	5 65	1.62	2.82	1 34	1.43	.53	.59

TABLE A-27 INDIAN FORK DAILY RAINFALL (IN) - WY 1977

DAY	OCT	NOV.	DEC.	JAN.	FEB.	MAR	APR	MAY	JUNE	JULY	AUG.	SEP
1	.01	0	15	0	0	.05	0	0	0	54	0	41
2	0	0	0	.01	0	.02	1.50	0	0	06	0	11
3	0	0	.01	.07	0	.30	1.10	40	0	0	0	11
4	0	0	0	.19	.01	60	4 50	0	0	0	0	0
5	0	0	0	.21	.01	0	15	0	0	0	01	0
6	.65	0	1 18	.36	0	0	0	.07	0	0	01	0
7	.07	0	.32	02	0	0	0	.01	0	0	16	1.38
8	29	0	.01	.04	0	0	0	0	0	0	37	01
9	47	0	0	.72	0	0	0	0	11	0	.06	0
10	0	0	0	.21	0	0	0	0	0	0	25	0
11	0	.04	.27	0	0	0	0	0	0	0	01	0
12	0	.18	33	0	.51	2.20	0	0	.36	0	0	0
13	0	.01	0	.01	0	0	0	0	40	0	.33	.50
14	0	.10	0	.02	.04	0	0	0	32	03	48	,50
15	.01	.08	15	0	0	0	0	0	0	0	0	.50
16	.14	0	0	0	0	0	0	0	1.32	0	12	.60
17	.01	0	0	0	0	0	0	0	11	03	16	01
18	0	0	0	0	.01	0	0	0	64	0	01	0
19	0	0	.05	0	01	30	0	0	75	0	0	.05
20	54	0	35	.02	.01	10	0	.01	.13	0	0	0
21	0	0	0	03	0	0	0	0	0	01	0	0
22	0	0	0	0	.02	.20	.50	.15	46	35	0	0
23	.03	.10	0	03	.50	0	1.00	41	28	0	0	.01
24	1.54	0	12	.03	.40	0	05	.01	15	0	1.10	0
25	3.13	0	.71	.04	01	0	0	.06	1.72	.30	0	.53
26	0	47	.03	.27	.05	0	0	.03	.66	29	0	1.42
27	01	0	0	.17	.40	0	0	0	0	17	0	01
28	0	.66	0	09	0	.20	.50	0	.02	.15	0	0
29	0	0	0	0	--	.20	.40	.50	0	.39	0	0
30	.86	0	.54	0	--	1 00	0	0	.01	0	0	0
31	02	--	0	0	--	0	0	0	--	0	0	--
Total	7.78	1.64	4.22	2 54	1.98	5.17	9.70	1.65	7 44	2 32	3 07	6 15
Total Annual		53.66										

TABLE A-28 INDIAN FORK MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	3.5	26	7.7	12	--	12	21	6.0	--	5.5	1.3	--
2	2 4	13e	7.1	8.0	--	7 7	27	4.6	--	4.2	1.2	--
3	2.0	9.2e	5 0	7.0	--	7 5	53	14	--	2.4	1.1	--
4	1.8	6 6e	4 9	9 2	--	28	719	10	--	2.0	1.1	--
5	1 7	4.9e	4 2	14	--	23	1800	31	--	1.8	1.1	--
6	3.8	3 8e	23	14	--	14	200	10	6 0	1 7	1 1	--
7	6.0	3.1e	59	16	--	9.2	50	--	1.0	1.5	1.2	--
8	3.2	2.9e	32	12	--	7 1	20	--	80	1.5	1 4	--
9	21	2.9	20	16	--	5.5	15	--	.88	1.4	1.5	--
10	6 0	2 8	12	29	--	4.6	10	--	73	1.4	2.2	--
11	3.8	3 2	10	--	--	3.8	8.0	--	.73	1.4	1.3	--
12	2.9	2 9	29	--	--	61	6.5	--	1.3	1.3	1.1	--
13	2.4	2.4	23	--	--	46	4.0	--	.97	1 3	1 4	--
14	2.2	2.7	17	--	--	23	2.4	--	5.0	1.2	3.2	--
15	2.0	2.9	15	--	--	13	2 4	--	1.4	1.2	1.8	--
16	2.0	2.7	11	--	--	7.7	2.4	--	7.1	1.1	1.4	--
17	2.0	2.4	8.4	--	--	6.5	2.4	--	2.7	1.1	2.2	15
18	1.8	2.4	7.1	--	--	6.0	2.2	--	2.2	1.1	1.7	11
19	1.8	2.4	6.5	--	--	5 5	2 2	--	27	1.0	1.3	8.4
20	6.5	2.4	11	--	--	7 7	2.0	--	14	1.0	--	6.5
21	2.9	2.0	7.7	--	--	4.6	1.8	--	5.5	1.0	--	5 5
22	2.4	1 8	5 0	--	2.4	8.4	3.2	--	6.0	1.4	--	4.6
23	2.0	2.0	6.5	--	6.0	6.5	33	--	6.0	1.1	--	4.2
24	18	2.0	6.0	--	43	5.5	31	--	5.5	1.0	--	4.2
25	130	2.0	8.4	--	21	5 0	13	--	38	7.1	--	6.5
26	45	3 5	16	--	15	4.6	7.1	--	39	2 4	--	43
27	28	4 2	13	--	29	4.2	5.0	--	21	1 4	--	31
28	23	13	12	--	20	4.2	5.0	--	7 1	1.3	--	12
29	21	17	11	--	--	4.6	16	--	4 2	1 3	--	4.6
30	28	9.2	16	--	--	58	7.1	--	2.9	1 3	--	2.9
31	32	--	18	--	--	39	--	--	--	1.2	--	--
Total												
(cfs)	411.1	158.3	432.5	--	--	443.4	3071.7	--	--	55.6	--	--
(in)	3.54	1.36	3.72	--	--	3.82	26.44	--	--	.48	--	--
Avg-cfs	13.3	5 28	14.0	--	--	14.3	102	--	--	1.79	--	--
cfsm	3.08	1 22	3.24	--	--	3.31	23.6	--	--	.41	--	--

TABLE A-29 INDIAN FORK DAILY RAINFALL (IN) - WY 1978

DAY	OCT.	NOV	DEC	JAN.	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1	0	--	.16	--	--	05	0	04	0	01	--	--
2	0	--	0	--	10	40	0	0	19	15	--	--
3	0	--	.12	--	.01	60	0	02	02	0	--	--
4	0	--	1.60	--	05	0	02	94	0	0	--	--
5	.01	--	20	--	0	0	0	0	0	0	--	--
6	--	--	10	--	0	0	0	0	.03	0	--	--
7	--	--	0	--	.01	0	0	.42	1.18	0	--	--
8	--	--	.41	--	0	0	0	1 16	1.58	0	--	--
9	--	--	.29	--	0	.04	0	01	10	.49	--	--
10	--	--	0	--	0	.01	15	0	0	.01	--	--
11	--	--	0	--	0	01	38	0	0	--	--	--
12	--	--	0	--	0	33	0	71	.32	--	--	--
13	--	--	0	--	61	0	0	1.49	.01	--	--	--
14	--	--	22	--	0	1 02	03	.33	0	--	--	--
15	--	--	0	--	0	0	0	.06	0	--	--	--
16	--	--	0	--	.16	.10	0	0	0	--	--	--
17	--	--	.32	--	0	.03	0	0	0	--	--	--
18	--	--	.09	--	02	.12	1.34	.01	0	--	--	--
19	--	0	0	--	0	0	.09	0	0	--	--	--
20	--	.20	.03	--	0	0	05	0	0	--	--	--
21	--	1.29	0	--	0	.40	08	0	0	--	--	--
22	--	1.84	0	--	0	0	0	.15	0	--	--	--
23	--	.09	--	--	0	.01	0	.09	0	--	--	--
24	--	.03	--	--	31	.06	.07	.36	0	--	--	--
25	1.65	.03	--	--	06	.93	.46	05	0	--	--	--
26	--	0	--	--	0	.02	55	0	22	--	--	--
27	--	.63	--	--	0	.02	0	0	0	--	--	--
28	--	.79	--	--	.24	0	0	0	0	--	--	--
29	--	1.68	--	--	--	0	0	0	01	--	--	--
30	--	.06	--	--	--	0	.29	0	0	--	--	--
31	--	--	--	--	--	0	--	0	--	--	--	--
Total	--	--	--	--	--	4.15	3 51	5 84	3.66	--	--	--
Total Annual	--											

TABLE A-30 INDIAN FORK MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT.	NOV.	DEC.	JAN	FEB.	MAR	APR	MAY	JUNE	JULY	AUG.	SEP
1	5.5	--	26	9.0	--	--	--	9.2	4.2	4.2	5.0	--
2	5 0	--	14	7.1	--	--	--	7.1	4.6	4.6	3.8	--
3	4.2	--	9.6	6.5	--	--	--	6.5	4 6	6.5	4.6	--
4	3.5	--	43	6.0	--	--	--	35	3.8	4.6	13	--
5	3.2	--	39	6.5	--	--	--	27	3.5	4.2	--	--
6	2.9e	--	18	13	--	--	--	15	3.5	4 0	--	--
7	--	--	9.0	12	--	--	--	17	16	3.9	--	--
8	--	--	7.1	75	--	--	--	67	59	3.8	--	--
9	--	--	7.7	44	--	--	--	50	39	4.6	--	--
10	--	--	5 1	17e	--	--	--	31	23	4.2	--	--
11	--	5.9e	4.5	13e	--	--	--	20	16	3 8	--	--
12	--	5.2e	4 2	12e	--	--	4 2	28	17	3.8	--	--
13	--	4 2e	4.2	12e	--	--	3.8	75	15	3.5	--	--
14	--	--	5 4	11e	--	--	3 8	62	10	3.5	--	--
15	--	--	4.1	9.2e	--	--	3 5	44	9.2	25	--	--
16	--	--	3 6	--	--	--	3 5	33	8.4	35	--	--
17	--	--	3.7	--	--	--	3 5	26	7.7	8.4	--	--
18	--	13e	6.4	--	--	--	32	17	7.1	5.5	--	--
19	--	9 0	4.9	--	--	--	23	13	6.5	5.0	--	--
20	--	7 2	4.5	--	--	--	14	11	6.4	6 0	--	--
21	--	32	4 0	--	--	--	11	9.2	6.0	5.0	--	--
22	--	108	3.3	--	--	--	8 4	7 7	6.0	4.2	--	--
23	--	40	2 9	--	--	--	7 1	8.4	5.9	3 8	--	--
24	--	16	24	--	--	--	6.5	9.2	5.5	3.8	--	--
25	--	8 9	42	--	--	--	12	8.4	5 0	8.4	--	--
26	--	5 9	23	--	--	--	28	6 5	6 0	5.0	--	--
27	--	6.8	14	--	--	--	27	6.0	5 0	5.5	--	--
28	--	14	10	--	--	--	17	5.5	4 9	5.0	--	--
29	--	123	8.4	--	--	--	13	5 0	4 6	4.2	--	--
30	--	37	9.2	--	--	--	14	4.8	4.6	3.8	--	--
31	--	--	9.2	--	--	--	--	4.6	--	13	--	--
Total												
(cfs)	--	--	374.0	-	--	--	--	669.1	318.0	205.8	--	--
(in)	--	--	3.22	-	--	--	--	5 76	2 74	1 77	--	--
Avg-cfs	--	--	12.1	--	--	--	--	21.6	10.6	6.64	--	--
cfsm	--	--	2.80	--	--	--	--	5 00	2.45	1.54	--	--

TABLE A-31 LOWE BRANCH DAILY RAINFALL (IN) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	28	0	0	0e	33e	0	0	47	.25	0	0	29
2	03	0	.01	.05e	0e	0	0	.01	49	0	0	16
3	01	0	0	.45e	05	0	0	0	[illegible]	1 73	0	0
4	0	0	0	0e	08	0	.10	0	0	02	0	05
5	0	0	0	.01e	.04	55	0	0	.02	.72	48	0
6	0	.01	0	0e	.09	0	0	24	0	.03	0	0
7	.02	52	09	.45e	0	0	0	.29	0	.01	0	.01
8	.80	0	0	.02e	0	.41	0	0	0	.30	0	0
9	.01	12	.27	0e	0	.53	01	0	0	61	0	85
10	0	.10	0	0e	.02	01	0	0	03	0	0	35
11	0	0	0	.30e	05	0	.12	.27	0	0	0	0
12	0	2 26	0	0e	.01	10	0	01	0	70	0	0
13	0	0	01	.50e	02	0	0	.13	0	0	0	0
14	0	11	0	0e	0	0	0	.59	0	0	0	0
15	0	0	.63	0e	0	01	0	1 09	0	0	11	20
16	1.07	.01	0	.03e	0	.21	0	13	.39	.02	0	0
17	1 29	0	0	0e	08	0	0	43	0	0	0	.01
18	.07	0	0	.05e	1.11	02	0	03	0	01	0	0
19	07	0	0	0e	0	0	0	0	1 19	0	01	0
20	0	32	0	07e	0	.11	0	0	1 39	0	0	35
21	0	01	0	0e	.36	71	53	0	41	0	0	0
22	0	0	02	0e	0	0	01	0	04	52	0	0
23	0	0	0	0e	0	0	0	0	0	0	0	0
24	0	0	0	.10e	0	06	0	0	0	0	0	0
25	.14	0	1 11	.80e	0	.29	20	0	74	0	0	0
26	.40	.08	.14	1.00e	50	.14	.04	0	03	0	0	12
27	.01	11	0	0e	0	.05	0	0	.24	04	0	.32
28	0	0	0	05e	0	0	0	1.85	.18	0	90	01
29	14	0	0	0e	0	2.08	0	.15	17	01	0	.71
30	.01	.68	.20	0e	--	.63	.16	.01	.15	08	0	56
31	0	--	1.0	0e	--	.32	--	0	--	.01	0	--
Total	4 35	4 33	3.48	3 88	2.74	6.23	1 17	5 70	5 73	4 81	1 50	3 99
Total Annual	47 91											

TABLE A-32 LOWE BRANCH MEAN DAILY FLOW (CFS) - WY 1976

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	03	.19	3.0	7.8	1.4e	61	5.2	.30	.85	.43	--	00
2	.04	18	2.4	3 6	1.2e	.54	2.8	26	.98	.32	--	00
3	.02	18	1.8	2.8	1.1e	.49	2.1	.18	1 1	3 4	--	.00
4	.01	.16	1.2	2 7	1.0e	.43	1 8	.14	.86	7 4	--	.00
5	.01	16	.96	2.3	.92e	.65	1.3	.11	.54	6.1	--	00
6	00	.15	80	1.9	.85e	79	1 1	09	31	5 2	04e	.00
7	.00	.29	.78	1.7	.80e	.76	.90	27	27	2 4	08e	00
8	.11	36	.76	2 1	.72e	.82	.77	19	22	1 6	02e	.00
9	27	34	.90	2 1	.69e	3.8	.62e	.14	.16	1.1	.00	.01
10	.18	34	1.1	2.0	.64e	4.4	52e	.10	13	70	00	05
11	.13	.34	1.2	1.8	.60e	2 6	.52e	.15	.11	48	00	01
12	.09	47	1 1	1.7e	.58e	2.1	.46e	.13	08	50	00	.00
13	.06	8.5	88	1.5e	.55e	1.6	.44e	.09	.07	41	.00	00
14	.04	3.6	.78	1 3e	.52e	1.2	41e	.10	.06e	28	00	00
15	.04	2 0	.90	1 2e	.50e	1 0	38e	3.8	05e	19	00	00
16	.65	1.5	2.2	1.1e	49	1.0	.34e	2.2	11e	.15	00	00
17	9.0	1.1	2 3	95e	.49	73	.29e	1.4	.05e	12	00	00
18	3 3	.86	1 9	87e	4.7	.64	27e	1.4	05e	08	00	.00
19	1.0	.74	1.4	79e	5.7	58	25e	1.3	.29e	06	00	.00
20	53	.78	1.1	.72e	2 8	57	25e	.97	7 5	04	00	.00
21	.35	.89	.90	.66e	2 2	2 2	28	66	3.9	.02	00	.00
22	.27	.76	74	.61e	2.2	2 5	.32	48	2 7	.12	.00	00
23	.20	.70	.60	.56e	2.0	2.0	.22	.40	1 6	.14	00	00
24	.16	69	.44	.52	1.7	1.5	.18	.31	98	05	.00	.00
25	14	68	2.1	.87	1 4	1.5	20	.22	1 1	.02	00	00
26	.22	62	9 0	9.3	1 2	1.3	.20	15	1.9	--	.00	.00
27	.29	65	4.5	8.2	94	1 4	.18	10	1.4	--	00	14
28	.27	58	2 5	3 6	81	1.2	.16	63	95	--	01e	05
29	25	50	1.9	2.4	.72	25	14	3 9	75	--	03e	08
30	23	1 0	1 7	1 9	--	27	11	2 1	64	--	00	23
31	20	--	7 1	1 5	--	6 6	--	1 3	--	--	00	--
Total												
(cfs)	--	75.84	58 94	71 05	39 42	97.51	22 71	23 57	24 71	--	--	57
(in)	--	3 06	2 38	2 87	1.59	3 94	.92	95	1.20	--	--	02
Avg-cfs	--	2.53	1 90	2.29	1 36	3.15	.76	76	99	--	--	02
cfsm	--	2.75	2 07	2 49	1.48	3 42	83	83	1 08	--	--	.02

TABLE A-33 LOWE BRANCH DAILY RAINFALL (IN) - WY 1977

DAY	OCT.	NOV	DEC	JAN.	FEB.	MAR	APR	MAY	JUNE	JULY	AUG.	SEP.
1	0	0	.22	.03	0	01	.02	0	0	.42	.02	0
2	0	.01	0	.01	0	0	.92	0	0	01	0	0
3	0	0	01	.11	01	.11	.21	.32	48	0	01	0
4	0	0	0	.09	0	.47	4 10	0	0	0	0	.01
5	0	10	0	09	.02	0	.10	0	0	0	16	0
6	.52	0	1 02	16	0	0	0	0	50	0	0	.16
7	04	0	40	02	0	0	0	33	0	0	17	.86
8	.24	0	0	.17	0	0	0	01	0	0	11	.02
9	.54	0	.03	.13	0	01	0	0	10	0	13	.01
10	0	0	01	.02	0	0	0	0	0	.08	25	0
11	0	0	.20	01	.01	0	0	0	0	.03	05	0
12	0	.29	37	.10	.27	0	0	0	04	22	0	0
13	0	.01	0	0	0	1.07	0	0	35	01	.06	.35
14	0	.05	0	.14	20	0	0	0	11	0	.05	.49
15	0	04	.20	0	.01	.01	0	0	.01	0	.13	.57
16	0	0	0	0	0	0	0	0	15	0	.03	.55
17	0	0	0	0	.01	0	.07	0	04	0	.02	.01
18	0	0	0	0	0	.07	.02	0	15	0	.02	0
19	0	0	.10	0	0	47	0	0	.37	0	.01	.08
20	.16	0	.29	0	.05	.07	0	.01	.33	0	.01	0
21	0	0	0	.04	0	.01	0	0	0	0	.01	0
22	0	0	.02	0	01	.13	.33	.17	26	0	0	0
23	0	0	0	.03	.26	.01	.12	.48	1.39	.01	.40	0
24	.72	0	0	.19	.65	0	07	.10	98	0	97	0
25	1.58	.01	.40	.05	0	0	.01	.07	84	.95	0	.52
26	.01	.17	.04	.04	.01	0	0	.23	05	0	0	1.35
27	0	.01	0	0	41	.01	0	.06	.01	0	0	.49
28	.01	.36	0	0	.01	.10	.52	.11	0	.01	0	0
29	0	0	0	0	--	.23	.39	20	0	.02	0	0
30	.59	.01	.24	0	--	.22	.01	0	0	0	0	0
31	0	--	0	0	--	0	--	0	--	.01	0	--
Total	4 41	1.06	3.55	1 43	1.93	3.00	6.89	2.09	6 16	1.77	2.61	5.47
Total Annual		40.37										

TABLE A-34 LOWE BRANCH MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP
1	.06	.37	.21	.63e	19e	2.0	.44	11	12	.09	.00	.00
2	.02	.22	.32	.63e	.16e	1.5	2.3	6.0	07	07	.00	.00
3	.01	.34	.31	.63e	.27e	1.0	10	5.0	07	.05	.00	.00
4	.01	.26	.31	.54e	.21e	2.0	112	4.0	07	.04	.00	.00
5	.00	.20	.31	.46e	.19e	2.4	68	2.6	07	.02	.00	.00
6	.00	.19	1.5	.54e	.17e	2.1	30	2.1	29	01	.00	.00
7	02	.16	13	1.0e	.16e	1.7	19	1.9	13	.00	.00	.02
8	02	.13	4.3e	1.0e	14e	1 0	14	2.1	07	.00	.00	.03
9	.33	.11	2.1e	1.1e	18e	.66	9.7	1.3	08	.00	.00	.01
10	.08	.11	1.2e	2.4e	.67e	.50	6.8	1.1	07	.00	00	.01
11	.03	.10	.68e	4.6e	1.2e	.41	5.0	.80	07	.00	.00	.00
12	.02	.10	1.8e	3.2e	.68	5.3	4.0	.63	07	.00	.00	.00
13	02	.09	2.3e	2.3e	1.0	7.4	3.5	54	07	.01	.00	.00
14	02	.09	2.1e	1.4e	1.1	3 1	3 0	.43	29	.00	.01	.01
15	.01	.09	1.8e	2.3e	1.2	2.1	2 6	29	07	.00	.02	.03
16	.01	.09	1.1e	1.8e	1.1	1.5	2.2	.16	07	.00	.03	.28
17	.01	.09	79e	1 5e	1.1	.93	2.1	.11	.07	00	.07	.07
18	.01	.09	.54e	1.4e	.63	1.1	2.0	.08	.07	.00	.04	.03
19	.01	.09	.46e	1.3e	.58	.81	1.9	.07	.17	00	.01	.02
20	02	.09	.54e	1.2e	.43	1.5	1.5	09	.11	.00	.00	.01
21	.02	.09	58e	.81e	.37	1.7	1.2	07	13	.00	.00	.01
22	.02	.09	58e	.30e	.34	1 6	1.0	.10	.06	.00	.00	.00
23	.02	08	.58e	.47e	34	.95	5.0	.24	.16	.00	.00	.00
24	.02	.07	.46e	.44e	6.3	.69	13	.40	1 0	00	.06	.00
25	3.2	.07	.50e	.36e	3.5	.54	8.7	.24	2 4	00	.01	.01
26	1 7	.07	1.7e	.37e	2.2	.45	5.3	21	2.3	.00	01	1.6
27	.34	.08	2.0e	.38e	2 2	36	3 8	.40	.31	.00	.00	.91
28	.15	.09	1.7e	.27e	2.2	.35	2.8	.26	12	.00	.00	.30
29	.10	.21	1.1e	.27e	--	.27	15	.21	07	.00	.00	.08
30	.12	.21	.73e	.26e	--	.41	16	.16	05	00	.00	.04
31	.50	--	.63e	.22e	--	.43	--	.12	--	00	.00	--
Total												
(cfs)	6 90	4.07	46.23	34.08	28.81	46.76	371 84	42 71	8 70	29	.26	3.47
(in)	.28	.16	1.87	1.38	1.16	1.89	15.02	1.73	35	.01	.01	.14
Avg-cfs	.22	.14	1.49	1.10	1.03	1.51	12.4	1 38	29	.01	.01	.12
cfsm	.24	.15	1.62	1.20	1.12	1 64	13 5	1 50	32	.01	.01	.13

TABLE A-35 LOWE BRANCH DAILY RAINFALL (IN) - WY 1978

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	.01	.01	.03	.01	.03	.07	.02	0	0	.02	0	0
2	0	0	0	0	.05	.42	.03	0	.05	.84	0	0
3	0	.02	0	0	.03	.09	.02	.06	.16	.06	.04	0
4	0	.16	.64	0	.11	0	.05	.66	0	0	50	0
5	0	.15	.06	.04	0	0	.02	0	0	0	.50	0
6	.01	.27	.14	.28	.01	0	.02	0	0	0	.08	0
7	0	.25	0	0	0	.02	.03	.06	.61	0	.02	0
8	1.8	0	.09	.99	.01	.18	.04	.44	1.35	.08	.96	0
9	.91	.10	.23	0	0	.34	.03	.01	.12	.36	.04	0
10	0	.04	0	0	0	.26	.03	0	0	.76	0	0
11	.09	0	.01	0	0	.01	.19	0	0	.01	.21	.40
12	0	0	0	0	0	.11	0	.39	.69	0	.60	.01
13	0	0	0e	.02	.49	.01	0	1.12	0	0	1.03	.07
14	0	0	.14	0	.01	.88	0	.37	0	0	0	.01
15	.22	0	0	0	.01	0	0	.20	0	1.07	0	.06
16	.15	.14	0	.09	.13	.08	0	0	0	.83	.06	0
17	0	.52	.34	.85	0	.02	0	0	0	0	.22	0
18	.01	0	.04	0	.03	.11	1.06	0	0	0	0	0
19	0	0	0	.19	0	.02	.04	0	.05	0	0	0
20	0	.10	.04	0	0	.02	.06	0	0	0	.04	0
21	0	.82	0	0	.03	.35	.14	0	0	0	0	0
22	0	1.6e	0	.10	.01	.02	.22	0	0	0	0	0
23	0	.02	0	.29	.05	.03	.23	.68	0	0	0	0
24	0	.02	.81	.57	.27	.90	.42	.61	0	.73	0	.04
25	1.26	.12	0	1.25	0	1.00	1.29	01	0	.93	39	0
26	.09	0	0	0	0	.15	.78	0	0	0	.03	0
27	.01	.53	0	0	0	.09	0	.01	0	0	0	0
28	0	.02	0	0	.19	.03	0	0	0	0	0	0
29	0	1.44	0	0	--	.03	.01	.17	.07	0	0	0
30	0	.04	.10	0	--	.03	.27	0	.01	0	.24	.69
31	.45	--	.02	0	--	.03	--	.01	--	.69	.19	--
Total	5.01	6.37	2.69	4.68	1.46	5.30	5.00	4.80	3.11	6.38	5.15	1.28
Annual Total		51.23										

TABLE A-36 LOWE BRANCH MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	02	.19	3.5	.37	.86	40	.85	.71	.02	.00	.01	.11
2	.02	.19	2.1	.29	.54	.68	.54	.41	.02	.00	.01	.09
3	01	.19	1 8	.24	.31	1.9	.37	.27	.02	.01	.00	.08
4	.01	.19	1.6	.22	.22	2.0	.26	1.2	.01	.00	.00	.06
5	.01	.18	4.7	.19	.21	1.9	.22	1.6	.01	.00	.02	.05
6	01	9.3	2.8	.24	.21	1.6	.21	1.6	.01	.00	.01	.04
7	.01	7.0	2.2	.26	.19	1.2	.16	1.4	.01	.00	.01	.03
8	.09	3.9	1.8	4.7	.17	1.8	.13	1.3	2.0	.00	1 7	.02
9	10	2.1	1.5	6.8	.16	2.2	.12	1 3	2.6	.00	1.9	.01
10	1.0	1.4	1.1	5.0	16	4.7	.11	.75	2.1	.01	1.0	.00
11	.24	.63	.92	4.0	.17	4.0	.11	.55	.42	02	.58	.01
12	.12	.41	.79	2.7	.15	2.4	.10	.43	.33	.01	2.6	.01
13	07	.26	.63	99	26	1.9	.08	6.4	.51	.00	11	01
14	.05	.21	.52	.58	.73	8.7	.07	5.3	.14	.00	4.1	.01
15	.04	.18	.47	.37	.79	3 5	.06	4.3	.10	.28	1.8	.00
16	.05	.16	.34	.31	.79	2.3	.05	3.0	.08	.81	.38	.00
17	.04	.72	.31	99	.73	1.8	.05	2 2	.06	.04	.55	.00
18	.03	.84	.68	2.0	.73	1.1	1.2	1.4	.01	.02	.38	.00
19	.03	.79	.79	2.0	.68	.79	1.9	.73	01	.01	31	.00
20	.03	.54	99	1.8	.63	.59	1.2	.40	.01	.00	.22	.00
21	.02	.92	.79	1.1	.50	.63	.73	.19	.01	.00	.22	.00
22	.02	16	.54	.68	.46	.63	.40	.07	.01	.00	.14	.00
23	.02	12	.43	.54	.37	.63	.29	.10	00	.00	.13	00
24	.02	3.8	.73	2.1	.34	.63	.24	1.1	.00	01	.09	.00
25	.22	2.3	4.0	21	.37	1.1	.43	1.9	.00	.40	.09	.00
26	.92	1.7	3.0	14	.31	5.0	3.0	1.3	.00	.05	.31	.00
27	.91	1.1	2.1	3.5	.29	3.8	3.3	.54	00	.01	.13	.00
28	.60	2.2	1.5	2.4	.27	2.4	2.1	.17	.00	.01	.11	.00
29	.30	18	.99	2.0	--	2.2	1.7	.07	.00	.01	.08	.00
30	.20	9.2	.63	1.5	--	1.8	1.2	.05	.00	.00	.14	.00
31	.16	--	.46	1.0	--	1.3	--	.03	--	.03	.14	--
Total (cfs)	15.27	96.60	44.71	83.87	11.60	65.58	21.18	40.77	8.49	1.73	28.16	.53
(in)	.62	3.90	1.81	3.39	.47	2.65	.86	1.65	.34	.07	1.14	.02
Avg-cfs	.49	3.22	1.44	2.71	.41	2.12	.71	1.32	.28	.06	.91	.02
cfsm	.53	3.50	1.57	2.95	.45	2.30	.77	1.44	.30	.06	.99	.02

TABLE A-37 CROOKED CREEK DAILY RAINFALL (IN) - WY 1977

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG.	SEP
1	01	0e	0	10	0e	03e	02	02e	0e	45e	48e	15e
2	0	0e	0	0e	0e	02e	78	04e	0	0e	0e	0e
3	0e	0	0e	0	0e	1 08	1 96	25e	0e	0e	24e	0e
4	0	0e	0e	20e	05e	35e	2 85	05e	0e	0e	0e	0e
5	0e	0e	0e	15e	03e	0	20e	0e	0e	0e	0e	0e
6	41	05	1 00e	.20e	0e	0	0e	0e	05e	0e	0e	40e
7	.44	0	20e	.05e	0e	0	0e	50e	0e	0e	0e	80e
8	05e	0e	0	0e	0e	0e	0e	0e	0e	0e	0e	0e
9	86e	0e	0e	29e	0e	0e	0e	0e	05e	0e	1.10e	0e
10	0e	.04	0	.05e	0e	0e	0e	0e	0e	75e	.18e	0e
11	0e	.28	45e	0e	0e	02	0e	0e	0e	.05e	0e	0e
12	0e	0e	.20e	0e	50e	2 67	0e	0e	.57	0e	.06e	0e
13	0	0e	0e	0e	0e	01	0e	0e	3 00e	0e	.23e	05e
14	0	0e	0e	85e	0e	0	0e	0	0e	0e	0e	0e
15	0	.10e	12e	.25e	20e	0	0e	0	0e	0e	20e	.60e
16	11	0e	0	0e	0e	0	0e	0	20e	0e	.10e	2 30e
17	0	0e	0e	0e	0e	0	0e	0	07	0e	75e	0e
18	0	0e	0	0e	0e	08	0e	0	03	0e	0e	0e
19	0	0e	0e	0e	.12e	.44	0e	0	22	0e	0e	1.05e
20	.71	0e	.23e	.15e	0e	0e	05e	0	50e	0e	0e	0e
21	0	0e	0e	0e	0e	.15	0e	.05	0e	0e	0e	0e
22	0e	0e	0e	0e	0e	03	.25e	.01	07	0e	0e	0e
23	0e	0e	0e	0e	.05e	0e	1.90e	0	30e	50e	0e	0e
24	.32	0e	0e	.40e	.68e	0	.75e	37	1 00e	03e	65e	0e
25	3 45e	0e	45e	.15e	0e	0	.20e	0e	.35e	2 45e	0e	.65e
26	.01	.53e	.01	02e	0e	0	0e	.03	05	0e	0e	30e
27	0	.10e	0e	0e	53e	0	0e	02	0e	0e	0e	.58e
28	0e	30e	0	0e	0e	.15	0e	0e	0e	0e	0e	0e
29	0	15e	.14e	0e	--	03	52e	0e	0e	0e	0e	0e
30	95e	0	05e	0e	--	18	0e	65	0e	15e	0e	0e
31	05	--	25e	0e	--	0	--	0	--	0e	0e	--
Total	7 37	1.55	3 10	2 86	2 16	5.24	9 48	1 99	6 46	4.38	3 99	6 88
Total Annual	55 46											

TABLE A-38 CROOKED CREEK MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR	APR	MAY	JUNE	JULY	AUG.	SEP.
1	1.1	5.3	2.0	1.6	.93	5.7	2.2	4 6	27	1.5	4.1	3.1
2	.51	3.0	2.4	1 4	.86	4.7	2.9	4 8	17	1.2	.80	1.0
3	.30	2.1	2.1	1 5	1.1	5.9	13	5.8	.12	.47	92	.33
4	.18	1.5	2.0	1 8	3.4	26	244	4 8	.07	.30	44	.20
5	.14	1.1	1 9	3.6	4.0	13	52	3.7	04	.18	.28	.11
6	.18	1 4	4.7	3.8	1.8	8.5	20	2 9	.05	.15	17	1 1
7	2.1	1.3	20	3.6	1.2	6 1	12	5.8	.02	13	.07	2.5
8	1 4	1.3	9.1	2.9	97	4.9	8.7	4.5	.01	.07	1.0	1 8
9	11	2.1	5.2	3.2	1.4	4.2	6.4	2.8	.04	02	4.6	.75
10	3.0	2.0	4.5	6.9	2.3	3.8	5.3	2 1	.01	16	6 4	.46
11	1.4	1.9	4 2	4.1	2.7	3.3	4.3	1.8	.00	10	1 9	.33
12	.96	1.9	10	3.4	10	63	3.7	1 5	.05	3 0	.64	.20
13	.69	1.8	7 0	2.4	8.1	49	3.2	1.4	13	1.1	45	.21
14	55	1 7	5 0	15	5.6	15	3.0	1.2	18	52	.61	1.1
15	.44	2.0	5.2	19	5.3	10	2.6	1.2	2.4	.58	65	2.9
16	.39	1.7	4.4	9.1	3.8	7 3	2 2	.96	1 0	.22	38	37
17	.35	1.5	3.6	6.6	3 2	5.8	1 9	84	2.0	.10	4 7	19
18	.34	1 5	3.1	5.8	3.1	5.4	1 7	74	1 0	.08	4.3	6 1
19	.30	1.5	2.8	3.8	3.2	4 2	1 8	66	6.2	.05	1.2	34
20	2 3	1 4	3 1	3.4	3.0	6.5	1.9	60	9 8	01	.61	14
21	2 1	1.3	2 4	2.6	2.8	4.1	1.6	58	2 4	.01	.31	6.3
22	1.0	1.2	2.0	2.3	2.7	4.6	7.9	50	1.3	.02	.18	4 0
23	.76	.98	2.0	1.9	3.2	3 4	61	2.7	6.6	.10	.09	2.8
24	.89	1.1	1.7	2 4	14	2.8	47	2.0	21	.06	2.7	2.3
25	69	1.2	2.2	2.3	6.7	2 4	19	1 0	15	15	.68	3.3
26	33	1 5	3 9	2 1	5.1	2 4	10	2 1	12	14	.29	11
27	10	4 0	2 8	2 3	12	2 3	7 0	82	5.0	2.1	.14	20
28	6 2	3.0	2.8	2.6	7 8	2.1	5.4	59	2.4	.98	.07	11
29	4 4	3.8	2.0	1.6	--	2 4	9.5	73	1.4	.81	.03	6 0
30	15	2.3	2 0	1.4	--	2 9	5.8	.85	90	.89	.03	4.6
31	12	--	2.3	1.1	--	3.1	--	.40	--	.61	02	--
Total												
(cfs)	181.98	58.38	128.4	125 5	120.26	284.8	567 0	64 97	122.25	70 26	38.76	197.49
(in)	1.87	.60	1.32	1.29	1 24	2.93	5.83	.67	1.26	72	.40	2.03
Avg-cfs	5.87	1.95	4.14	4 05	4 30	9 19	18.9	2 10	4 08	2.27	1.25	6.58
cfsm	1.62	.54	1 14	1 12	1 19	2 54	5.22	58	1 13	63	.35	1.82

TABLF A-39 CROOKED CREEK DAILY RAINFALL (IN) - WY 1978

DAY	OCT	NOV.	DEC	JAN	FEB	MAR.	APR	MAY	JUNE	JULY	AUG	SEP
1	0e	01	10e	.03e	0	.28	0e	.10e	0e	0e	0e	03e
2	.04e	0	0e	0e	.25e	.19	0e	0e	50e	20e	0e	0e
3	0e	.56	0e	0e	0	41	0e	0e	-	45c	0e	0e
4	0e	15e	.65e	0	0	.02	0e	.45e	0e	0e	20e	0e
5	0e	.15e	1.00e	40	.07e	0e	0e	0e	0e	0e	20e	0e
6	0e	85e	.15e	.07	0	0	0e	0e	.15e	0e	45e	0e
7	0e	02	0e	03	0	0	0e	.10e	35e	0e	12e	0e
8	1 90e	0e	0e	1 10e	0	.10e	0e	.15	85e	0e	.20e	0e
9	60e	10e	.27e	02	0	18e	0e	38	15e	50e	05e	0e
10	0e	02	0e	0	0	.37e	.20e	0	.05e	.45e	0e	55e
11	0e	0	0e	0	0	0e	45e	0e	0e	0e	0e	90e
12	.02	0e	0e	0	60e	.05e	.02	50	0e	0e	33e	03e
13	0e	0e	0e	40e	0	.07	0	1 43	.45e	03	20e	0e
14	0	0	.01	.02	0	1.40e	0	.65	0e	0	15e	0e
15	0e	0	0	0	11	0e	0	15e	0e	2 00e	0e	.55e
16	15e	40e	0e	01	.18	.24	0	.02	0e	95e	45e	0e
17	0e	13	44	.75e	0	08	05e	0e	0e	0e	0e	0e
18	0	0	0e	01	10	21	.75e	0e	.05e	0e	0e	0e
19	0	0	0e	20e	.01	0e	40	0e	0e	65e	0e	0e
20	0e	15e	.20e	.25e	0	0e	06	0e	0e	0e	65e	0e
21	0	1 10e	0	01	.25e	.22	0e	0e	0e	15e	0e	13e
22	0	1 10e	04	.09e	.15e	0e	0	0e	0e	0e	0e	0e
23	0	05e	0	0e	30e	0e	0e	0e	0e	0e	0e	0e
24	0	.02e	75e	75e	0e	0e	0e	.38e	0e	2 05e	0e	0e
25	.45	0e	0	1.05e	0e	.30	.50e	0e	0e	85e	0e	0e
26	.45e	0e	0e	.09	0e	05	80e	.08e	25e	01	40e	0e
27	.01	.80e	0e	0e	0e	.16	.15e	0e	0e	0	0e	0e
28	0e	0e	0e	0	20e	0e	0e	0e	0e	0	0e	0e
29	0	1.20e	0	0	--	0e	0e	0e	0e	0	0e	0e
30	0	.05e	.12e	0e	--	0e	08e	0e	10e	0	0e	0e
31	0e	--	.03	0	--	0e	--	0e	--	.01	0e	0e
Total	3.62	6.86	3.76	5 28	2 22	4 33	3 46	4 39	3 05	8.30	3.40	2 19
Total Annual	50.86											

TABLE A-40 CROOKED CREEK MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT.	NOV.	DEC	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP
1	4 0	3 2	18	4.9	5.3	7.8	4.5	--	--	10	2.8	.46
2	3.4	2.4	12	3.6	5 6	6.6	4.0	--	--	35	2 0	46
3	2.8	4 0	9.4	2.1	4 7	18	3 8	--	--	.58	1 7	40
4	2.1	8 4	19	2.3	4.2	11	3 0	--	--	.30	1.9	.35
5	1 8	7.1	54	2 6	4.5	7.8	2.8	--	--	10	4.5	30
6	1.6	19	24	8.1	3 6	8.5	3.4	--	.81	03	6 3	.26
7	1 6	12	13	6.3	3 6	9.5	3.0	--	2.0	.01	4.7	.26
8	33	8.1	11	22	3.0	14	2 8	--	11	.40	3.2	26
9	53	6 4	16	19	3.0	17	2 8	--	10	98	3 4	22
10	14	6 2	9 1	8.8	3.2	20	4 5	--	3 6	1 1	2 8	.30
11	8.5	4 6	7 3	6 3	3 0	12	5 1	--	2.1	40	2 0	2 1
12	6.2	3 8	6.8	5.8	3 4	11	4 2	--	2 8	30	2.3	1 2
13	4.8	3 2	7.5	6.1	15	8 5	3 0	--	3.6	.40	2.8	81
14	4 1	3 1	7 2	5.3	19	59	2 4	--	1 5	52	2.1	1 1
15	3 4	3 0	5.8	4 2	8 5	21	2.3	--	98	29	1 7	1.5
16	4.0	3.1	4 9	4.5	7 2	17	2 1	--	73	36	1 5	52
17	3.1	6.1	5 6	12	7 2	13	2 0	--	58	6 3	2 3	.35
18	2.6	3.7	9.5	12	7.2	13	9 5	--	46	2 6	1 4	19
19	2 2	2 9	5.6	8 1	5.8	11	9 1	--	2 3	3 4	1 1	22
20	2.0	2.3	5.3	7 2	5 1	9 1	6.1	--	1 4	2 8	3 2	--
21	1 9	23	4 7	5.6	5 1	9 1	4.9	--	73	1.7	1 9	--
22	1.7	55	4 0	5 1	4.5	9 5	3 8	--	.52	1 2	1 4	--
23	1.6	34	3.8	4.7	4.5	6.9	7 2	--	40	98	1 2	--
24	1 5	17	5 8	17	4 5	6 1	8.5	--	35	27	89	--
25	3 6	12	8 8	66	8 1	8 1	4 7	--	26	64	89	--
26	8.4	8 7	4.7	64	7.8	8 1	--	--	35	20	1 1	--
27	4 6	12	3 8	18	5.8	7 8	--	--	26	12	81	--
28	3 7	23	3 2	11	6 6	6.9	--	--	13	13	65	--
29	3 0	76	2 8	8 1	--	6 1	--	--	10	6 3	58	--
30	2 6	33	3 6	7 2	--	5 3	--	--	13	4 2	52	--
31	2 7	--	4 7	6 3	--	4 9	--	--	--	3 8	46	--
Total												
(cfs)	193 5	406.3	300 9	364 2	169.0	373.6	--	--	--	239 85	64 10	--
(in)	1 99	4 17	3 09	3 74	1 74	3 84	--	--	--	2 46	.66	--
Avg-cfs	6 24	13 5	9 71	11 7	6 04	12 1	--	--	--	7 74	2 07	--
cfsm	1 72	3 73	2 68	3 23	1 67	3 34	--	--	--	2 14	57	--

TABLE A-41 CROOKED CREEK TRIBUTARY DAILY RAINFALL (IN) - WY 1977

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1	05e	0e	0e	0e	0e	02e	.02e	03e	0e	45e	45e	05e
2	0e	0e	0e	0e	0e	02e	65e	0e	0e	0e	0e	0e
3	0e	0e	0e	15e	0e	40e	1 20e	45e	0e	0e	20e	0e
4	0e	0e	0e	0e	0e	70e	3 60e	0e	0e	0e	0e	0e
5	0e	0e	0e	07e	03e	0e	10e	0e	0e	0e	0e	0e
6	30e	0e	.45e	50e	0e	0e	0e	0e	10e	0e	0e	40e
7	75e	0e	50e	0e	0e	0e	0e	60e	0e	0e	0e	95e
8	03e	0e	10e	0e	0e	0e	0e	0e	0e	0e	0e	
9	85e	0e	0e	29e	0e	0e	0e	0e	12e	0e	1 10e	0e
10	0e	0e	0e	04e	0e	0e	0e	0e	0e	85e	30e	0e
11	0e	31e	0e	0e	0e	0e	0e	0e	0e	03e	0e	0e
12	0e	0e	.50e	0e	47e	2 35e	0e	0e	10e	0e	06e	0e
13	0e	0e	0e	0e	0e	0e	0e	0e	2 00e	0e	26e	0e
14	0e	.05e	0e	70e	20e	0e	0e	0e	0e	0e	0e	50e
15	0e	0e	13e	0e	0e	0e	0e	0e	0e	0e	0e	15e
16	10e	0e	0e	15e	0e	0e	0e	0e	0e	0e	.75e	1 90e
17	0e	0e	0e	0e	0e	0e	0e	0e	30e	0e	20e	.75e
18	0e	0e	0e	0e	0e	0e	0e	0e	0e	0e	0e	0e
19	0e	0e	0e	.02e	0e	15e	0e	0e	1.15e	0e	0e	0e
20	65e	0e	.20e	.15e	09e	30e	15e	05e	0e	0e	0e	1.05e
21	.10e	0e	0e	10e	0e	0e	0e	0e	0e	0e	0e	0e
22	0e	0e	0e	0e	0e	13e	20e	05e	20e	50e	0e	0e
23	0e	0e	0e	0e	73e	0e	1 75e	65e	50e	0e	0e	0e
24	1 00e	0e	0e	.45e	05e	0e	.90e	0e	1.45e	02e	.65e	0e
25	1 50e	0e	.35e	12e	0e	0e	21e	0e	.50e	2.48e	0e	65e
26	75e	.53e	0e	.03e	0e	0e	0e	0e	0e	05e	0e	.20e
27	0e	05e	0e	0e	55e	0e	0e	0e	0e	0e	0e	.60e
28	0e	.45e	0e	0e	0e	.14e	0e	0e	0e	0e	0e	0e
29	0e	.02e	11e	0e	--	0e	.51e	20e	0e	0e	0e	0e
30	80e	0e	35e	0e	--	.65e	0e	0e	0e	20e	0e	0e
31	25e	--	0e	0e	--	0e	--	0e	--	0e	0e	--
Total	7 13	1 41	2 69	2.77	2 12	4.86	9.29	2 03	6 42	4.58	3 97	7.20
Total Annual		54 47										

TABLE A-42 CROOKED CREEK TRIBUTARY MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT.	NOV	DEC	JAN	FEB.	MAR.	APR	MAY	JUNE	JULY	AUG.	SEP
1	.10	39	45	--	1.8	.28	19	39	10	28	61	--
2	.09	.33	28	--	2.1	23	.39	39	.09	23	19	--
3	.07	.28	19	--	.74	45	1 7	45	.09	15	.23	--
4	07	23	15	--	1.2	1 4	12	33	07	12	15	--
5	07	19	15	39	.45	.52	1 4	28	07	.10	15	--
6	.09	19	.52	.28	.28	.39	.74	28	.09	.12	.12	--
7	28	19	1.1	.28	.39	33	66	45	.07	.10	.10	--
8	.15	15	.45	.28	1.3	28	.52	33	.07	10	.39	--
9	.92	15	39	--	1.2	.28	45	28	09	.10	.66	--
10	.15	.15	.23	--	.45	22	.45	23	07	2 5	28	--
11	10	15	.23	--	28	.23	39	23	07	39	--	--
12	.09	.19	66	--	83	5 4	39	23	.09	19	--	--
13	.09	.17	.45	--	.45	1.2	.33	23	3.4	12	--	--
14	09	18	28	--	39	.74	.33	23	.74	10	--	--
15	.09	16	33	74	33	59	.33	19	19	09	--	--
16	09	14	28	.66	.23	.45	28	18	15	07	--	--
17	09	12	28	1 4	39	.39	.23	15	.19	.07	--	--
18	.07	.12	.23	.74	23	39	.23	15	15	.09	--	--
19	07	.12	.23	.45	.23	.39	.28	15	66	07	--	--
20	39	.15	23	.52	.23	.45	28	15	.33	07	--	--
21	12	15	.23	28	.23	.33	23	15	15	07	--	--
22	10	12	23	--	23	33	1.8	15	19	09	--	--
23	09	12	23	--	.28	28	4 8	74	39	09	--	--
24	12	28	28	--	.83	.28	1 3	28	.92	09	--	--
25	5 4	12	.15	--	.39	23	83	19	74	3 4	--	--
26	66	19	--	--	33	23	60	18	45	59	--	--
27	33	28	--	--	74	23	45	16	23	.19	--	--
28	23	28	--	--	39	28	.45	15	.15	.12	--	--
29	19	45	--	--	--	28	60	19	15	.15	--	--
30	1 1	39	--	--	--	28	45	15	12	.12	--	--
31	66	--	--	--	--	19	--	12	--	.28	--	--
Total												
(cfs)	12 16	6 13	--	--	16 92	17 55	33 08	7 76	10 27	10.25	--	--
(in)	1 80	91	--	--	2 51	2 60	4 90	1 15	1 52	1 52	--	--
Avg-cfs	39	20	--	--	60	.57	1.10	25	34	.33	--	--
cfsm	1 56	80	--	--	2 40	2 28	4 40	1 00	1 36	1 32	--	--

TABLE A-43 CROOKED CREEK TRIBUTARY DAILY RAINFALL (IN) - WY 1978

DAY	OCT	NOV.	DEC.	JAN.	FEB.	MAR	APR.	MAY	JUNE	JULY	AUG.	SEP
1	0e	0	0	.04	03	09	0e	01		21	0e	03e
2	.05e	0	0	0	0	.40	0e	0	0e	46	0e	0e
3	0e	.50	.10e	0	.20	.25	0e	0	75e	.01	0e	0e
4	0e	.22	.95	.01	08	0	02	48	.20e	0	20e	0e
5	0e	.46	76	.07	0	.02	0e	0	0e	0	25e	0e
6	0e	28	.50e	.40e	0	0	0e	0	0	0	45e	0e
7	0	.03	0	.01	03	.02	0e	16	46	0e	10e	0e
8	2.53	.01	22	83	.02	.29	0e	64	1 03	0e	15e	0e
9	.02	15	05	.05e	0	24	.16	.12	.03	.35e	08e	0e
10	0	.02	0	0	0	.10	03	0	01	45e	0e	65e
11	.01	0	0	0	0	01	30	0	0	0e	0e	90e
12	0	0	0	.02	.01	05e	.02	50	0e	0	35e	0e
13	0	0	0	.30e	59	0e	0	1.08	.45e	.01	25e	0e
14	0	0	0	07e	0	1.40e	0	45	0	0	0e	0e
15	.16	0	0	06	.07	0e	0	14	0	2 62	0e	52e
16	0	.40	0	.01	12	24	0	0	0	74	0e	0e
17	0	0	.38	.78	0	.08	0	0	0	0	.40e	0e
18	0	0	0	0	.01	21	.70	0	0e	0	0e	0e
19	0	.19	.01	0	.02	0e	.08	0	66	59	0e	0e
20	0	.07	.03	.40e	01	0e	.07	0	.02	.09	65e	0e
21	0	.96	0	.05e	0	22	09	0	0	01	0e	13e
22	0	1.13	0	.05e	.13	04	.01	0	0	0	0e	0e
23	0	.05	01	0e	01	0e	0	.06	0e	50	0e	0e
24	0	0	43	1.05e	.31	0e	.26	.36	0e	1.74	0e	0e
25	.84	0	0	1.20e	0	30	32	.10	0	1 03	0e	0e
26	.07	0	0	.01	0	.05	.63	.01	.24	.02	.35e	0e
27	.01	0	0	0e	.01	.16	.01	0	.01	15e	0e	0e
28	0	.45	0	0	.19	0e	0	0e	0	0e	0e	0e
29	0	1.04	.01	0	--	0e	0	0e	0e	0e	02e	0e
30	0	.07	.15	.02	--	0e	.24	0e	.10e	0e	0e	0e
31	.28	--	.02	0	--	0e	--	0e	--	.01	0e	--
Total	3.97	6.03	3.62	5.43	1.84	4.17	2.94	4.11	3.96	8 99	3 25	2.23
Total Annual		50.54										

TABLE A-44 CROOKED CREEK TRIBUTARY MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT	NOV.	DEC.	JAN	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP
1	--	--	.83	--	--	--	33	--	--	--	.16	--
2	--	--	70	--	--	--	.31	--	--	--	.11	--
3	--	--	63	--	--	--	.28	--	--	--	12	--
4	--	--	2.2	--	--	--	.28	--	--	--	.12	--
5	--	--	3.5	--	--	--	.27	--	--	--	.15	--
6	--	--	93	--	--	--	23	--	12	--	.24	--
7	.10	--	.92	--	--	--	.23	--	.24	--	.24	16
8	2.7	--	.75	--	--	--	.22	1.2	.45	--	.19	.04
9	1.9	--	.83	--	--	--	.24	.73	.28	--	.20	.06
10	.49	--	.83	--	--	--	.29	.49	24	--	13	.07
11	.36	--	.67	--	--	--	.45	.40	.33	--	.09	.19
12	.30	--	.48	--	--	--	33	.50	.24	.06	15	.12
13	.24	--	48	--	--	--	--	2.1	.12	.06	.15	.10
14	.23	.19	51	--	--	--	--	1.1	.10	.04	.12	.11
15	23	.19	.45	--	--	78	--	74	.10	1.8	.10	.20
16	.23	25	44	--	.57	78	--	66	.09	2.5	11	.13
17	.19	.46	.49	--	.54	.66	--	.52	09	.33	--	.12
18	.19	.28	.56	--	.54	.64	--	.39	.07	15	--	10
19	.18	.23	.45	--	53	.59	--	33	.06	.24	--	.10
20	.15	.28	.42	--	1 2	51	--	.19	--	.28	--	.10
21	.15	1.6	39	--	42	52	--	--	--	.19	--	.16
22	.15	3.0	.36	--	.41	.52	--	--	--	.12	--	.15
23	.15	.85	.33	--	--	.45	--	--	--	.12	--	.15
24	.15	69	.47	--	--	.42	--	--	--	5.1	--	12
25	.36	59	.49	--	--	53	--	--	--	4.4	--	.12
26	.36	.52	45	--	--	52	--	--	--	1 0	--	.10
27	.21	89	45	--	--	51	--	--	--	33	--	.11
28	19	97	45	--	--	.43	--	--	--	28	--	.12
29	17	4 7	--	--	--	36	--	--	--	24	--	13
30	15	1 1	--	--	--	33	--	--	--	15	--	24
31	16	--	--	--	--	33	--	--	--	.16	--	--
Total												
(cfs)	--	--	--	--	--	--	--	--	--	--	--	--
(in)	--	--	--	--	--	--	--	--	--	--	-	--
Avg-cfs	--	--	--	--	--	--	--	--	--	--	--	--
cfsm	--	--	--	--	--	--	--	--	--	--	-	--

TABLE A-45 LONG BRANCH DAILY RAINFALL (IN) - WY 1977

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP.
1	0e	01	01	0e	0e	04	03	05e	0	43	55e	10e
2	0e	02	0	0e	0e	0e	88	0e	0	02	0e	0e
3	0e	01	03	15e	0e	.56	1 74	40e	0	0e	20e	0e
4	0e	02	03	0e	0e	47	2 21	0	0	0e	0e	0e
5	0e	02	04	05e	03e	02	08e	0	0	0e	0e	0e
6	25e	.03	60e	30e	0e	0	0e	0	.45	0e	0e	20e
7	60e	0	.50e	19e	0e	0e	0e	36	0	0e	0e	90e
8	0e	04	10e	0e	0e	0e	0e	0	0	0e	0e	0e
9	.85e	01	0e	.30e	0e	0e	0e	0	.10e	0e	.05e	0e
10	0e	01	0e	10e	0e	0e	0e	0	0	.80e	1.00e	0e
11	0e	01	0e	0e	0e	02	0e	0	0	0e	0e	0e
12	0e	01	50e	0e	50e	2 46	0e	0	.18	.16	0e	0e
13	0e	11	0e	0e	0e	0e	0e	0	.63	0e	0e	15e
14	0e	08	0e	.70e	15e	0e	0e	0	1.30e	0e	30e	.60e
15	0e	07	15e	0e	0e	0e	0e	0	0	0e	0e	1.00e
16	0e	.02	0e	.05e	0e	0e	0e	0	0e	0e	40e	.80e
17	0e	02	0e	0e	0e	0e	0e	0	.06	0e	70e	0e
18	0e	.03	0e	0e	0e	10e	0e	0	.20	0e	0e	0e
19	0e	.01	0e	0e	.07e	.39	.20e	0	.53	0e	0e	1 25e
20	70e	01	.20e	.20e	0e	0e	.05e	20e	.26	0e	0e	0e
21	.01	.01	0e	0e	0e	11	0e	0	0e	0e	0e	0e
22	.01	0	0e	0e	0e	03	80e	0	.88	.70e	0e	0e
23	04	01	0e	0e	60e	0e	1 85e	86	.21	0e	0e	0e
24	50	.01	0e	35e	.10e	0e	50e	0	.80	0e	90e	0e
25	1 89	01	.34e	.10e	0e	0e	.15e	.02	.82	2 10e	0e	65e
26	0	.43	02e	.05e	0e	0e	0e	0	.03	.20e	0e	.60e
27	0	.02	0e	0e	.50e	0e	0e	01	0e	0e	0e	.40e
28	.01	20e	0e	0e	0e	0e	.25e	11	0e	0e	0e	0e
29	01	.30e	10e	0e	--	.09	.20e	.04	0e	10e	0e	0e
30	93	0	0	0e	--	.30	0e	0	0e	0e	0e	0e
31	02	--	.35	0e	--	0e	--	0	--	0e	0e	--
Total	5.82	1.53	2.97	2.54	1 95	4.59	8.94	2.05	6.45	4.51	4.10	6 65
Total Annual	52.10											

TABLE A-46 LONG BRANCH MEAN DAILY FLOW (CFS) - WY 1977

DAY	OCT	NOV.	DEC	JAN	FEB	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.
1	.02	82	.33	1 5	.80	2.8	1.6	2.6	.05	.39	.00	.00
2	01	.61	33	1.3	.70	2 7	2 0	2.3	.02	45	00	.00
3	00	.53	33	1.2	.60	2.8	6.3	2.3	.01	.32	.00	00
4	00	.48	.33	1.2	.56	6.5	76	2.0	.01	.22	.00	.02
5	00	.41	.33	1.3	.73	5.6	23	1.7	.01	.13	00	.01
6	00	.38	67	1 5	73	4 3	11	1.5	.04	.10	.00	.02
7	07	36	3.2	1 5	66	3 6	8.1	1.4	.06	.07	.00	09
8	06	.32	2 7	1 5	.58	3 1	6.0	1.4	.03	.04	00	.08
9	17	.28	2.0	1 6	52	2 7	4.7	1.3	.02	.03	00	.04
10	11	28	1.7	2.9	50	2 4	3.8	1.1	.01	.02	.00	.01
11	09	28	1 6	2.8	.51	2 2	3.1	.99	.00	.02	00	.01
12	05	.28	2 5	2 7	1 1	12	2 7	80	.00	.01	.00	.01
13	01	.28	2 5	2 3	1 6	16	2 5	.66	.00	.01	00	.00
14	.01	.28	2.1	3 1	1.0	9.2	2.1	.56	.01	01	.00	.02
15	.01	28	2 0	4 2	95	6 3	2 0	49	.01	00	00	05
16	01	28	1 9	3.9	90	4 9	1 7	.43	.54	00	.00	1.3
17	01	25	1 8	3.7	88	3 9	1 5	33	.52	00	00	1 1
18	01	24	1 6	3.5	.85	3 8	1.2	27	.20	.00	.00	55
19	01	24	1 5	3.2	.80	3 4	1.1	23	13	.00	.00	.35
20	07	24	1 5	2 9	75	3.8	1.0	21	40	00	.00	.35
21	14	20	1 6	2 7	.70	3.4	1.0	19	25	.00	.00	.27
22	.09	20	1 4	2 4	68	3.2	2.0	16	40	.00	.00	.19
23	.08	.20	1.3	2 1	1.0	2.9	10	29	68	.00	.00	.12
24	.11	.20	1.2	2.0	3.7	2.5	11	48	65	.01	.10	.08
25	2 4	.20	1.2	1.5	2 6	2 3	8.9	.33	3.1	.02	.02	.97
26	1 2	21	1 6	1.1	2.2	2 1	6 2	.22	3.3	.01	.00	4.9
27	53	.41	1 6	1 0	4 1	1 9	4 7	.16	1.6	00	.00	7.1
28	.35	43	1.5	98	3 6	1 8	3 8	.13	.92	00	.00	6.8
29	.29	.40	1 4	95	--	1.6	3.4	.15	.57	00	.00	3.7
30	.88	35	1 3	90	--	1.7	3.0	14	.42	.00	.00	2.8
31	1.4	--	1 6	.88	--	1 7	--	.10	--	.00	.00	--
Total												
(cfs)	8.19	9.92	46 62	64 31	34.30	127 10	215 40	24.92	13 96	1 86	.12	30.94
(in)	.27	.33	1.56	2 15	1.15	4.26	7.21	.83	.47	.06	.00	1.04
Avg-cfs	.26	.33	1.50	2.07	1.23	4.10	7.18	.80	.47	.06	.00	1.03
cfsm	.23	30	1.35	1 87	1 11	3.69	6.47	.72	.42	.05	00	.92

TABLE A-47 LONG BRANCH DAILY RAINFALL (IN) - WY 1978

DAY	OCT.	NOV	DEC	JAN	FEB.	MAR	APR	MAY	JUNE	JULY	AUG	SEP
1	0e	0	10e	03e	03	04	0e	.05e	02	08	0e	03e
2	07e	0	0	0	.22e	.50	0e	0	31	36	0e	0e
3	0e	50e	0	0e	0e	.29	0e	01		30e	0e	0e
4	0	16	70e	0	0	0	0e	42	01	0	25e	0e
5	0	49	1 05e	05	0	0e	.02	0	0	0	10e	0e
6	0	25e	20e	40	.03e	0e	0e	.01	.02	0	45e	0e
7	0	01	0e	.01	0	.04	0e	.14	18	0	20e	0e
8	2.55e	0	.10e	.85	0e	.09	0e	.59	1.39	.50e	10e	0e
9	02	.10	20e	30e	0	39	0e	01	02	.45e	15e	0e
10	0	01	0	.03e	0	.15	15e	0	01	0e	0e	65e
11	0	0	0	0	0	0e	45e	.01	0	0e	0e	.90e
12	08	0e	0	03	.02	.10e	.02	15	55	0	35e	0e
13	0	0	0e	.20e	.65	0e	0	1 8	01	0	30e	0e
14	0e	0	02	07e	0	1.16	0	.30e	0	0	20e	0e
15	10e	0	0	08e	.02	0e	0	.15e	0e	1 40e	0e	53e
16	0	60	0e	.04	15	.24e	0	0	0	1.77	25e	0e
17	0e	.05	.47	.71e	.08e	.07	0	0e	0	01	0e	0e
18	0	0	0	0	02	.10	.74	0	.07	0e	0e	0e
19	0	0	0e	0	0	0e	06	0	.01	0	0e	0e
20	0	30	.16	40	0e	0e	03	0e	01	.42	65e	0e
21	0e	1 10e	0	0	0	.22	10	0	0e	02	0e	13e
22	0	.90	01	05	02	.03	0	0	0	0e	0e	0e
23	0	.04	0e	37	.02	0e	.01	0	0	0e	0e	0e
24	0	.02	.57	.70e	.23	.02	0	.61	0e	2 15e	0e	0e
25	1.05e	02	0	1.05e	0	22e	.45e	.01	0	.80e	0e	0e
26	05	05	0	0	0	.05	90e	0	09	01	.40e	0e
27	.01	.37	0	.03	0e	.09	.01	.01	0	.10e	0e	0e
28	0e	.50	0	0	.23	03	0	0	0e	0e	0e	0e
29	0	1.02	.01	0	--	.03	0e	0	0e	0e	0e	0e
30	0	.06	.12	03	--	0e	20e	0	12	0e	0e	0e
31	15e	--	.03	0	--	0e	--	0	--	0e	0e	0e
Total	4 08	6 55	3.74	5 43	1 72	3.86	3 14	4.27	3 14	8 37	3.40	2 24
Total Annual		49 94										

TABLE A-48 LONG BRANCH MEAN DAILY FLOW (CFS) - WY 1978

DAY	OCT	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG	SEP.
1	2 4	1 3	7.9	1 4	2 6	1.5	1 5	1 5	.40	.08	65	01
2	2.1	1 2	5.4	1.3	2.3	1.6	1.0	1 3	.42	11	60	01
3	1.6	1 2	4.4	1.2	2.1	3.8	.92	1.2	.42	.10	.55	.01
4	.95	1 7	4 6	1.0	2 1	3.3	.84	1.8	.40	.09	.50	01
5	79	1.7	6.9	1.1	1.9	2.7	81	1.6	.39	09	.47	.01
6	.66	2 6	5 7	1.1	1 8	2 6	.71	1 3	.38	.08	45	.00
7	61	2 4	4.4	1 0	1.6	2.6	.66	1.3	.39	.08	.40	.00
8	7.2	2.1	3.7	2.9	1.4	2.8	61	2.3	1.0	07	.38	.00
9	21	1 9	3.7	4 4	1.2	2.9	65	2 5	.79	07	.35	01
10	8 2	1 9	3 3	3 5	1 1	5 2	97	2.0	.71	06	33	.01
11	4 7	1 7	2 9	2 4	1 0	4 2	79	1.7	63	.06	.37	37
12	3 4	1.5	2.6	1.8	92	3.5	.71	2.2	1.0	.05	.22	.11
13	2 6	1 4	2.4	1.8	1.5	3 0	70	13	1.2	.04	.26	.05
14	2.1	1.2	2 2	1.7	2 6	9 6	60	9 0	78	.04	27	07
15	1.8	1 1	2.0	1.7	2.4	6.0	59	6 7	59	.90	.18	.10
16	1.5	1 1	1.7	1.7	2 1	4.9	56	5.0	52	2 9	.12	07
17	1.4	1.9	1 7	2 6	1 9	3 9	52	3 9	.39	.40	.17	.06
18	1 2	1.5	2.5	3.3	1.9	3.4	1 3	3 1	31	20	.12	06
19	1.1	1 4	2 1	3.1	1.8	3.0	1.0	2 5	.29	44	07	.06
20	98	1.3	1.9	2.9	1 7	2 6	90	2.1	.27	68	24	06
21	87	4.6	1 8	2.6	1 7	2 7	90	1.7	.21	.60	18	06
22	.78	12	1 6	2.3	1.6	2.7	86	1.5	.19	.58	10	06
23	72	10	1 5	2 1	1 5	2 3	.82	1 2	.21	.65	.06	06
24	.64	6 3	1 8	3.6	1 4	2 0	76	1 6	12	.65	04	07
25	1 1	4.6	2 8	12	1 5	2.0	78	1 8	.10	1 0	03	.08
26	2 9	3 7	2 4	17	1.8	1 8	1 7	1.2	10	.95	.05	.08
27	2 2	3 9	2.1	8 7	1 6	1 8	1 4	95	09	90	06	08
28	1 9	6 6	2 0	5 9	1 5	1 6	1.2	.79	08	85	03	08
29	1 7	18	1.8	4 4	--	1 5	1 1	71	09	80	.03	08
30	1 6	14	1 7	3 5	--	1 3	1 6	63	09	75	01	.09
31	1 4	--	1.5	3.1	--	1 5	--	.48	--	70	01	--
Total												
(cfs)	82.10	115 8	93 0	107 1	48.52	94.3	27 46	78 56	12 56	14 97	7 30	1.82
(in)	2.75	3.88	3 11	3.59	1 62	3.16	.92	2 63	42	50	24	06
Avg-cfs	2.65	3.86	3.00	3.45	1 73	3 04	92	2 53	42	48	24	.06
cfsm	2 39	3 48	2 70	3 11	1.56	2 74	83	2 28	38	43	22	.06

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Ten small watersheds in east Tennessee were studied during a four year period from 1975-1979 in order to provide background data for the development and demonstration of regional mathematical models for predicting the impacts of coal surface mining on the aquatic environment.

Analysis of the geological data from watershed core samples revealed that there was sufficient alkalinity and neutralization potential within the plateau rock strata to neutralize acidity produced from surface mining.

Analysis of other water quality parameters did not reveal any significant metal contamination, but did show higher suspended and dissolved solids associated with mined areas.

Streams in six contour-mined areas were sampled for benthos using Surber, drift, artificial substrate, and kick nets. Functional, taxonomic, species composition, and number differences were attributed to mining activities.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Ecology	Hydrology	Nonpoint Source Model,	6F	8F
Mining	Coal Mining	Stream Ecology, Over-	8H	7B
Water Quality	Hydrologic Models	burden, Tennessee, Surface	13B	7D
Aquatic Biota	Mine Drainage	Mining, Strip Mining,		
		New River Watershed,		
		Input Assessment,		
		Ecological Effect		

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GENERAL DESCRIPTION OF A BOILING WATER REACTOR

ATOMIC POWER EQUIPMENT DEPARTMENT
SAN JOSE, CALIFORNIA