EFFECTS ON WATER QUALITY OF COAL MINING IN THE BASIN OF THE NORTH FORK KENTUCKY RIVER, EASTERN KENTUCKY

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Water-Resources Investigations Report 81-215

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By Kenneth L. Dyer

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Conversion of inch-pound units to metric units

Data in this report are given in inch-pound units. To convert inch-pound units to metric units, the following conversion factors are used:

Multiply inch-pound units	By	To obtain metric units
	Length	
miles (mi)	1.609	kilometers (km)
feet (ft)	0.3048	meters (m)
inches (in.)	25.4	millimeters (mm)
	Slope	
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
acres	0.004047	square kilometers (km^2)
	Volume	
gallons	3.785	liters (L)
million gallons (10^6 gal)	3785	cubic meters (m^3)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
acre-feet	1.233×10^{-6}	cubic kilometers (km^3)
	Flow	
cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
	0.02832	cubic meters per second (m^3/s)
gallons per minute (gal/min)	0.00309	liters per second (L/s)
millions gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
	Mass	
tons (short, 2,000 lb)	0.9072	megagrams (Mg)
	Specific conductance	
micromhos per centimeter (umho/cm)	1.000	microsiemens per centimeter (uS/cm)

EFFECTS ON WATER QUALITY OF COAL MINING IN THE
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ABSTRACT

A detailed investigation of the effects of mine drainage on stream water quality was carried out on the watershed of the North Fork Kentucky River in 1975. Specific-conductance measurements were made at 415 sites, repeatedly at some of them. Discharge estimates and pH values, were also obtained in most instances while sulfate and chloride data were obtained about half the time.

Based on a daily sulfate record simulated from daily conductivity values, trends in sulfate loads were assessed for the North Fork Kentucky River at Hazard for the 1963 through 1973 water years. The mean annual sulfate concentration declined from a maximum of 140 milligrams per liter in the 1963 water year to 72 milligrams per liter in the 1973 water year, about half of what it had been 11 years earlier. The irregular appearance of acid and high sulfate discharges in the earlier years indicates that these probably originated as sudden releases of water from underground mines or as water flushed from coal washing ponds.

Over the area as a whole, coal mining has caused the mean annual dissolved-solids concentration to increase from about 50 to 150 milligrams per liter while the most responsive ion, sulfate, increased in concentration from about 8 to 50 milligrams per liter.

The most damaging effect of strip mining on water quality appears to be the generation of sediment. Even in those watersheds where streams are adequately protected by silt-catchment dams and ponds, both road construction and the dam construction itself may, for a time, introduce large quantities of sediment into the streams. Strip mining of the Hazard Number 9 seam near Hazard has introduced large quantities of acid sulfate mine drainage into Lotts Creek, Yellow Creek, and other streams, but still only a very small part of the total study area is severly affected by acid water.

The bulk of acid mine drainage produced in the study area is immediately neutralized by carbonate minerals or replaced by exchangeable bases from the aquifer material before it ever reaches the streams. The most acid water sample collected during this study had already lost 63 percent of the acidity presumed to have originally been associated with the sulfates in the sample.

Unusually high concentrations of several trace elements were observed in acid mine drainage and in streams affected by it, but in no case were these at levels harmful to human health; although both iron and manganese concentrations were commonly high enough to give the water a bad taste and to leave deposits on containers. The highest concentrations observed for some of the trace elements include: 76 micrograms per liter total arsenic, 400 micrograms per liter dissolved colbalt, 100 micrograms per liter dissolved copper, 82,000 micrograms per liter dissolved iron, 1,000 micrograms per liter total lead, 22,000 micrograms per liter dissolved manganese, 1,200 micrograms per liter dissolved nickel, and 67 micrograms per liter dissolved vanadium.

Some watersheds, especially those where only the Fire Clay and Leatherwood seams have been mined, have recovered to the point where the water draining from them is similar in pH and in concentrations of dissolved solids to that which was present prior to mining. Evidence from this and other studies seems to indicate that strip mining produces less acid per unit of coal mined than does underground mining.

INTRODUCTION

Acid drainage water and sediment from coal mines in eastern Kentucky are known to seriously lower the quality of stream water (Federal Water Pollution Control Administration, 1969, p. 15-19). These wastes frequently kill fish and other aquatic life (Katz, 1969, p. 1-2, 6-7; Branson and Batch, 1971, p. 508, 515) and sometimes render the water unsuitable for municipal or industrial use without expensive treatment (Appalachian Regional Commission, 1969, p. 67-68; The Fantus Company, 1969, p. 4). Increased mining associated with the current energy crisis may in time cause an increase in acid wastes beyond even the capacity of the larger streams to neutralize them. There is, therefore, a need to assess the relative waste loads released to streams by the major coal seams when each is mined by different surface and underground mining techniques.

The easiest way to assess the effects of additional mining was to study in detail the historical development of the mining industry and the changes already caused in water quality by this mining. In view of the resources available it was necessary to restrict this study to a small part of eastern Kentucky. The drainage basin of the North Fork Kentucky River was chosen for detailed study since it is centrally located and cuts diagonally across most of the major coal seams in eastern Kentucky. A map showing the location of the study area is given in figure 1. Details of the study area are shown on plates 1-3.

The original objectives of the study were (1) to use historical water-quality data together with coal production data to show the relation between coal production and the acid or sulfate loading of streams of the basin, (2) to map stream conductivities and sulfate loads in great detail so that areas unaffected by mining might be located and used as a base and so that points of origin of acid mine water might be identified, (3) to establish relations between specific conductance, discharge, sulfates, and other dissolved constituents, (4) to relate rate of acid release to the coal seam being mined and the method of mining, and (5) to give a better basis for estimating the probable effect of new mines on downstream water quality. Only objective 2 and parts of objectives 1 and 3 were satisfactorily fulfilled during the course of this one-year study.

During the 9 months of field work (December 1974 through August 1975) water-quality data were collected at 415 sites. Historical water-quality data within the project area extended back to 1939, but some chemical data with transfer value applicable to the study area were collected in 1906 and 1907. The daily specific-conductance record on the North Fork Kentucky River at Hazard from October 1962 through September 1973 was used to synthesize sulfate loads for the period of record and this in turn was especially useful in assessing sulfate-runoff patterns and their relation to storm runoff and coal mining.

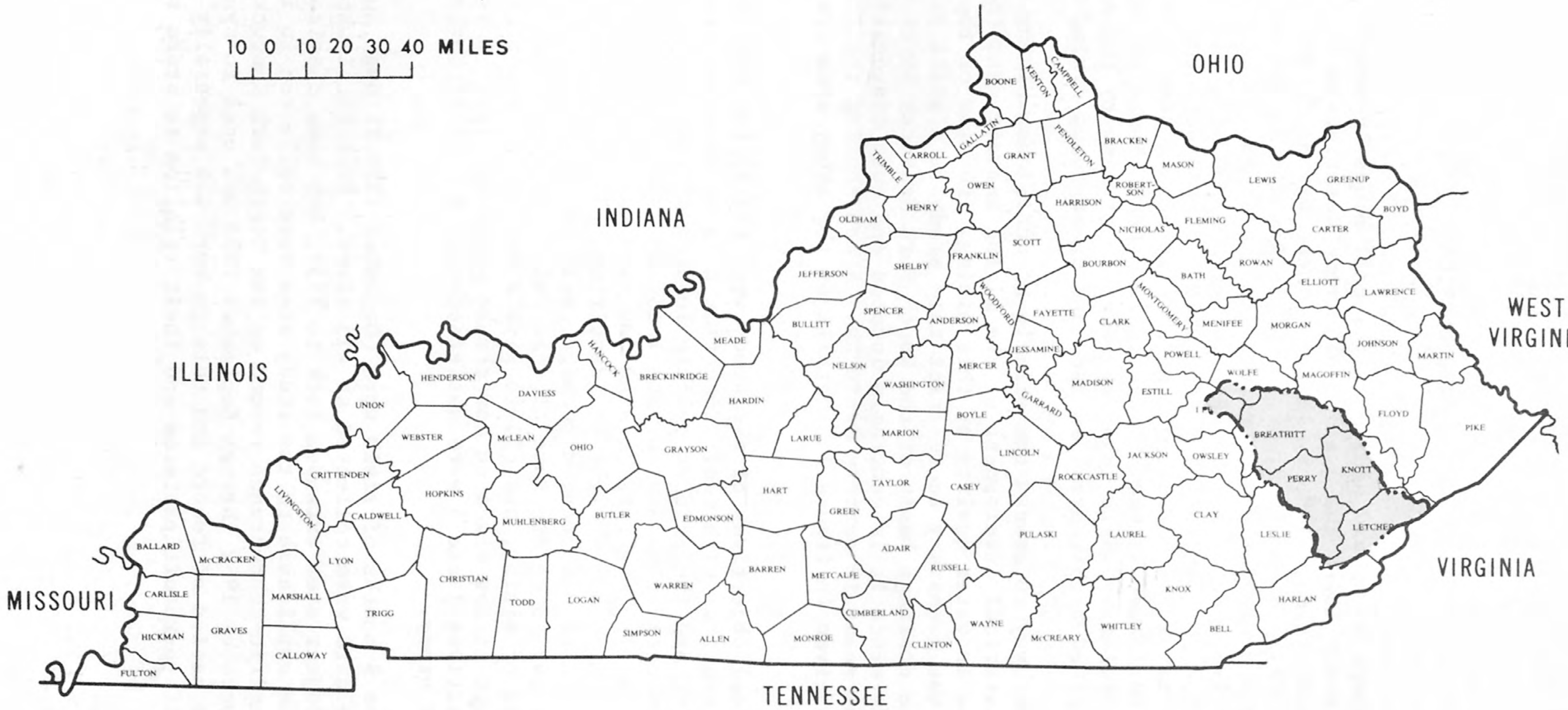

Figure 1.-- Study area and county boundaries.

The data collected and presented in this study are only a part of what would be needed for a full evaluation of the effects of mine drainage on water quality in the study area. More complete historical data on locations of mines and dates of mining operations are needed before the relative effects of mining different seams of coal on downstream water quality can be fully evaluated. Detailed records of most mining operations (showing location, date of mining, reclamation, production of coal, and seams mined) are kept on file by various Kentucky State agencies; but these usually are indexed only by name of company, a fact which makes them almost unusable for the older operations unless someone can be found who can recall the name of the company. Aerial photographs offer good coverage of the area for about 1965 and for either 1972 or 1974. These make it possible to compute acreages disturbed by strip mining on individual watersheds and approximately when the mining occurred. Tying all this information together for the study area alone, would be a major undertaking; but it is information badly needed, not only for the North Fork Kentucky River, but for all the strip-mining areas of eastern Kentucky.

BASIN CHARACTERISTICS

Topography and Streams

The North Fork Kentucky River is in the Cumberland Plateau physiographic section. The Cumberland Plateau, now highly dissected, is underlain by sedimentary strata composed of shale, sandstone, coal, limestone, and conglomerate. The headwaters in the southeast are delimited by the crest of Pine Mountain, a long, almost straight, overthrust fault trending in a northeast-southwest direction. Headwater streams along Pine Mountain tend to follow this fault and closely parallel the mountain through much of their course.

The crest of Pine Mountain is generally aboout 2,700 feet in altitude and, in the study area, reaches a maximum of 3,040 feet near Jenkins. The headwater valleys along the fault line lie about 1,000 feet below the crest of Pine Mountain and range from about 1,400 to 2,000 feet in altitude.

To the northwest of the Pine Mountain Fault the Cumberland Plateau has been deeply eroded by numerous streams to form a maturely dissected, irregular upland surface with high, steep ridges and narrow, winding valleys. Extremes in relief generally range from about 800 feet in the southeast to about 500 feet in the northwest.

Streams throughout the North Fork Kentucky River basin respond quickly to rainfall or snowmelt. The smaller first and second order streams return quickly, usually within hours, to the normal seasonal flow and the larger fourth and fifth order streams do so within a few days. There are few truly perennial streams within the basin since zero flow has been observed at stations on the North Fork Kentucky River as far downstream as Jackson. Aquatic life may survive these periods of no-flow quite well because at this time the major streams are a series of elongated pools. Springs and deep mine outflow may maintain perennial flow in short reaches of some streams. The larger natural springs are all believed to be near the base of Pine Mountain, and these probably never have a discharge in excess of 1 ft^3/s.

Flow-duration curves for the North Fork Kentucky River at Jackson (station 03280000), North Fork Kentucky River at Hazard (station 03277500, site 227) and Troublesome Creek at Noble (03278500) have been published by Kirkpatrick, and others (1963, p. 18, 29). They also report miscellaneous low flow data for 38 other stations within the study area (table 7, p. 39-41). Seven-day, ten-year low flow values have been computed and published for eight stations in the study area (Swisshelm, 1974). Much additional flow data for these streams has been published in the annual water resources data reports of the U.S. Geological Survey for Kentucky, and in the compilations of these reports.

Most of the stream discharge occurs in the spring. The lowest discharges occur in the fall when the smaller branches commonly dry up. Stream discharge in the study area averages highest in March and lowest in October with the discharge ratios for these months ranging from about 15 or 19 to 1 in the larger streams with drainage areas ranging from 177 to 1101 square miles (Beaber, 1970, appendix A, table A-3). The corresponding ratio for Bear Branch near Noble, drainage area 2.2 square miles, (station 03278500 or site 324 in this study) was 36 to 1. This more extreme ratio is probably characteristic of most of the smaller streams, there being sound hydrologic reasons to expect greater variability in the flow of small streams.

Floods may occur at any season of the year. The more widespread floods usually occur in the cooler months but they can occur on rare occasions in the autumn if the storm system from a dissipated hurricane passes over the area. Flash floods from summer thunderstorms may be severe, but they are usually limited to relatively small areas.

Geology

The generalized surficial geology of the watershed of the study area has been mapped by Kirkpatrick, and others (1963, plate 7). Detailed geologic maps published by the U.S. Geological Survey in cooperation with the University of Kentucky, Kentucky Geological Survey are available on 7-1/2 minute quadrangle maps for all the study area.

A review of the above named publications indicates that most of the strata outcropping in the study area belongs to the Breathitt Formation of Early and Middle Pennsylvanian age. Rocks of the Lee Formation of Early Pennsylvanian age are exposed at the lower elevations downstream from Jackson in the northern portion of the area. The extreme southeast edge of the Kentucky River basin is delimited by Pine Mountain -- which is the high exposed face of the Pine Mountain overthrust fault. On the north facing slopes of Pine Mountain are exposures of Mississippian and Devonian rocks. Exposures of the Lee Formation also occur near the top of Pine Mountain.

The exposed rocks of the entire area are sedimentary in origin with nearly horizontal strata of shale and sandstone predominating. The strata comprising Pine Mountain dip to the southeast. Coal strata are scattered throughout rocks of Pennsylvanian age. Except for the Newman Limestone of Mississippian age, exposed and quarried on Pine Mountain (Froelich, 1973), calcareous materials are uncommon throughout the study area in the other formations.

Narrow, shallow bands of alluvium of Quaternary age occur along streams in most of the valleys.

Climate

The climate of eastern Kentucky is continental in character. Wide fluctuations in temperature can occur in a short period of time. Extended droughts are uncommon, but violent storms and extremely heavy rainfall sometimes occur in a limited area. Most of the precipitation originates in moisture-bearing low-pressure formations which move from the Gulf of Mexico to the northeast. Annual precipitation in the entire drainage area of the North Fork Kentucky River averages about 48 inches. This is well distributed throughout the year so vegetation rarely suffers severely from drought. Precipitation in half the months averages between 4 and 5 inches per month, but July averages about an inch more, and September, October, November, December, and February about an inch less. The average annual snowfall is about 15 to 20 inches, but rarely is the ground snow covered for more than a few days each year, except perhaps on steep north facing slopes. Through most of the year precipitation from individual storms falls fairly uniformly over large areas; but during the warmer months intense thunderstorms may deliver heavy rainfall in small areas and little or none at locations in between. A brief discussion of the chemistry of precipitation in eastern Kentucky is given under the heading "Chemical characteristics of water in unmined areas."

The seasonal temperature variations characteristic of a temperate climate prevail in the area. Mean temperatures in January, the coldest month, average 3.5°C (38°F) with the northwestern extremity of the area being about 1.5°C (3°F) colder than the southeastern valleys. Mean temperatures in July, the hottest month, average about 24.5°C (76°F) over the entire area (Kincer, 1941, p. 889-892; Anderson, 1959; U.S. Department of Commerce, 1951-75.)

ECONOMY AND RESOURCES

Economics

The economy of almost the entire watershed of the North Fork Kentucky River is dominated by the coal industry. Only in the downstream extremity of the area does agriculture, and perhaps oil and gas, replace coal as the dominant industry. Service industries, and even timber and agricultural production, are to a major extent controlled by the needs of the coal industry and the needs of the people employed directly by it. Entire communities may spring up suddenly near a new mine while other communities near a worked out or closed mine may be abandoned or even cease to exist. When the price of coal is high the economy booms and the region prospers, but when the price is low the economy of the region suffers severely.

Coal

Types of Coal

Numerous seams of coal are found in the area, most of them extending horizontally in discontinuous beds or seams over a major portion of the area. Since most of these seams pinch out completely over portions of their range or have been removed by erosion, many names have sometimes been applied to the same seam when it occurs in other areas. Geologists can now correlate most of the names which relate to a given seam. In table 1 is a listing of all the coal seams found in the study area together with a list of other names by which each of these seams is known. This information was largely taken from Coal Age (1975), Pocahontas Land Corporation (1971), Rice (1978), and Kimball (1974, p. 29-30). The various coal seam names are sometimes correlated differently in different references, but this is to be expected since through local usage the same name has sometimes been incorrectly applied to more than one seam of coal.

Table 1.--Correlation of coal seam names

Sequence number[1]	Coal seam names
15	Coalton, Middle Kittanning
16	(Helton)[2/], (High Splint), Knob Coal Zone, L-Knob 2, Lower Kittanning, No. 5 Block, Princess No. 5, (Red Spring), Richardson, Skyline, Stamper, Tip Top, U-Knob 3
17	Clarion, Lick Creek
18	(Broas), Princeton No. 4, Stockton, (Torchlight)
19	Belmont, (Broas), (Cornett), Hazard No. 9, (Helton), Hindman, Lewiston, Lewiston-Belmont, Main Block, (Morris), Stockton-Belmont, (Torchligh)
20	Boghead Cannell, (Broas), (Coalburg), (Flag), Francis, Fugate, Hazard No. 8, (Peach Orchard), Princess No. 4, Sebastian
21	(Broas), Flag Rider, Hazard No. 7 Rider
22	Buffalo Creek, (Flag), (Hazard No. 6), Hazard No. 7, (High Splint), (Leatherwood), Nickell, Oakley, (Red Spring), Upper Hignite
23	Adel, Clod, (Coalburg), Colvin, (Cornett), Dinkey, Flatwood, Haddix, Hignite, Hazard, Hazard No. 5, Hazard No. 5A, (Hazard No. 6), Index, (Leatherwood), (Limestone), Lower Hignite, Lower Stinson, (Morris), Pardee, (Peach Orchard), Prater, Princess No. 3, Smith, Trace Fork, Winifrede, Young
24	Big Mary, Chilton Rider, Copeland, Fire Clay Rider, Hamlin, Hazard Rider No. 4A, Klondike, Lower Hamlin, Sharp, (Starling or Sterling), Taylor, Wax

Table 1.--Correlation of coal seam names--Continued

Sequence number[1]	Coal seam names
25	Bevins or Blevins, Chilton, Dean, Fire Clay Rider, Hazard No. 4, Hyden, (Limestone), No. 7, Poplar Lick, (Starling or Sterling), Wallins, Wallins Creek
26	Hernshaw, Little Fire Clay, Upper Pioneer, Whitesburg
27	Amburgy, Buckeye Spring, Cannell City, Creech, Dirty, Gun Creek, Howard, Jordan, Knott, Low Splint, Lower Pioneer, (Mason), Moss, Rim, Sandstone Parting, Upper Mason, Williamson, Williamson No. 6
28	Beech Creek, "C", Caney, (Cedar Grove), Darby, Darby No. 5, Elkhorn, Elkhorn No. 3, Elkhorn Rider, (Jellico), Kellioka, Keokee, Little Caney, (Mason), (Millers Creek), Mingo, Nosben, No. 5, Rhoda, Rim of Moss, Sidney, (Straight Creek), Taggart, Thacker, Tom Cooper, Upper Elkhorn No. 3, Upper Mason, Van Lear
29	("B"), (Cedar Grove), Collier, Elkhorn Leader, Elkhorn No. 2, Grassy, Leonard, Lower Cedar Grove, Upper Elkhorn Leader, Upper Elkhorn No. 2
30	Alma, ("B"), (Blue Gem), Elkhorn No. 1, Hance, (Harlan), (Millers Creek), North Fork, (Penny), Rock House, Sandy Lick, Upper Elkhorn, Upper Elkhorn No. 1, Warfield, Wilson
31	(Penny)
32	"A", Bennett Fork, (Black Wax), Freeburn, (Harlan), Howard, Imboden, (Jellico), Lacy Creek, Little Blue Gem, Lower Elkhorn, Mingo, No. 2 Gas, Path Fork, Pond Creek, Rich Mountain, Shelby Gap, (Straight Creek), Upper Howard, Vulcan, Wayland
33	(Blue Gem), Lower Howard, Powellton
34	Bacon Creek, Bingham, (Black Wax), Clintwood, Feds Creek, Matewan, Turner
35	Blair, Eagle, Millard
36	---------
37	Cedar, Glamorgan
38	Auxier, Hagy, Little Cedar, Splash Dam
39	Colony, Horse Creek, Lily, Kent, Manchester, River Gem, Swamp Angel, Van Cleve, Wheelersburg, Williamsburg, Zachariah
40A	Upper Banner
40B	Elswick, Lower Banner
41	Kennedy
42	---------
43	Raven
44	Jawbone
45-47	---------
48	Barren Fork, Mine Fork
49 (?)	Beattyville

[1] These sequence numbers, assigned by the Pocahontas Land Corporation (1971), begin with 1 for the uppermost coal seam in Appalachia and increase downward to 57 for the lowest. Not all of these coal seam names are used within the study area.

[2] Coal seam names in parenthesis will be found under more than one sequence number.

History of Coal Mining

Roving bands of Indians may have occasionally burned coal in their campfires, but they certainly did not use a significant amount of coal within the study area. Neither did the early settlers of European extraction who first began to claim and occupy the land in the late 18th century. They sometimes dug small amounts of coal for home use when a suitable seam lay nearby, but the overall effect on quality of water in the streams was negligible. It is possible for coal veins to be ignited by lightning, forest fires, or man; after which they may burn for many years. No evidence was found to indicate that any appreciable amount of coal has been lost in this way in the study area. The first recorded production of coal in Kentucky was in 1790 on Sturgeon Creek in Lee County, (Eavenson, 1942, p. 300) near the study area. Reports of coal production in Breathitt County date back to 1837 and in Knott, Letcher, and Perry Counties to 1889 (Currens and Smith, 1977, p. 28, 29, 31).

In 1912 coal was first commercially mined in Letcher and Perry Counties (Jillson, 1924, p. 38) where production expanded rapidly and has since remained at a high level. By 1915 Letcher County was in second place in commercial production of coal in Kentucky and in 1916 it was in first place, but only temporarily. By 1920 there were 61 mine operations in Perry County, 45 in Letcher County, 20 in Breathitt County, 3 in Knott County, and 2 in Lee County (Jillson, 1924, p. 111).

Annual coal production in Kentucky since 1790 has been compiled for each county by Currens and Smith (1977). Annual surface and underground coal production tonnages for Breathitt, Knott, Letcher, and Perry Counties have been extracted from this publication and are graphically depicted on a yearly basis for the period 1790 through 1975 in figure 2.

Until 1944 all or essentially all of the coal produced in the study area was by deep mining wherein the surface of the land is not disturbed except for occasional openings to the surface. Strip mining to recover coal was introduced into the study area in 1944. By 1947, 416 acres had been strip mined in the study area, 217 acres in Perry County, and 199 acres in Letcher county (Merz, 1949, p. 4). The No. 9 coal seam was being stripped with a cut approximately 50 feet wide along a contour for more than 15 miles. The spoil was very acid with 20 percent of the spoil in the area being stripped, having a pH of less than 4.0 units (Merz, 1949, p. 11).

Auger mining was first introduced into Kentucky in 1949 near Isom in Letcher County (Camplin, 1965, p. 12) and since then has commonly been used to extract coal, alone, or in conjunction with strip mining. The auger mining of thicker coal seams is not commonly practiced at the present time because it may make complete recovery of the coal by underground mining or mountain top removal at a later date impractical or uneconomical.

Plass (1967, p. 5, table 1) lists acreages disturbed through strip mining operations by county and by coal seam as of 1964. Stripped acreages by county in 1964 followed by stripped acreages estimated to be within the drainage basin of the North Fork Kentucky River at this time were: Breathitt 1,811-1,811, Knott 3,063-2,600, Letcher 2,399-2,149, and Perry 4,651-4,440 acres. Corresponding acreages disturbed by coal haul roads were Breathitt 77-77, Knott 161-135, Letcher 160-145, Perry 203-193 (Plass 1967, p. 6, table 2). Thus land

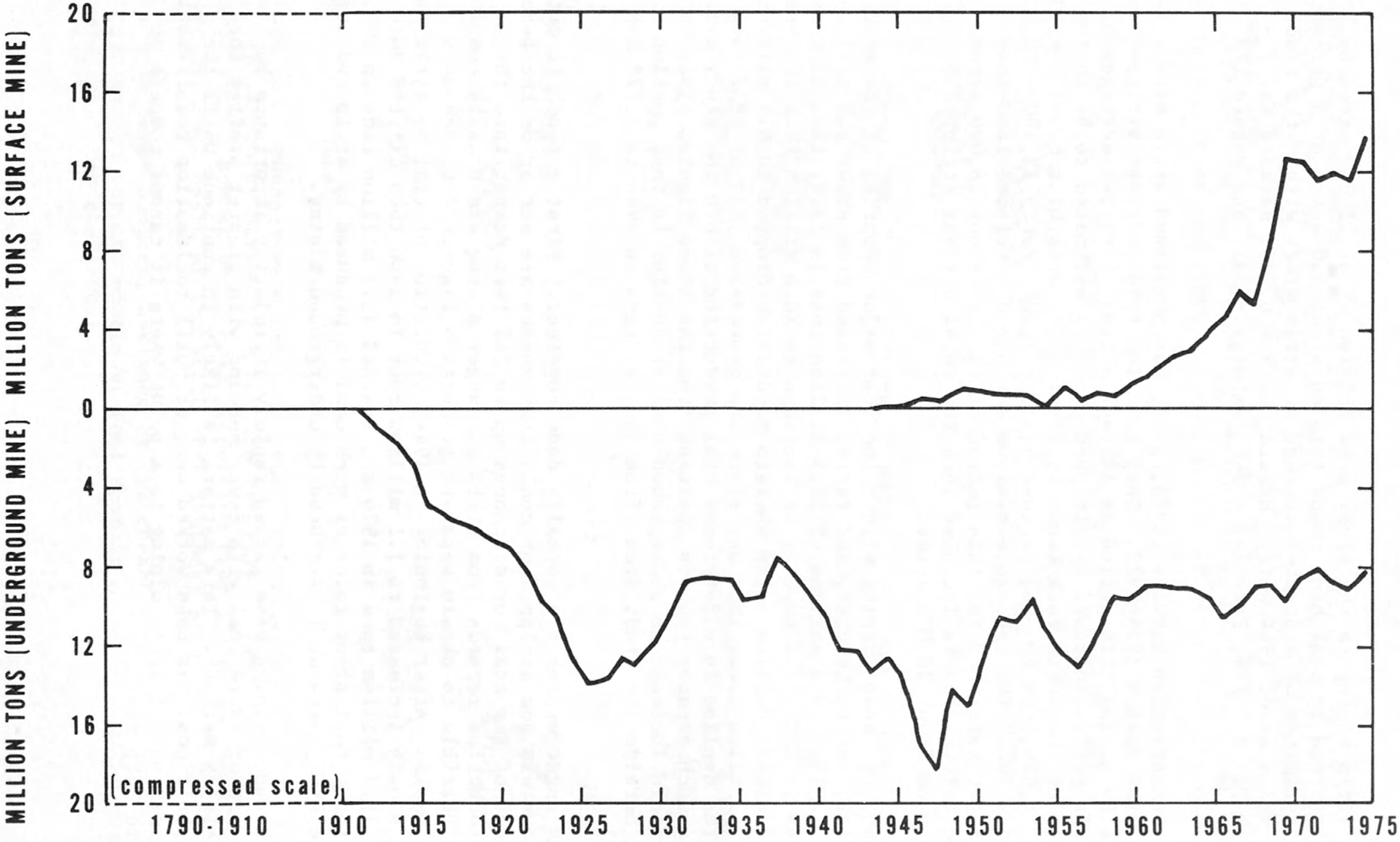

Figure 2. -- Mean annual surface and underground coal tonnages mined in Breathitt, Perry, Knott, and Letcher Counties, Kentucky.

disturbed by strip mining in the study area totaled about 11,000 acres by 1964 while land disturbed by coal haul roads totaled about 550 acres or 5 percent additional. Estimates of disturbed acreage on strip mines within the study area by coal seams as of 1964 were: Hazard No. 9 - 6,300, Harzard No. 7 - 2,482, Elkhorn No. 3 - 774, Fireclay - 840, Amburgy - 381, and Hazard 223 acres.

The Soil Conservation Service (1973, p. 3) has published strip mine acreage by county for the period 1954-1972. They give the total acreage stripped in eastern Kentucky during this period as 107,447 acres. Stripped acreages by county for this period followed by stripped acreages estimated to be in the drainage basin of the North Fork Kentucky River are: Breathitt 6,047 - 6,000, Knott 6,984 - 5,000, Lee 80 - 0, Letcher 9,113 - 7,000, Perry 12,190 - 10,000, and Wolfe 143 - 100. The aggregate minimum acreage of stripped land thus estimated for the watershed for this period of time is about 28,000 acres. If land stripped before 1954 is included then the total acreage stripped by 1972 would probably be about 30,000 acres.

Underground or "deep" mining within the four major counties of the study area (Breathitt, Knott, Letcher, and Perry) increased from about 1.2 million tons of coal in 1913 to a maximum of 18.5 million tons in 1948, then decreased to 8.9 million in 1962, followed by an increase to 10.6 million tons in 1966; after which a steady decline began wherein production dropped to 8.1 million tons in 1972, a value lower than any since the depression year of 1937 (see figure 2). The decline in underground coal production within the study area after 1966 is much greater than is apparent from the above figures since they include a tenfold increase in underground coal production in that portion of Knott County outside the study area (from 168,797 tons in 1966 to 1,798,048 tons in 1972).

Strip and auger mining are normally done together. First a bench is cut around the mountain and stripped of coal, then augers are set up on the bench to extract much of the coal for distances up to 212 feet deeper into the mountain. Production records from strip and auger mining are usually combined so it is not possible to obtain separate production figures for each on a year-to-year basis. After beginning in 1944, production of coal by strip and auger mining slowly increased to 1.1 million tons in 1960 then climbed quickly to a peak of 12.7 million tons in 1970 and reached 13.7 million tons in 1975. It is now evident that about twice as much coal is produced by strip and auger mining in the study area as is produced by underground mining.

Strip and auger mining have gained rapidly in relative importance because they usually produce more coal with fewer men and with greater profits than do underground mining methods. This pattern is likely to continue until the easily strippable coal has been worked out, or until reclamation requirements increase the expense of strip mining to a point where it cannot compete so favorably with deep mining.

The first commercial coal mines were in Letcher and Perry Counties in the southeastern portion of the study area. Much coal is still produced in this area, but the center of production has gradually shifted northwest and continues to move in this direction as large new strip and auger mines are opened in previously unmined portions of Breathitt County. Total coal production in the study area by coal seam for 1962 is listed in table 2 and for 1973 in table 3.

Table 2.--Tonnage of coal produced from different seams in 1962[1]

Sequence number[2]	Coal seam (see table 1)	Auger strip	Auger	Strip	Underground	Total
19	Hazard No. 9, Hindman	9,000	250,790	314,677	124,438	698,905
22	Hazard No. 7, Flag	30,000	647,030	94,884	649,474	1,421,388
23	Hazard No. 5A, Leatherwood	--	1,300	102,116	2,380,567	2,483,983
24	Fireclay Rider	--	--	--	7,966	7,966
25	Hazard No. 4, Fireclay	34,868	277,513	--	2,229,110	2,541,491
26	Whitesburg	32,000	96,193	--	60,663	188,856
27	Amburgy	--	--	--	3,921	3,921
28	Upper Elkhorn No. 3	--	23,275	--	1,160,318	1,183,593
32	Lower Elkhorn, "A"	--	--	--	39,850	39,850
	Total	105,868	1,296,101	511,677	6,656,307	8,569,953

[1] These coal tonnages were computed from unpublished data in the files of the Kentucky Bureau of Mines and Minerals in Lexington, Ky., and represent a summation of coal production from all mines reported within the drainage basin of the North Fork Kentucky River.

[2] These sequence numbers, assigned by the Pocahontas Land Company (1971), begin with 1 for the uppermost coal seam in Appalachia and increase downward to 57 for the lowest.

Table 3.--Tonnage of coal produced from different seams in 1973[1]

Sequence number[2]	Coal seam (see table 1)	Auger strip	Auger	Strip	Underground	Total
16	Richardson	1,408,478	--	207,418	--	1,615,896
18	Hazard No. 11	368,322	--	--	--	368,322
19	Hazard No. 9, Hindman	1,546,123	173,055	24,248	458,232	2,201,658
20	Hazard No. 8, Francis	845,236	146,514	--	--	991,750
21	Flag Rider	266,820	63,388	--	--	330,208
22	Hazard No. 7, Flag	1,842,947	135,399	215,125	454,148	2,647,619
23	Hazard No. 5A, Leatherwood	2,390,047	56,907	26,212	1,616,078	4,089,244
24	Fireclay Rider	111,413	8,000	2,000	42,000	163,413
25	Hazard No. 4, Fireclay	528,328	136,720	15,278	1,460,209	2,140,535
26	Whitesburg	84,458	--	--	15,874	100,332
27	Amburgy	96,979	12,000	--	11,018	119,997
28	Upper Elkhorn No. 3	22,000	--	--	1,694,683	1,716,683
29	Upper Elkhorn No. 2	--	--	--	4,800	4,800
30	Upper Elkhorn No. 1	--	--	--	15,000	15,000
32	Lower Elkhorn, "A"	854,737	--	--	--	854,737
	Total	10,365,888	731,983	490,281	5,772,042	17,360,194

[1] These coal tonnages were computed from data in the 1973 Annual Report of the Kentucky Bureau of Mines and Minerals, and represent a summation of coal production from all mines reported within the drainage basin of the North Fork Kentucky River.

[2] These sequence numbers, assigned by the Pocahontas Land Company (1971), begin with 1 for the uppermost coal seam in Appalachia and increase downward to 57 for the lowest.

Water Resources

Precipitation

The quantity and seasonal distribution of precipitation in eastern Kentucky has been discussed under the section on climate. The chemical quality of precipitation within the study area is discussed in the next section entitled: "Chemical Characteristics of Water in Unmined Areas."

Surface Water

There is an abundance of surface water in eastern Kentucky; however, its seasonal distribution is poor. Approximately 17 inches of the 48-inch mean annual precipitation discharges from the area as stream flow. Most of this discharge comes in the cooler months from December through May when evapotranspiration requirements are low and soil moisture is high. In the summer months most streams have, on occasion, dropped to zero flow. The reservoir on Carr Fork will control or moderate floods downstream and will delay flow of water out of the basin. In summary, the surface-water supplies, though abundant, are undependable unless stored and regulated by reservoirs. The quality of surface water is discussed in other sections of this report.

Ground Water

Ground water can be found throughout the study area, but, except for very shallow wells, is likely to be of poor quality in regard to iron, manganese, and dissolved solids. Individual wells rarely yield more than a few gallons per minute. The most dependable source of high quality ground water in the area is probably that found in abandoned coal mines. Much of this water will meet Federal drinking water requirements (U.S. Environmental Protection Agency, 1976) if suspended iron and manganese are filtered out, as is true of samples 4, 6, and 7 in table 9, part 2. Sample 7 is an outflow from an abandoned and sealed mine in the Hazard No. 7 seam of coal and has been used as a domestic supply for the community of Harveyton. The mine is alleged to fill with water during the winter and spring, then lose water at a fairly constant rate throughout the summer and fall. Ground water associated with coal seams in the study area is generally used as domestic supplies and that associated with the coal seam located near Wiscoal has been used as an industrial supply for washing coal. The quality of ground water is discussed further in other sections of this report.

CHEMICAL CHARACTERISTICS OF WATER IN UNMINED AREAS

Precipitation

No chemical analyses of precipitation in eastern Kentucky are known to predate extensive mining for coal and its use as fuel in the area. Precipitation at the present time should not differ appreciably in chemical characteristics from mined to unmined areas; however, it undoubtedly does differ signigicantly from the time prior to the extensive use of fossil fuels.

Numerous studies in recent years from many parts of the world document the fact that airborne wastes from many industries together with extensive burning of fossil fuels produce downwind changes in the chemical quality of precipitation and in the quantity and quality of dry fallout. Much of the dry fallout dissolves in rain water or melting snow and eventually finds its way into streams. Cogbill and Likens (1974) document the major chemical changes in precipitation and the gradual increase in acid rain over the northeastern United States.

Concentrations of sulfate, chloride, and nitrate in the precipitation have undoubtedly increased overall during the past century in the study area because of the increase in industrial wastes discharged into the atmosphere. Increases in these ions will tend to increase the acidity of the precipitation, and this in turn can affect the rate at which it can dissolve minerals, rocks, and soil materials.

Seay (1957, p. 454) reported that from June 1953 through May 1956 an annual average of 14.18 pounds/acre of sulfur was deposited at Quicksand, Kentucky by rainfall averaging 41.4 inches per year for this same period. This is equivalent to 4.53 mg/L (milligrams per liter) sulfate dissolved in the precipitation, but it should be stated that some of the sulfate could have first settled as dust on the rain gage, then been dissolved by the rain and melting snow. Hydrologically the end result is the same as long as the sulfate dust is soluble in the water. Johnson (1924, p. 354) reported about double this much sulfur in rain water in Kentucky during a similar study in 1921-22, perhaps because higher sulfur coal was burned at this time.

No studies of chlorides in the precipitation of eastern Kentucky are known to have been made; however, Laney (1965, p. C189) found 0.2 mg/L chloride in precipitation in western North Carolina during 1962-63. Cogbill and Likens (1974, p. 1133-1134) observed 0.15 mg/L chloride at Gatlinburg, Tennessee during 1973.

In 1922-23 Freeman (1924, p. 358) observed averages of 7.17 pounds/acre nitrate-nitrogen and 11.61 pounds/acre ammonium nitrogen deposited at seven Kentucky locations over a period of exactly one year. This is the equivalent of 3.28 mg/L nitrate and 1.54 mg/L ammonium dissolved in the year's precipitation. Data by Cogbill and Likens (1974, p. 1134) indicate that the nitrate value is similar to, or a little higher than, those prevailing in the northeastern United States today. The ammonium value of 1922-23 is about five-fold that which is prevalent today in the northeast and probably is not a valid measure of present day ammonium levels in eastern Kentucky precipitation.

Recent work by Cogbill and Likens (1974, p. 1133) indicates that in the northeastern United States precipitation has a consistent pH value of less than 4.4 units when the expected pH value from atmospheric carbon dioxide equilibria alone would be 5.6 units. They could generally calculate the pH value of raw water from its chemical concentration within 0.1 pH unit assuming stoichiometric formation of acid from the sulfate, nitrate, and chloride ions excess to that neutralized by the major cations, other than hydrogen common to precipitation: ammonium, calcium, magnesium, sodium, and potassium.

Table 4 is a comparison of chemical constituents in milligrams per liter and milligram equivalents per liter estimated to have been in precipitation in the study area in 1800 and in 1975. Some of these estimates are rather tenuous; nevertheless, they illustrate the striking changes which may have occurred in the chemistry of precipitation as a consequence of man's activites. Pure rain water with the chemical characteristics described for 1975 could not support fish or certain other types of aquatic life, but in most watersheds of the study area a brief exposure of rain water to soils or aquifer materials is sufficient to allow most of the acid to become neutralized. The supply of neutralizing bases in soils and aquifers is not inexhaustable and is only a temporary solution to the problem of acid rain.

Acid precipitation with a pH of 4.01 units, such as that postulated to occur in the study area in 1975 will have some far reaching environmental consequences. The effects of acid precipitation, though slow to materialize, are likely to be far more serious than the more direct and immediate pollution attributable to mining for coal. Calculations show that 100 years of rain with this pH would leach most of the exchangable bases from the top few inches of the soil profile, thus reducing the soil pH enough to seriously reduce crop production and forest growth -- unless compensated for by applicaton of lime (about 52 pounds of lime per acre per year). Dochinger and Seliga (1976, p. 564-565) report that these effects of acid rain are already significant in Norway and Sweden and in the Adirondack Mountains of New York State.

Surface Water

Before the effects of acid-mine drainage can be evaluated it is necessary to establish the characteristics of stream water prior to mining. An ideal frame of reference would be the characteristics of the water when the land was under pristine or primeval conditions, that is, prior to settlement by man; however, water samples were not collected and analyzed when such conditions prevailed.

Early chemical data were collected on the Kentucky River at Frankfort, Kentucky (probably at Lock 4, U.S. Geological Survey gaging station 03287500) during 1906 and 1907 (Dole, 1909, p. 69) but even then the basin had been extensively logged and farmed, though not extensively mined. These data showed that sulfates ranged from 4.0 to 12 mg/L and averaged 8.3 mg/L, nitrates ranged from 0.0 to 7.4 mg/L and averaged 2.5 mg/L, and chlorides ranged from 0.6 to 3.6 mg/L and averaged 2.0 mg/L. Water from the North Fork Kentucky River was not analyzed at this time but it is assumed to have been similar chemically. Corresponding averages during the 1975 water year (for samples collected 35 river miles downstream from Frankfort at Lockport, Kentucky, station 03290500) were 33 mg/L sulfate (range 22 to 44 mg/L), 2.6 mg/L nitrite plus nitrate (0.66 to 4.2 mg/L), and 9.4 mg/L chloride (range 4.7 to 29 mg/L) (U.S. Geological Survey, 1975). No water-quality records were found for any station on the North Fork Kentucky River or its tributaries prior to 1939, and by this date the quality of water in the river had already been severely affected by mine drainage.

Table 4.--Estimates of dissolved-ion concentrations in precipitation, North Fork Kentucky River watershed, 1800 and 1975

Ion	Estimated 1800 concentration (mg/L)	Estimated 1800 concentration (me/L)	Estimated 1975 concentration (mg/L)	Estimated 1975 concentration (me/L)
Hydrogen	0.001	[1]0.001 (pH = 6.00)	0.10	[4]0.098 (pH = 4.01)
Ammonium	1.00	[2].056	.33	[7].018
Calcium	.20	[3].010	.30	[8].015
Magnesium	.04	[3].003	.05	[8].004
Sodium	.05	[3].002	.07	[8].003
Potassium	.05	[3].001	.07	[8].002
TOTAL CATIONS		.073		.140
Sulfate	1.50	[4].031	4.50	[7].094
Nitrate	1.50	[5].024	2.50	[7].040
Chloride	.15	[3].004	.20	[7].006
Bicarbonate	.85	[6].014	.00	[9].000
TOTAL ANIONS		.073		.140
GRAND TOTAL	5.34		8.12	

[1] Extrapolated form data by Cogbill and Lykins (1974, p. 1135) for an area little affected by the industrialization along Mississippi River. This pH value of 6.0 units is similar to snow melt form most areas in the western United States (Feth, Rogers, and Robertson 1964, p. J24) which are little affected by industrialization.

[2] This high value of ammonium ion is based largely on early data presented by Freeman (1924, p. 358). Freeman reported even more ammonium than this but there is doubt that pre-industrial values would have been this high. The 1800 estimate given for ammonium is unsubstantiated by theory or confirming data so it is considered to be the most questionable value in the table.

[3] These estimates for 1800 were based on the 1975 estimates. Pre-industrial concentrations of these ions are assumed to be less than the 1975 concentrations so the 1800 estimates are simply the 1975 concentrations arbitrarily reduced by subtracting out the fraction believed contributed by industrial fallout.

[4] Calculated by difference - Remaining ions were estimated and this value is the one required to give an ion balance between cations and anions.

[5] This is another rough estimate which could be too high. It is a compromise between data presented by Cogbill and Likens (1974, p. 1134) and that presented by Freeman (1924, p. 358).

[6] Estimated from figure 1 of article by Galloway, Likens, and Edgerton (1976, p. 722).

[7] Estimated largely from data by Cogbill and Lykins (1974, p. 1134), but nitrate and sulfate were biased upward a little because of the high nitrate values reported in Kentucky by Freeman (1924, p. 358) and high sulfate values reported by Seay (1957, p. 454).

[8] Extrapolated from data given by Cogbill and Lykins (1974, p. 1134) but greater weight given to data from the Gatlinburg, Tennessee station.

[9] The bicarbonate concentration has to be essentially zero in water with a pH value less than 5.6 units.

Under pristine conditions the chemistry of surface waters at any given time of the year should have been nearly uniform throughout the entire basin of the North Fork Kentucky River. The only exception would be the streams and springs coming off of Pine Mountain. These waters contact more limestones and other carbonate materials and consequently have higher concentrations of calcium and bicarbonate ions much of the year. The chloride and sulfate concentrations originally found in water from Pine Mountain would have been similar to those for the watersheds downstream despite the considerable difference in total dissolved solids.

Observations made during the 1975 water year on the chemical quality of water in unmined watersheds are discussed later in this report under the heading: "Stream chemistry reconnaissance, 1975 water year."

Ground Water

Three distinct zones of ground water are found over almost the entire basin of the North Fork Kentucky River. The shallow ground water (zone 1) occurs in the valley alluvium and in the shallow subsoils which overlie most of the bedrock of the area. Water in this aquifer slowly seeps into the streams and maintains some flow except during extended dry periods. In quality it is very similar to that found in the streams during seasons of low flow. Based on the low-flow surface-water data just presented, and the unmined watershed data collected during the 1975 stream reconnaissance, it is estimated that under natural conditions sulfate and chloride concentrations would average about 15 mg/L and 1.5 mg/L, respectively, while specific conductance would average about 100 umhos/cm. Most of the hand-dug domestic wells of the region produce water from this aquifer. The water in much of this aquifer is still similar in quality to that present under natural conditions. Additional data on the quality of water in this zone may be found in publications by Price and others (1962) and Mull (1965).

The second and third zones of ground water are found in the consolidated sedimentary rock aquifers which underlie the subsoils and alluvium. The water in the upper part of this aquifer (zone 2) is similar in quality to that found in the overlying aquifer (alluvium subsoils) except that most constituents are present in somewhat higher concentrations. This is espcially true of iron and manganese which may be present in concentrations many times higher than those normally found in the alluvium. The lower boundary of the upper part of the rock aquifer is the interface between fresh circulating ground water (zone 2) and saline, relatively stagnant, water at depth (zone 3). The bulk of the ground water in zone 2 is similar in quality today to that which would have been found there several hundred years ago; and, since circulation in this zone is so slow, most of it is probably the identical water.

The third zone of ground water is found at depths below the fresh circulating ground water. It is composed of noncirculating saline water that was entrapped in the interstices of the sediments that formed the sedimentary rock, and later was modified in quality by various geochemical processes. This water is found in bedrock starting at depths a few feet lower in elevation than that of the regional stream beds. The water in this zone contains a very high concentration of sodium chloride and generally, salinity about the same as sea water. Gas and oil wells penetrate this zone and may release highly saline water into streams as was the case in Bowman's Branch (site 341) where one sample of water contained 2,400 mg/L of chloride ion. The chemical characteristics of this interstitial water are discussed by McGrain (1953). The upper parts of this saline ground-water body are commonly mixed to some extent with the overlying fresh water. The sample from the James Griffith well, 120 feet in depth, (see table 9, part 2) is a case in point.

Wells penetrating the consolidated sedimentary rock aquifers (containing water in zones 2 and 3) commonly yield less water per unit depth than do wells tapping alluvial aquifers; but, occasionally they may yield large quantities of water if they tap a fracture zone or a rare permeable zone.

ORIGINS AND CHARACTERISTICS OF DRAINAGE FROM COAL MINES

Characteristics of Drainage from Unmined Areas

The earth's surface in eastern Kentucky is intensely weathered to a depth of 20 feet or more. This weathered zone contains essentially no sulfide minerals. Its thickness depends on lithology, degree of structural fracturing of the rock, and position of the water table (Grube and others, 1973, p. 135).

Rain water percolating through this intensely weathered zone will dissolve little from it except for a few milligrams per liter silica. Water found in the streams of undeveloped watersheds, especially at low flow, is believed to be representative of water which has been in contact with this weathered zone. The chemical characteristics of precipitation and the water in these undeveloped watersheds are discussed in the section entitled "Characteristics of water in unmined watersheds." Chemical data collected during the 1975 water year from streams in undeveloped watersheds is found in the section entitled "Stream chemistry reconnaissance, 1975 water year."

All water observed entering underground mines in Pennsylvania is alkaline unless it has passed through some other mined area first (Braley, 1954, p. 10). This may be true in eastern Kentucky; however, we do not have direct substantiating data. The pH of water in drilled wells and springs in eastern Kentucky is reported by Price and others (1962, p. 45, 46, tables 7, 9) as ranging from 5.8 to 7.5 units for the wells and from 6.7 to 7.9 units for the springs; the inference being that water entering underground mines in this area would likely be near neutral.

Oxidation of Ferrous Disulfide to Form Acid Mine Drainage

Chemistry of Ferrous Disulfide Oxidation

When coal mines are developed, the deeper strata enclosing the coal are exposed to the oxygen containing atmosphere and thus to oxidation, and in the case of strip mines, to direct weathering as well. This allows iron disulfides (pyrite and marcasite), normally associated with coal deposits, to oxidize and release as end products, sulfuric acid and ferrous sulfate. These oxidation products, in most cases, eventually find their way into the streams and ground water of the area. The ferrous sulfate can oxidize further to produce an insoluble precipitate of ferric hydroxide and more sulfuric acid. It is stated by Ohio State University Foundation (1971B, p. 1) that the only pyritic material in natural systems which can be oxidized at a significant rate is that which is exposed to an oxygen containing atmosphere. Iron disulfide minerals continually submerged under water will be effectively blocked from oxygen and no significant oxidation will take place.

The oxidation of pyritic materials has often been described by the following equations:

$$FeS_2(s) + 3\ 1/2\ O_2 + H_2O \longrightarrow 2SO_4^{=} + Fe^{++} + 2H^+ \quad (1)$$

$$Fe^{++} + 1/4\ O_2 + H^+ \longrightarrow Fe^{+++} + 1/2\ H_2O \quad (2)$$

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

These three equations may be added to give the overall stoichiometric relation:

$$FeS_2(s) + 3\ 3/4\ O_2 + 3\ 1/2H_2O \longrightarrow 4H^+ + 2SO_4^{=} + Fe(OH)_3 \quad (4)$$

Researchers at Harvard University (1970, p. XVI-XVII) have given experimental evidence showing that the slow oxygenation of ferrous iron (Fe^{++}) shown in equation (2) is the rate-determining reaction and this is followed immediately by the rapid reduction of much of the resulting ferric iron (Fe^{+++}) by more iron disulfide. The equation for this latter reaction may be written:

$$FeS_2(s) + 14\ Fe^{+++} + 8H_2O \longrightarrow 15Fe^{++} + 2SO_4^{=} + 16H^+ \quad (5)$$

Rewriting equation (2) to show the oxidation of 14 moles of ferrous iron gives:

$$14Fe^{++} + 3\ 1/2\ O_2 + 14H^+ \longrightarrow 14Fe^{+++} + 7H_2O \quad (6)$$

Adding equations (5) and (6) gives the overall reaction:

$$FeS_2(s) + 3\ 1/2\ O_2 + H_2O \longrightarrow Fe^{++} + 2SO_4^{=} + 2H^+ \quad (7)$$

Equations (1) and (7) are identical showing that by either path (O_2 or Fe^{+++} as the oxidizing agent) the net reaction is the same. In both cases oxygen must be supplied to the system at a rate equivalent to the rate of iron disulfide oxidation (Shumate and others, 1970, p. 8, 20).

As shown in equation (4) the products of iron disulfide oxidation are: (1) hydrogen ions which lower the pH and increase the acidity of the receiving water, (2) sulfate ions which contribute to the salinity of the receiving water, and (3) ferric hydroxide which is essentially insoluble in water and which precipitates in the mines or on the stream beds as the yellow-orange deposit of ferric hydroxide commonly referred to as "yellow-boy." In addition to these oxidation products it is likely that some of the iron will precipitate out as ferric sulfate.

Potential for Release of Acid Mine Drainage

The potential of coal and associated strata for releasing acid mine drainage may be computed from its iron pyritie or sulfur content, but not all materials with a high pyritie or sulfur content release troublesome concentrations of acid drainage. This is because not all pyrites are equally reactive or equally stable. Caruccio (1970, p. 128, 130, and 1972, p. 48) has found that the fine-grained or "framboidal" pyrite (believed to have been formed contemporaneously with the coal) is extremely reactive and will oxidize readily when exposed to oxygen and moisture. He also observed that the coarse-grained pyrite (formed as secondary deposits in joints and pre-existing plant structures) is stable and did not oxidize even when ground to a particle size of 2 to 5 microns in diameter.

Continued Release of Acid Mine Drainage After Mining Has Ceased

It is a characteristic of watersheds with strip-mining for the production of acid to come to a peak, then gradually decline once mining has ceased. Full return to the original water quality may take many years. Einspahr and others (1955, p. 334) have shown that in one instance overburden exposed to moisture and air developed maximum acidity after about 6 months. Struthers (1964, p. 130) found that the total salt in leachate from spoils generally decreased with time, though in one instance it increased for 3 years before declining. Dyer and Curtis (1977, p. 10) found that some elements continued to increase in concentration for at least 2 years after mining while others peaked rather quickly after the land disturbance and soon returned to premining levels.

It may be useful to think of salt and acid yields in terms of half-lives, that is, the time required for the salt or acid output to drop to one-half its original value. On this basis Vimmerstedt and Struthers (1968, p 157) found in a lysimeter study that toxic Ohio coal mine spoils had a half-life of 6 to 8 years. No attempt was made to ascertain half-lives of waste production from any spoils as part of this study. If accurate information were obtained on the creation of each spoil bank, it should be possible to compute half-lives by comparing waste production per acre of spoil with nearby spoils from the same seam mined by the same method at other times.

Effect of Bacteria on Rate of Oxidation of Pyritic Minerals

It is known that autotrophic bacteria of the Ferrobacillus-Thiobacillus group under favorable environmental conditions can catalyze the oxidation of pyrite (Ohio State University Research Foundation, 1971B, p. 1). Lau, and others (1970, p. 118-119) concluded that biological catalysis of pyrite oxidation is unlikely in underground environments but states that sound evidence existed which shows that oxidation could be significant at the surface of refuse piles or spoil banks. The Ohio State University Research Foundation (1971A, p. 57) cited conditions which make it difficult to believe that microbial catalysis of pyrite oxidation can be a significant factor in the formation of acid mine drainage.

Acid mine drainage frequently has not been completely oxidized at the time it leaves the mines, and will thus contain ferrous iron in addition to sulfate and hydrogen ions. With continued exposure to atmospheric oxygen, the reactions illustrated in equations (2) and (3) gradually occur thus yielding even more hydrogen ion and leaving the deposit of ferric hydroxide to mark approximately the areas where the oxidation of ferrous iron occured. Recent observations by Joel Dysart (oral communications, 1976) indicate that the water draining from deep mines generally contains appreciable dissolved oxygen even though most of the iron may be in the ferrous state. This is further indication that prolonged exposure to dissolved oxygen is required before complete oxygenation of iron occurs. Deposition of appreciable quantities of ferric hydroxide has been observed for at least three miles downstream from the point of acid mine drainage inflow into a small Virginia stream. Dissolved iron in the stream decreased from about 4.7 to 3.5 mg/L in the reach (Hoehn and Sizemore, 1977, p. 157, figure 2). This decrease in iron was associated with a decrease in pH as would be expected from equations 2 and 3. Alkalinity also decreased downstream and this is a direct consequence of the reaction between hydrogen ion and bicarbonate ion shown in equation 8.

$$H^+ + HCO_3^- \rightleftharpoons H_2CO_3 \rightleftharpoons H_2O + CO_2\uparrow \qquad (8)$$

Release of Additional Minerals by Acid Mine Drainage

The direct additions of sulfate, ferrous, and hydrogen ions are not the only changes in water quality induced by acid mine drainage. The acidity of mine drainage can directly affect the concentrations of other ions in solution in several ways.

Highly acid waters break down the clay minerals thus contributing aluminum, silica, other major species, and high concentrations of trace elements to the acid solution (Gang and Langmuir 1974, p. 54). The solubility of many trace elements is highly dependent upon the pH value of the solution. Compounds of most trace metals such as iron, aluminum, zinc, lead, copper, chromium, cobalt, nickel, and cadmium are more soluble in acid solutions than in neutral or alkaline solutions. Gang and Langmiur (1974, p. 60) observed that nickel, zinc, cobalt, and copper are the most abundant trace metals in acid mine drainage. They found good correlations on Tobey Creek in western Pennsylvania between zinc, the most abundant of trace metals, and several other trace metals including nickel, cobalt, copper, chromium, and cadmium. They concluded that since all the trace elements except cadmium load on the same factor or have the same source of variation in the components analysis, it is possible to measure the most abundant trace element (zinc) and predict the other metals with some degree of certainty. They also found very highly significant relations between the logarithm of specific conductance and the logarithms of discharge, zinc, iron, and maganese.

Acid mine drainage may also dissolve any calcium or magnesium carbonates such as limestone, calcite, aragonite, magnesite, or dolomite that it contacts in the stream bed or on suspended sediment, thus neutralizing an equivalent amount of acid. This would directly increase the concentrations of calcium, magnesium, and perhaps bicarbonate ions in solution. This same end result may also come through another route. The hydrogen ions (acid) may replace exchangeable cations such as calcium, magnesium, sodium, and potassium from any soil or aquifer material it contacts; thus neutralizing at least some of the acidity in the water and at the same time making the soils or aquifer materials more acid by an equivalent amount.

Reactions involving solution and precipition of minerals are major controls on metal levels in acid mine drainage. Such controls can be identified in a given water by comparing the equilibrium solubility product or quotient to the corresponding product and quotient computed from the analysis of the water (Gang and Langmuir, 1974, p. 45). A general development of chemical equilibria concepts as applied to natural waters is beyond the scope of this report, but may be found in such sources as Garrels and Christ (1964), Stumm and Morgan (1970, p. 534-545), Van Breeman (1973) and Truesdell and Jones (1974). Thermodynamic data for minerals and dissolved species are often either lacking or of highly uncertain acccuracy; thus, some apparent undersaturations or supersaturations computed by these approaches may be in error (Gang and Langmuir, 1974, p. 46).

Neutralization of Acid Mine Drainage

The common cations (calcium, magnesium, sodium, and potassium) normally account for almost all the positively charged ions in natural waters. In acid mine drainage the hydrogen ion and sometimes ferrous, aluminum, and manganese ions are also important. In extreme cases the hydrogen ion may even be the dominant cation. Acid drainage waters normally remain acid until the hydrogen ion has been replaced by a chemically equivalent quantity of the common cations. Whenever mining activities cause an increase in dissolved solids in streams the common cations normally account for about half of this increase, unless the water is extremely acid. This is evident from the mass of published and unpublished data on the chemistry of streams throughout Appalachia. The proportions of cations dissolved in stream water are usually dependent upon the cation exchange characteristics of the soil or aquifer materials in the last part of the flow path followed by this water before it reaches the stream. In the study area and throughout Appalachia in general, calcium is almost always the dominant exchangeable cation. In some areas exchangeable magnesium is predominant. Exchangeable hydrogen, sodium, and potassium are also important but rarely exceed exchangeable calcium or magnesium. The presence of high concentrations of sodium in stream water as in Bowmans Branch near Dice, site 341, (table 9, part 1) is almost a sure indication that saline ground water is being discharged into the stream from deep wells, and does not normally indicate the presence of a large area of exchangeable sodium in soils or aquifer materials.

Acid mine drainage water is frequently neutralized as it passes through soils or aquifer materials before it reaches the streams. This neutralization of acid may be either real or apparent. It is real if the acid water contacts carbonate minerals (calcite, aragonite, magnesite, dolomite, and so forth), wherein reactions of the type given in equations 9 and 10 can occur, giving as products water, carbon dioxide, and in this case, calcium ions. It is only an apparent neutralization of the acid if the hydrogen ions in the water simply replace the common exchangeable cations from the soil or aquifer materials, because in this case the hydrogen ion transferred to the soil or aquifer is still actively acid and produces a zone of acid soil or aquifer material which in turn is free to transfer this acidity elsewhere through the exchange process. Highly acid soils must be neutralized with lime ($CaCO_3$) before they can be farmed to most crops. The exchangeable hydrogen ions in the aquifer will gradually migrate with ground-water flow and eventually, perhaps years later, reach the streams although perhaps so diffuse or dispersed as to create no problem or significant change in the receiving water.

$$CaCO_3 + 2H^+ \longrightarrow Ca^{++} + H_2CO_3 \quad (9)$$

$$H_2CO_3 \rightleftharpoons H_2O + CO_2\uparrow \quad (10)$$

Beers and others (1974) describe how the chemistry of acid mine drainage water was changed by its passage through 40 inch profiles of two soils. The partly calcareous soil neutralized essentially all the acid drainage passed through it, while acid soil neutralized most of the acid in the water percolating through it.

PROBLEMS ASSOCIATED WITH ACID MINE DRAINAGE

Problems frequently associated with highly acid mine drainage include: (1) unsuitableness for human or even animal consumption because of the high level of salinity or because of the high concentrations of toxic elements, (2) toxicity to fish and other aquatic life, (3) toxicity to plants exposed to it, (4) unsatisfactory for certain industrial uses, (5) corrosiveness to metals that come into contact with it, and (6) precipitation of ferric hydroxide (yellow-boy) which interferes with establishment of stream benthos and the feeding of fish.

Gang and Langmuir (1974, p. 63) reported that coal-strip mining in western Pennsylvania produced iron, manganese, sulfate and dissolved solids concentrations in streams and ground waters that were generally far in excess of levels recommended in drinking water standards. In the course of the present study on the North Fork Kentucky River a farmer at site 340 reported the loss of pigs and other livestock when they drank "red" water draining from underground mines that had just been cut into by strip-mining operations.

Some workers have reported prolonged survival of various species of fish at pH values below 5.0 units, but a host of others reported extermination of fish when the pH value remained below 4.0 units for any length of time (Branson and Batch, 1971, p. 508). The sediment commonly associated with strip mining may also be harmful to aquatic life. Silt kills or smothers the benthos thus starving the bottom feeding fish, but fish feeding on surface insects or terrestrial insects can survive longer in silted waters (Branson and Batch, 1971, p. 514-515). The ferric hydroxide which commonly precipitates on the bottoms of acid streams may also smother the benthos.

Acid mine drainage may be responsible for the destruction of plant life. On many spoil banks such drainage may prevent revegetation for many years. The primary source of toxicity to plant materials appears to be one of the elements brought into solution by the acidity, rather than the acidity itself (Berg, 1966, p. 91). The toxicity of extremely acid coal-mine spoils is caused primarily by excess soluble manganese (Berg and Vogel, 1973, p. 57). High concentrations of manganese, aluminum, iron, zinc, and sulfur were major factors limiting plant growth on coal-breaker refuse (Czapowskyj, 1973, p. 132), and this presumably could be the case on some coal mine spoil banks as well. Berg (1966, p. 93) states that on extremely acid spoils zinc, copper, and nickel may also be present in toxic concentrations.

The fact that acid mine drainage generally creates an unfavorable aquatic environment for plant and animal life has been widely reported. Much of this literature has been reviewed by Parsons (1957) and Riley (1960) and will not be discussed here.

Waters containing acid mine drainage may not be suitable for some industrial uses; however, of all potential users, industry is the most likely to be able to afford the cost of reclaiming the water to a satisfactory quality.

Acid mine drainage can be very corrosive to metals that it may contact. If transmitted through pipes it may quickly destroy them. It may corrode away metal culverts or concrete bridge abutments thus necessitating their repair or replacement in a relatively short period of time (Havens, 1952, p. 5, 8). Residents along Lotts Creek at Darfork, Kentucky claim that sometimes the stream is so acid that it will dissolve a tin can in a few days, leaving only the metal rings at each end.

One of the most destructive aspects of acid mine drainage is the sudden but short-lived releases of large quantities of acid drainage into the receiving stream. This can occur when an operating deep mine or a drainage pit on a surface mine is periodically pumped to remove accumulating water, or when an abandoned mine is suddenly cut into by a new mine and thus drained of acid waters that may have accumulated there. As noted by Biesecker and George (1966, p. 5) occasional flushing of mines by excessive precipitation may also produce temporary, but often dramatic, stream damage and fish kills.

Chemical pollution is the eventual by-product of acid mine drainage once the acid has been neutralized. A 4-year study of the chemical quality of water in six small watersheds in Breathitt County, Kentucky (all within the North Fork Kentucky River drainage basin) indicates that surface mining for coal may result in chemical pollution of streams, even in areas where no acid production is present (Curtis, 1972B, p. 19). He further noted that the greatest increases in dissolved constituents following mining in this area were sulfate, calcium, and magnesium ions with lesser increases observed for aluminum, manganese, iron, and zinc.

Acid mine drainage may be neutralized by the direct introduction of alkaline materials into the acid ponds or streams. Neutralization with chemicals, though highly effective, is expensive and is generally done only when all other measures fail. Some of the chemicals which have been used to neutralize acid mine drainage include lime, ignited magnesite, soda ash, sodium carbonate, sodium hydroxide, and ammonia. Limestone, dolomite, and various industrial wastes have also been used to neutralize acid mine drainage.

STREAM CHEMISTRY RECONNAISSANCE, 1975 WATER YEAR

Coal mining has had a major impact on the chemical characteristics of water in streams in much of the study area. The causes and nature of these changes have been discussed earlier in this report under the heading "Origins and Characteristics of Drainage from Coal Mines." To obtain a detailed picture of the effects of coal mining on chemical characteristics of streams in the watershed of the North Fork Kentucky River it was necessary to sample a large percentage of the tributaries, including many having drainage areas of 1 square mile or less. Sampling was more intensive in areas which had been heavily mined or which had water of lower quality. Water samples were collected at a total of 415 sites. A specific conductance measurement was always obtained, generally in the flowing stream water, but sometimes in a collected sample. Samples collected at the bulk of these sites were analyzed for sulfate and chloride, while in-stream pH values were obtained for about half of the samples. Occasionally the stream velocity was so high that pH measurements made in the stream would not have been valid, so in these instances the pH measurement was made at stream side in a cup of water taken from the stream.

It should be pointed out that these are spot measurements taken at different flow levels. They tend to approximate a yearly average. Discharge weighted averages of dissolved constituents would be somewhat lower than this since the bulk of the discharge in almost all watersheds occurred during brief floods when dissolved solids concentrations were relatively low compared to those measured and reported herein.

The 415 sampling sites were grouped according to the amount and type of developments on their respective watersheds. Those watersheds which fell clearly into one type of development or another are discussed below. All pH, sulfate, chloride, and specific conductance data collected at all sites in each category were averaged together on a sample by sample basis - not site by site basis. There may be some question regarding the validity of averaging occasional or one-time grab samples in this way; nevertheless, the sampling is of like populations spread over approximately a year's time with some emphasis given to the seasons of high flow. So the averages and ranges, though approximate, appear reasonable in comparison with other available data and are believed to give a meaningful, though perhaps not statistically significant, assessment of the quality of water in each population of streams. Curtis (1977A) has shown that the chemical characteristics of several streams draining both mined and unmined watersheds in eastern Kentucky tend to follow annual cycles, which, for a given stream can be characterized almost as well by monthly samples as by weekly samples. Dissolved constituents in streams in eastern Kentucky tend to vary inversely with the logarithm of the discharge, so do not fluctuate nearly so wildly as do the discharges (Dyer and Curtis, 1977, figs. 2-7). This relation is most clearly evident in the unmined watersheds.

A tabulation of all the data collected on samples subjected to these partial analyses (specific conductance, sulfate, chloride, pH, and temperature) is presented in table 8. More detailed chemical analyses were performed on a number of selected samples and the data from these analyses are presented in table 9.

Undeveloped Watersheds

Early chemical data were collected on the Kentucky River at Frankfort, Kentucky during 1906 and 1907 (Dole, 1909, p. 69). These data have been discussed in the chapter entitled "Chemical Characteristics of Water in Unmined Areas" and show that sulfate ranged from 4.0 to 12 mg/L and averaged 8.3 mg/L while chloride ranged from 0.6 to 3.6 mg/L and averaged 2.0 mg/L. Water in the North Fork Kentucky River was not analyzed at this time but is believed to have been chemically similar.

Despite all the activities of man, it is still possible to deduce rather closely the changes in water quality induced by mining. The dissolved solids observed in streams from the undeveloped watersheds must originate from one of three sources: (1) solution of rocks, minerals, and soils by rain water, (2) dissolved solids carried to earth in precipitation and dry fallout, and (3) solids dissolved from materials introduced into the watershed by man such as fertilizers or wastes. Since we are here considering only the undeveloped watersheds, we should be fairly safe in assuming that dissolved contaminants from the third source are negligible.

The coal on many streams and branches has not been mined. Many of these branches do not have roads or residences and have now become reforested so they closely resemble the pristine situation, except perhaps for the size of the trees. Stream sampling sites 17, 32, 75, 108, 117, 163, 281, 292, 307, 311, 349, 358, 375, 391, 394, 400, 401, and 404 belong to this category. These streams, listed in downstream order are scattered over the entire study area (see plates 1-3) and are named in table 8. Specfic conductance measured at these stations from December 1974 through August 1975, ranged from 23 to 245 umhos/cm and averaged 75 umhos/cm. Sulfate concentrations ranged from 6.4 to 22 mg/L and averaged 12.6 mg/L. Chloride concentrations ranged from 0.1 to 5.0 mg/L and averaged 1.6 mg/L. The pH values ranged from 6.0 to 8.5 units. As expected, these undeveloped watersheds as a group had the best quality of stream water observed during this reconnaissance study.

It is apparent that streams observed in undeveloped watershed during the current study are somewhat higher in sulfate, nitrate, and chloride than was the Kentucky River at Frankfort in 1906 and 1907. It is probable that much or all of this observed difference is due to increased concentrations of sulfate, nitrate, and chloride in precipitation and atmospheric fallout induced by increased industrialization in the area upwind of the study area; though differences in geology of the areas may account for some of the difference.

According to the estimate in table 4, precipitation over the entire study area averaged about 4.5 mg/L sulfate during 1975. Considering that about 31 inches of the 48 inches precipitation is lost by evapotranspiration, this would concentrate dissolved substances 2.82 fold. Precipitation should thus contribute about 12.7 mg/L sulfate to stream runoff. This would almost exactly account for the 12.6 mg/L sulfate observed on the undeveloped tributaries to the North Fork Kentucky River in 1974 and 1975. Some sulfate undoubtedly is released by natural erosion and also should appear in the streams, but the above data do not allow for any such contribution. The 1974 and 1975 data were not weighted for discharge in any way, but had this been done the discharge weighted ion concentrations (including sulfate) should have been even lower than the crude averages presented here. In view of the even higher sulfate concentrations reported earlier by Seay (1957, p. 454) and Johnson (1924, p. 354) the 4.5 mg/L estimated for 1975 seems a conservative estimate. It is believed that part of the sulfate in precipitation is being adsorbed by the anion exchange complex in soils, a process which could continue for many years before a new equilibrium is reached with the higher sulfate ratios now found in precipitation. Until such an equilibrium is reached, only part of the sulfate reaching a given watershed in precipitation will be transported from that watershed by streamflow.

Chloride concentrations in the precipitation over the study area averaged about 0.2 mg L during 1975 according to the estimate given in table 4. When concentrated 2.82 fold by evapotranspiration this chloride can account for about a third of that in water discharged from the undeveloped basins. The remaining 1.0 mg/L chloride in discharge from the undeveloped basins is derived from the rocks, minerals, and soils of the watershed through the processes of natural erosion and weathering. Some chloride may have been displaced from the anion discharge complex of the soils by the high concentrations of sulfate now prevalent in the precipitation.

It would be futile to compare the remaining ions in discharge from undeveloped watersheds with those in the precipitation. Plants are likely to utilize a large percentage of the nitrate in precipitation while cation exchange processes in the soils and subsoils are likely to rearrange the cation concentrations and ratios in drainage water before it reaches the streams.

Watersheds with Minor Developments

Watersheds included in this group do not have mines but will have some roads or farmland. A number of streams draining watersheds having roads, houses, or an appreciable quantity of cleared land also produced water similar in quality to that draining from the undeveloped watersheds. Stream-sampling sites 19, 21, 22, 101, 111, 115, 165, 267, 276, 280, 282, 284, 302, 303, 304, 305, 306, 308, 310, 320, 325, 331, 365, 370, 371, 381, 402, 403, 412, and 413 are included in this category. At these stations specific conductance ranged from 37 to 258 umhos/cm and averaged 91 umhos/cm. Sulfate ranged from 5.3 to 19 mg/L and averaged 13 mg/L while chloride ranged from 0.4 to 4.5 mg/L and averaged 1.6 mg/L. The pH values ranged from 6.7 to 8.4. units

Watersheds with Deep Mines

It was observed that many watersheds with one or more small underground mines may produce water very close in quality to that found in the undeveloped watersheds. Stream-sampling stations 73, 102, 103, 139, 142, 170, 197, 198, 199, 283, 285, 286, 382, 386, 388, 406, 407, and 411 are in this category. At these stations specific conductance ranged from 37 to 245 umhos/cm and averaged 101 umhos/cm; sulfate ranged from 6.2 to 27 mg/L and averaged 17 mg/L; and chloride ranged from 0.6 to 7.2 mg/L and averaged 2.1 mg/L. The pH values ranged from 6.7 to 8.3. units.

Drainage from deep mines may seriously affect the quality of water in streams. Numerous streams sampled during the course of this study had been severely affected by deep mine drainage, yet in most cases the effects of the deep mines could not be isolated from those of strip mines on the same watershed. The chemical characteristics of drainage from four deep mines in the study area are given in table 9, part 2. These drainage waters are near neutral or are alkaline in reaction and are believed to be fairly representative of drainage from most deep mines within the study area.

Water collected at site 188 represents deep mine and auger mine drainage and is representative of the very few deep mines within the study area which produce highly acid drainage.

Watersheds with Strip and (or) Auger Mines

Many watersheds with strip and auger mines, and sometimes with deep mines as well, produce water very close in quality to that found in the undeveloped watersheds. Examples of these would be stream sampling stations 28, 30, 51, 62, 113, 125, 139, 142, 193, 219, 321, 361, 366, 367, 408, 409, and 410; but it should be pointed out that only a very small percentage of the land surface has been disturbed on some of these watersheds and only a small amount of the coal removed. The specific conductance of these samples ranged from 37 to 250 umhos/cm and averaged 80 umhos/cm. Sulfate ranged from 8.7 to 28 mg/L and averaged 15 mg/L. Chloride ranged from 0.5 to 20 mg/L and averaged 2.6 mg/L. The pH values ranged from 7.0 to 8.7 units.

Several of these watersheds have been extensively mined but still they produce water which shows little of the effects normally associated with strip and auger mining. These watersheds include those sampled at sites 28, 51, 62, and 125 (Fire Clay (Hazard No. 4) coal seam); 113, 125, 139, and 142 (Leatherwood or Hazard No. 5A coal seam); and 361. This last watershed (Leatherwood Creek at Watts) has strip and auger mines in several coal seams: Upper Knob, Lower Knob, Hindman (Hazard No. 9), Francis (Hazard No. 8), and Hazard No. 7. In addition it has small underground mines in the Hindman, Francis, Hazard No. 7, Fire Clay Rider (Hazard Rider No. 4A) and Lower Whitesburg coal seams. Neither the Fire Clay nor Leatherwood coal seam is very productive of either acid or sulfate so it is not surprising that many of the watersheds on which these seams were mined were only slightly affected. The coal in some of these watersheds is still being mined, but in most, mining ceased 5 to 20 years ago.

Strip and auger mining can produce sufficient acid mine drainage to severely degrade the quality of water in streams. This was most evident near Hazard where the Hazard No. 9 seam of coal had been mined. Examples of severely affected streams with pH values of 5.0 units or below include those sampled at sites 173, 188, 189, 190, 192, 215, 231, 233, 240, 247, 339, 340, and 341. Deep mines may have contributed much of the acid drainage at some of these sites, but it is believed that strip and auger mines were primarily responsible for the observed degradation in water quality. The high chloride concentration and high specific conductance at site 341 are both attributable to drainage from a gas well that was being drilled on the watershed and consequently were not included or averaged with the other values given below. Specific conductance (omitting the saline sample from site 341) ranged from 266 to 5,720 umhos/cm and averaged 1,550 umhos/cm. Sulfate ranged from 230 to 6,000 mg/L and averaged 1,230 mg/L. Chloride (omitting site 341) ranged form 0.5 to 6.2 mg/L and averaged 2.3 mg/L. The pH values ranged from 2.5 to 5.0 units. Any samples from these sites which had pH values exceeding 5.0 units were excluded from this summary.

Large quantities of acid mine drainage were produced and neutralized on many other watersheds as evidenced by the high sulfate concentrations and alkaline or near neutral pH. Watersheds in this category (which have for at least part of the year pH values 6.0 units and greater and having sulfate concentrations of at least 300 mg/L or conductivities exceeding 900 umhos/cm) were sampled at sites 71, 72, 74, 80, 84, 215, 225, 226, 228, 229, 247, 251, 255, 344, and 389. Sites 215 and 247 were near neutral or alkaline only in the summer and fall but were acid during the winter and spring. This same seasonal acidity undoubtedly prevailed in many of the tributaries of Lotts Creek such as sites 238, 240, 241, 243, 245, and 246, though sufficient samples were not taken to show this. Specfic conductance at these sites ranged from 655 to 2,200 umhos/cm and averaged 1,270 umhos/cm. Sulfate ranged from 290 to 1,300 mg/L and averaged 633 mg/L. Chloride ranged from 0.7 to 35 mg/L and averaged 6.9 mg/L. The pH values ranged from 6.4 to 8.4 units. Individual samples from these sites which did not meet the above given criteria for pH and either sulfate concentration or specific conductance were excluded from this summary.

Characterization of Stream Water Quality in the Study Area

Four water quality parameters are compared in table 5 for each of the seven categories of watersheds just described. Mean chloride ion concentrations were less than 3 mg/L in all watershed categories other than those affected by strip and auger mines. Drainage from watersheds in this last category contained more than twice this concentration of chloride ion. These are very low chloride concentrations in all cases. It was anticipated that higher chloride concentrations would be associated with the high sulfate water draining from many strip and auger mines; nevertheless, the small increases in chloride are negligible in comparison with the massive increases in sulfate concentrations on these watersheds due to mining.

The sulfate ion concentrations were low (less than 30 mg/L) in all designated watershed groups except those in the high sulfate and acid affected categories, which discharged water with 6 to 140 fold greater sulfate. The sulfate in both the high sulfate and acid affected streams originated as acid mine drainage from oxidation of sulfide minerals however, these acids were neutralized by contact with carbonate minerals or exchangeable bases prior to reaching streams in those watersheds classified as salt affected. The sulfate remains unaffected by this neutralization process but is still indicative of the acid mine drainage generated on these watersheds.

Table 5.--Summary of minimum, mean or median, and maximum values for pH, chloride, sulfate, and specific conductance observed in different categories of watersheds on the North Fork Kentucky River and its tributaries

	pH			Chloride mg/L			Sulfate mg/L			Specific conductance umhos/cm			Number of sites	Number of samples
	Minimum	Median	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum		
Kentucky River at Frankfort 1906-1907	--	--	--	0.6	2.0	3.6	4.0	8.3	12	--	--	--	1	36
Undeveloped basins 1975	6.0	7.6	8.5	.1	1.6	5.0	6.4	13	22	23	75	245	18	21
Slightly developed basins 1975	6.7	7.6	8.4	.4	1.6	4.5	5.3	13	19	37	91	258	30	39
Basins with underground mines 1975	6.7	7.6	8.3	.6	2.1	7.2	6.2	17	27	37	101	245	18	28
Basins with good quality runoff from surface or auger mines 1975	7.0	7.7	8.7	.5	2.6	20	8.7	15	28	37	80	250	18	29
Basins with sulfate affected runoff (pH 6.0 or above) from surface or auger mines 1975	6.4	7.5	8.4	.7	6.9	35	290	633	1,300	655	1,270	2,200	21	23
Basins with acid affected runoff (pH 5.0 or below) from surface or auger mines 1975	2.5	3.7	5.0	.5	[1]2.3	[1]6.2	230	1,230	6,000	266	[1]1,550	[1]5,720	13	24

[1]Discharge from the stream on watershed 341 was severely affected by salt (largely sodium chloride) discharging from a gas well. Chloride and specific conductance values which were severely affected by salt from this gas well were not included in these means and maximums so the values presented would more truly reflect the consequences of mining.

A large percentage of the watersheds sampled in this study are drained by streams of intermediate quality and have not been divided into separate categories or discussed. These generally have specific conductance values between 75 to 900 umhos/cm, sulfate values between 15 and 300 mg/L and pH values always greater than 5.0 units. All of these appear to have been mined or otherwise appreciably disturbed by man. The streams draining these watersheds show an increase in dissolved constituents over and above what would be expected in undisturbed watersheds; yet the chemical quality of the water is such that it can still generally support a full range of aquatic life. A large percentage of these watersheds have been little disturbed by mining while others may have extensive mining on coal seams which were not highly productive of salts or acid mine drainage.

Over the great bulk of the study area, coal mining has tended to increase chemical pollution in general rather than to increase the acidity of the water. This is apparent from the data reported in tables 8 and 9. Specific conductance is a very good measure of dissolved solids and overall chemical pollution, and in general closely paralleled the sulfate concentration in all categories of watersheds. The reader is referred to the section of this report "Specific conductance and dissolved solids" for an assessment of the aerial distribution of dissolved solids within the study area. Separate sections of the report also deal with the aerial distribution of sulfate, chloride, common cations, pH, and trace elements.

WATER QUALITY OF THE NORTH FORK KENTUCKY RIVER AT HAZARD, 1963-73

The daily water-quality records collected on the North Fork Kentucky River at Hazard beginning in 1962 make it possible to relate changes in water quality to changes in mining methods occurring upstream during the period since 1962. The sulfate ion concentration is the most sensitive indicator of acid-mine pollution; but, because sulfate fluctuates so greatly at this station, the available periodic sulfate analyses were of little direct value in establishing sulfate loads and mean concentrations. It was observed, however, that there was a high level of correlation between sulfate ion concentration and specific conductance. A similiar high level of correlation between these parameters was observed in the Tradewater Basin of western Kentucky by Grubb and Ryder (1973, p. 131, 133-134, 136). The curvilinear regression for sulfate versus specific conductance for the 289 data pairs available at the North Fork Kentucky River at Hazard is shown in figure 3. Because of this high level of correlation, it was possible to synthesize daily sulfate data for the 1963 through 1973 water years from daily specific-conductance values and then compute monthly and annual sulfate loads. Periods of missing conductivity record, sometimes as long as a month, were estimated from the daily discharge and its general relation to other conductivity measurements for that season.

Monthly and annual summaries of mean discharge, mean simulated sulfate concentration, and total simulated sulfate load for the station North Fork Kentucky River at Hazard for the 1963 through 1973 water years are presented in table 6. Mean monthly simulated sulfate concentrations and loads and mean monthly discharges for this same station are depicted graphically in figure 4. The highest annual mean sulfate concentrations and highest annual sulfate load both occurred in the 1963 water year. The lowest mean annual sulfate

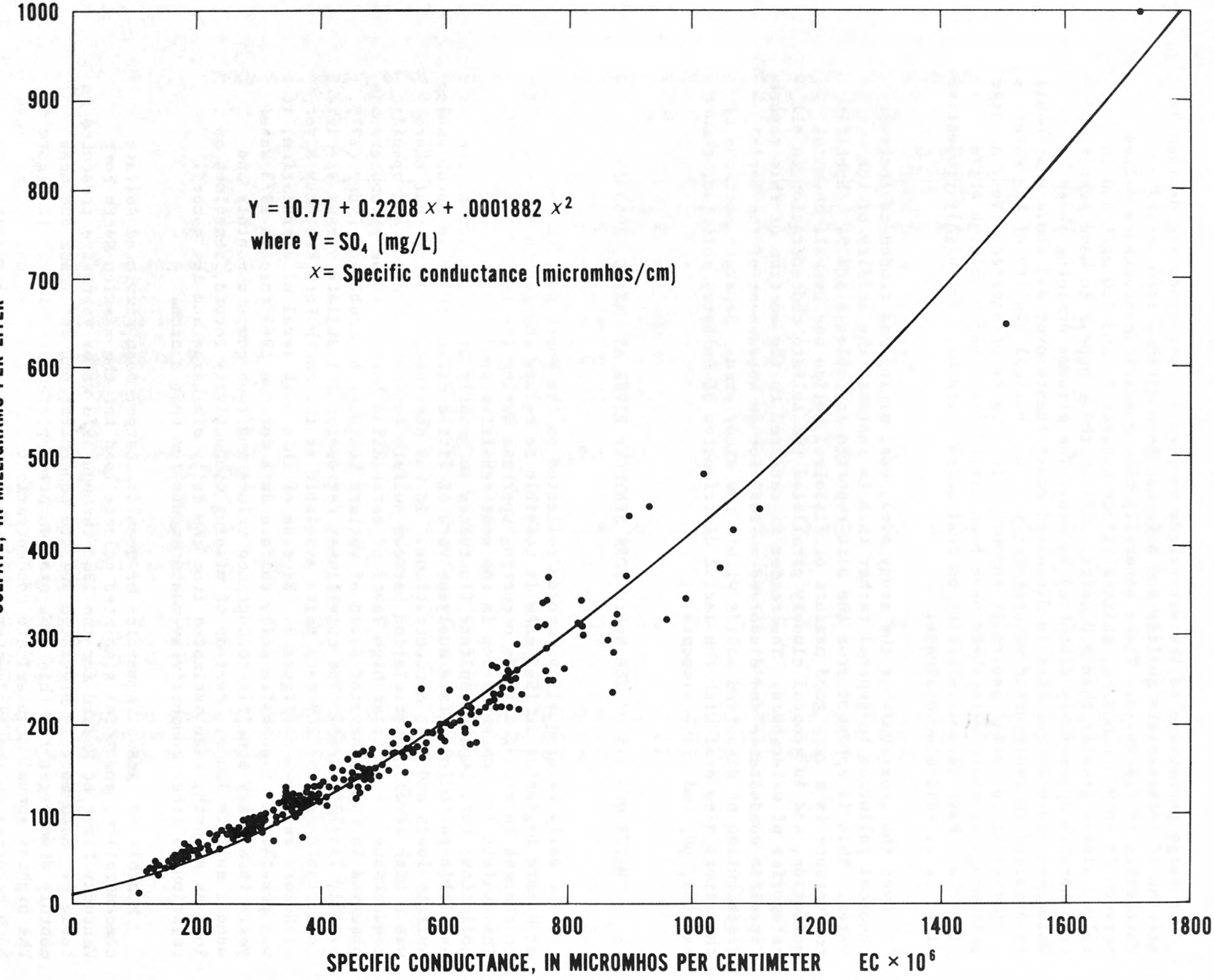

Figure 3. -- Relation between specific conductance and sulfate concentrations for the North Fork Kentucky River at Hazard, 1949-74.

Table 6.--Monthly and annual summaries of mean discharge, mean simulated discharge-weighted sulfate concentration, and total simulated sulfate load for the North Fork Kentucky River at Hazard, 1963 through 1973 water years[1]

		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1963	Mean discharge	34.0	458	375	332	1,029	4,123	196	257	81.7	85.3	85.1	30.7	591
	Mean sulfate, mg/L	206	194	240	107	101	131	142	107	155	182	166	203	137
	Sulfate load, tons	585	7,195	7,524	2,986	7,824	45,062	2,251	2,297	1,024	1,298	1,185	506	79,737
1964	Mean discharge	11.1	34.6	88.1	879	897	1,620	1,128	141	131	69.3	153	130	439
	Mean sulfate, mg/L	262	287	161	69	67	51	71	146	156	172	129	166	77
	Sulfate load, tons	244	806	1,186	5,095	4,713	6,949	6,488	1,726	1,660	996	1,656	1,743	33,262
1965	Mean discharge	751	401	1,004	1,106	661	2,253	1,195	235	75.6	72.4	31.1	20.0	653
	Mean sulfate, mg/L	71	80	74	76	84	58	79	113	158	181	150	239	75
	Sulfate load, tons	4,439	2,584	6,255	7,004	4,204	10,981	7,682	2,219	965	1,094	391	386	48,204
1966	Mean discharge	30.0	47.0	27.2	38.2	594	362	782	734	64.4	119	556	359	307
	Mean sulfate, mg/L	284	290	238	142	113	124	74	149	204	149	86	104	116
	Sulfate load, tons	732	1,091	548	455	5,060	3,744	4,688	9,142	1,065	1,483	4,004	3,027	35,039
1967	Mean discharge	504	857	1,490	937	890	2,246	1,020	717	891	398	278	59.4	859
	Mean sulfate, mg/L	80	72	81	77	78	101	87	116	100	155	110	179	93
	Sulfate load, tons	3,364	5,011	10,066	6,025	5,264	18,911	7,195	6,956	7,226	5,167	2,567	859	78,611
1968	Mean discharge	69.8	328	1,193	1,095	268	1,355	943	653	182	95.3	200	34.1	538
	Mean sulfate, mg/L	183	92	63	82	104	64	80	79	116	188	125	223	81
	Sulfate load, tons	1,067	2,452	6,301	7,470	2,187	7,296	6,103	4,293	1,713	1,500	2,094	615	43,091
1969	Mean discharge	54.5	125	280	567	783	529	588	276	118	121	38.8	22.7	289
	Mean sulfate, mg/L	226	187	102	88	70	80	77	113	150	160	196	210	97
	Sulfate load, tons	1,029	1,895	2,382	4,177	4,130	3,564	3,654	2,608	1,433	1,622	636	386	27,516
1970	Mean discharge	19.4	72.5	1,316	342	1,550	682	1,517	571	165	45.9	87.5	60.2	528
	Mean sulfate, mg/L	348	193	54	95	85	102	82	144	185	283	241	210	95
	Sulfate load, tons	565	1,131	5,913	2,729	10,000	5,821	10,084	6,884	2,479	1,087	1,764	1,026	49,483
1971	Mean discharge	134	242	497	899	1,054	618	920	2,270	250	375	259	487	666
	Mean sulfate, mg/L	186	148	81	74	72	85	74	72	135	80	105	85	83
	Sulfate load, tons	2,091	2,898	3,359	5,559	5,700	4,400	5,539	13,735	2,741	2,522	2,270	3,368	54,182
1972	Mean discharge	409	336	522	2,557	2,391	1,169	2,291	384	172	163	114	62.1	874
	Mean sulfate, mg/L	89	96	80	76	74	88	68	124	172	145	139	199	82
	Sulfate load, tons	3,047	2,606	3,482	16,199	13,860	8,568	12,531	3,988	2,392	1,974	1,330	1,002	70,979
1973	Mean discharge	114	283	1,910	373	683	2,525	1,500	1,062	319	526	193	63.6	800
	Mean sulfate, mg/L	169	113	74	100	73	54	63	69	96	93	106	181	72
	Sulfate load, tons	1,610	2,594	11,832	3,134	3,787	11,519	7,632	6,104	2,470	3,284	1,715	934	56,615

[1] Sulfate was computed from daily specific conductance values using the relation--Sulfate in mg/L = 10.77 + (0.2208)(Specific Conductance in micromhos/cm) + (0.0001882)(Specific Conductance)^2. Missing specific conductance values were estimated from daily discharge using the relation of specific conductance to discharge for adjacent days or months.

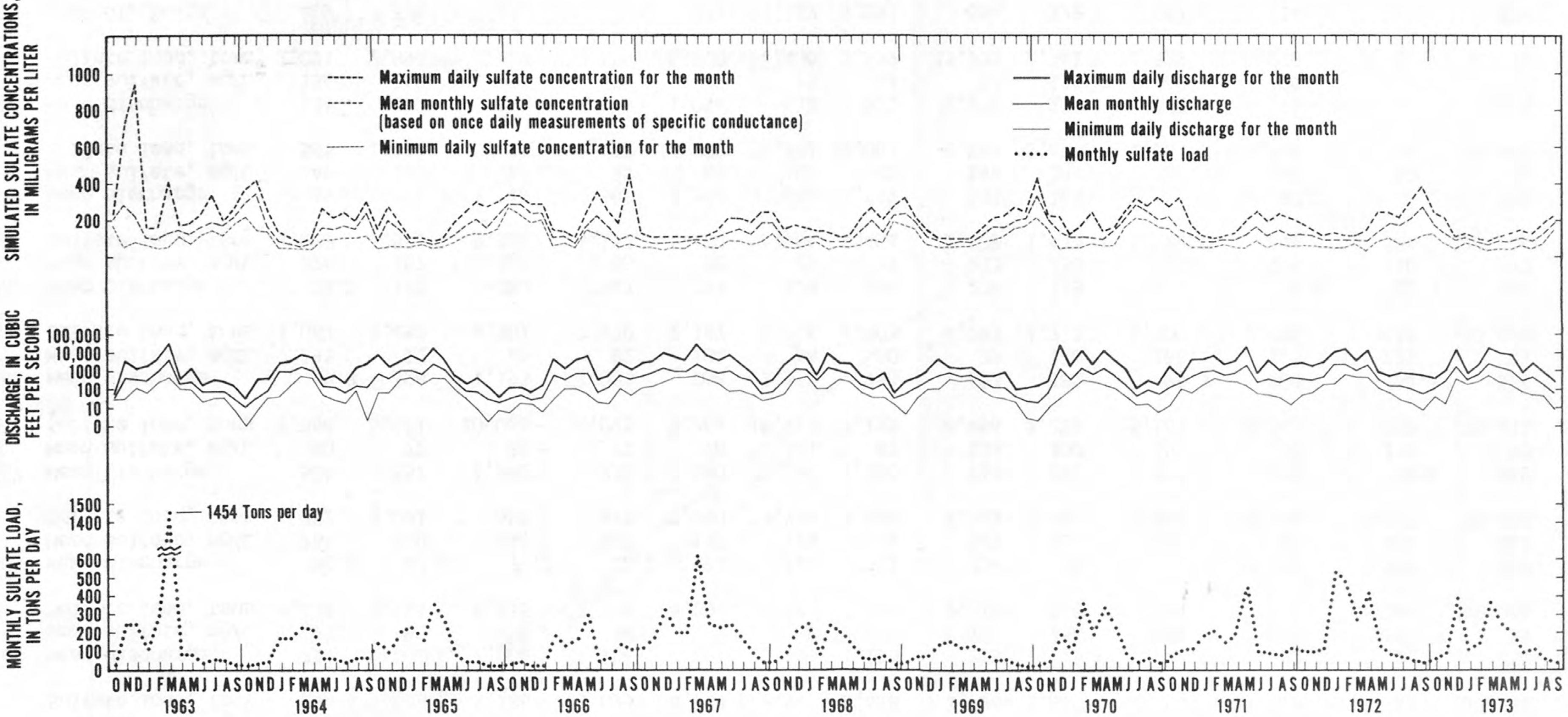

Figure 4. -- Monthly simulated sulfate concentrations and loads and monthly discharges for the North Fork Kentucky River at Hazard.

concentration (discharge weighted), 72 mg/L was observed in the most recent year of record (1973 water year). This was only about half the corresponding concentration of 137 mg/L observed in the 1963 water year. This was also the dryest year during the period under consideration and it would appear likely that the low precipitation for that year was insufficient to displace or remove as much mine drainage water as usual from the places where it was being formed.

It is apparent from figure 4 that the sulfate load tends to cycle on a yearly basis with maximum loads in late winter or early spring which correspond to the periods of heaviest runoff. Sulfate concentrations fluctuate less than either sulfate loads or discharge and tend to peak in the fall when discharges are at a minimum. Sulfate loads for 1963 through 1973 water years peaked sharply in March, the month of greatest stream discharge, as is shown figure 5. Grubb and Ryder (1972, p. 47) observed a similar sulfate load pattern in the Tradewater River basin of Western Kentucky.

Mean and extreme simulated sulfate concentrations are plotted by month in figure 6. Mean daily sulfate concentrations averaged highest (about 200 mg/L) in September and October and lowest (about 90 mg/L) in February, March, and April, a ratio of a little more than two to one between extreme months. Discharge weighted mean monthly sulfate concentrations varied even less, from a maximum of 131 mg/L for July to minimum of 76 mg/L for April. Sulfate concentrations for any month or day depend much more on stream discharge than they do on the season of the year. For example, midsummer floods may reduce sulfate concentrations to a level comparable to those which would prevail in a winter or spring flood of the same magnitude.

The quality of water in the North Fork Kentucky River at Hazard is believed to have been most severely affected by acid mine drainage during or shortly before the 1963 water year. Data presented by Kirkpatrick and others (1963) indicate that the river at this station was somewhat less affected by acid for the water year 1959 than it was for the water year 1963 (U.S. Geological Survey 1949-75). The earliest water quality data available for this station, collected during the 1950 water year (U.S. Geological Survey 1949-75), show that the river at this time was much less affected by acid than it was in 1959 or later. No water quality data are known to exist for this station for water years 1951 through 1958 or for 1960 through 1962.

One significant observation from table 6 is that years of high sulfate concentrations such as 1963, 1966, and 1969 tend to be followed by a series of years of steadily decreasing sulfate concentrations. These cycles appear to have little or no relation to discharge or to "flush outs." The last sulfate concentration cycle has continued a steady decline for at least four years through 1973 and might still be continuing. Some, but not all, of this steady decline can be attributed to a decrease in coal production from upstream underground mines from approximately 6.2 to 4.4 million tons during the period from 1963 to 1973. Surface mining is known to have increased from about 1.1 to 3.1 million tons during these same years, thus more than compensating for the loss in underground production. It is thought that strip mines, except during

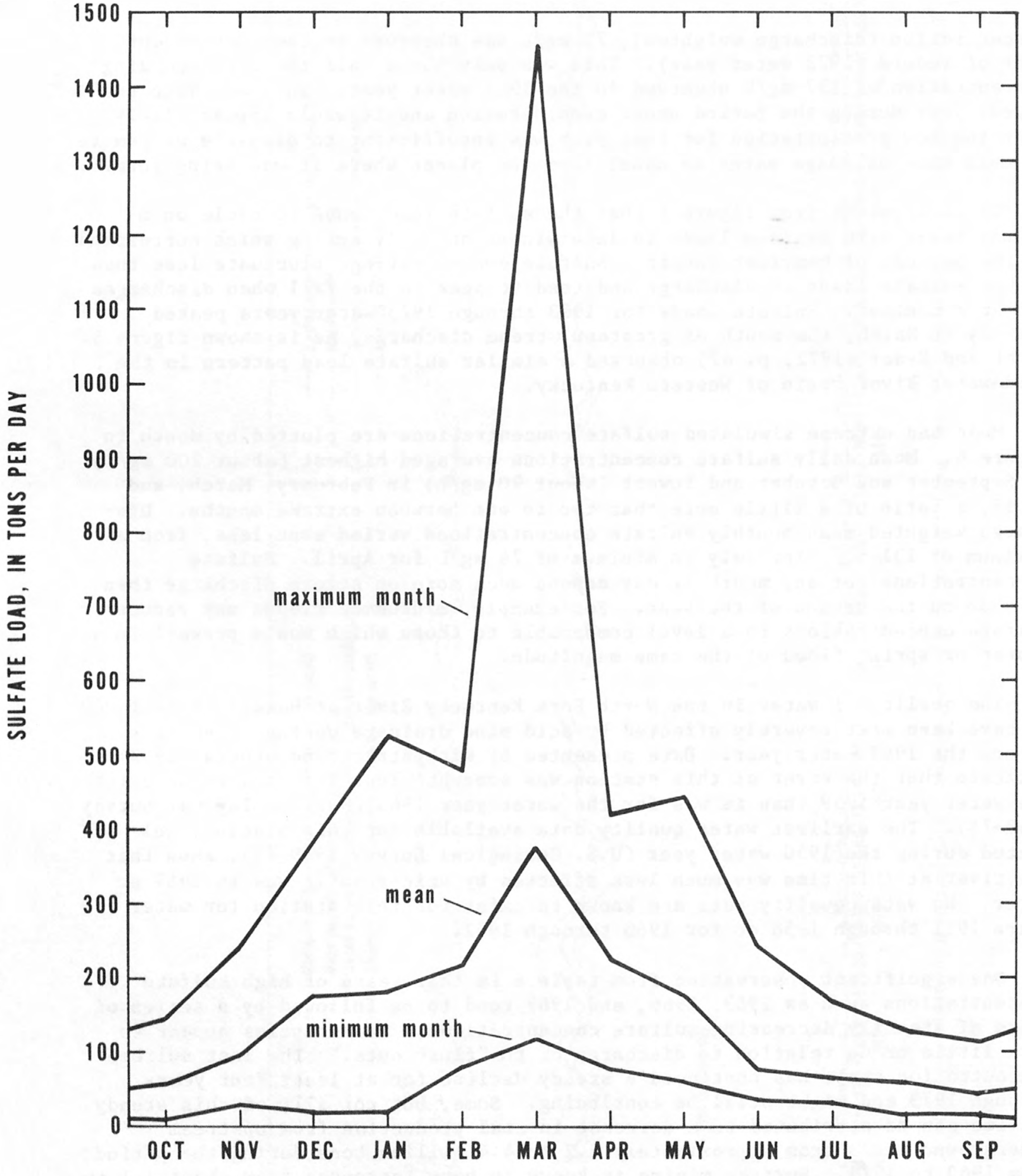

Figure 5. -- Variation in mean monthly simulated sulfate loads for the North Fork Kentucky River at Hazard, 1963-73 water years.

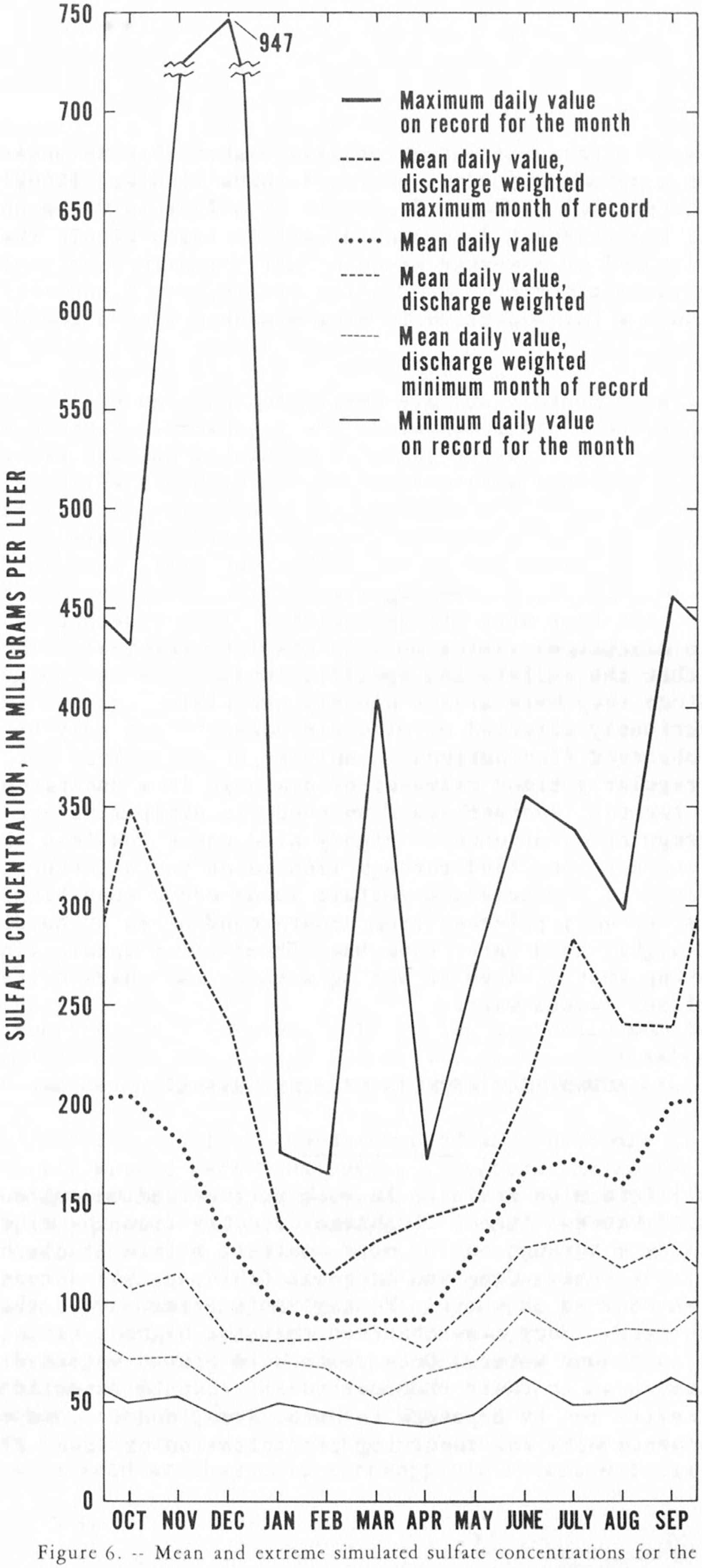

Figure 6. -- Mean and extreme simulated sulfate concentrations for the North Fork Kentucky River at Hazard, 1963-73 water years.

the initial stages, are less productive of acid wastes than is underground mining per unit of coal mined (Office of Appalachian Studies, 1969, p. C16); but even if the strip mines produce no sulfate at all, this would not be enough to account for all the observed decrease in sulfate loads within the study area above Hazard. Abandoned or unworked mines normally continue to produce sulfate and acid for many years after coal production ceases, so it had not been anticipated that such a large decline in mine-drainage wastes could occur so quickly.

Regressions of mean monthly sulfate concentrations, as estimated from specific conductance, were plotted against the logarithms of the mean monthly discharges for each of the 11 water years of simulated sulfate record. Table 7 is a summary of the equations and correlation coefficients which relate the logarithm of discharge to sulfate concentrations by year. It may be noted that there was relatively poor correlation between estimated sulfate concentrations and the logarithm of discharge during the 1963 water year, the year of highest sulfate loads. A more detailed investigation of the data revealed that sulfate concentrations for that year were highly erratic. They rose and fell with little relation to discharge. Twice monthly complete chemical analyses would seem to indicate that the sulfate and specific conductance determinations were both reliable. Since they were always closely correlated, as should be the case in streams seriously affected by mine drainage, it can only be assumed that most of the observed fluctuations in sulfate and dissolved constituents were caused by irregularly timed releases of drainage from underground mines, from coal-washing lagoons, and perhaps from ponds in strip-mine areas. The occasional and irregular occurrence of highly aicd water (pH less than 5.0 units) at this station in the 1963 through 1966 water years further supports the premise that much of the acid and sulfate loads occur when highly acid or sulfate waters are suddenly released from underground mines or holding ponds. No occurrences of highly acid water have been observed at Hazard since June 1966, thus indicating that changes in mining methods must have halted these sudden releases of acid-waste water.

DOWNSTREAM EFFECTS OF MINE DRAINAGE

Ground Water

Practically all acid mine drainage in both surface and underground mines starts off as ground water. It may discharge directly from the mine opening or it may travel at length through one or more aquifers before it discharges into streams at seeps or springs. Gang and Langmuir (1974, p. 54) demonstrated that the major pollution sources on certain Pennsylvania streams were shallow ground-water discharges. They also observed that the highest trace element values were found in ground water. Once these acid ground waters discharge into streams, improvement in their chemical quality can be expected due to dilution, to neutralization by exposure to carbonates, and to more complete oxidation of components with the resulting precipitation of iron, aluminum, and other trace metals.

Table 7.--Terms for regressions of simulated mean monthly discharge-weighted sulfate concentrations on the logarithms of the mean monthly discharges for the North Fork Kentucky River at Hazard, 1963 through 1973 water years[1]

Year	Intercept I	Slope b	Correlation coefficient r
1963	240	- 34.1	-0.467
1964	387	-107.6	-.948
1965	304	- 77.0	-.936
1966	397	-105.9	-.823
1967	279	- 62.6	-.761
1968	356	- 96.1	-.955
1969	378	-106.8	-.953
1970	477	-130.5	-.944
1971	341	- 89.5	-.830
1972	297	- 69.5	-.882
1973	300	- 74.8	-.929
1963-1973	355	- 91.1	-.853

[1] This equation takes the form $SO_4 = I + b \log Q$ wherein SO_4 is the sulfate concentration in milligrams per liter, I is the intercept, b is the slope and Q is the discharge in cubic feet per second.

Much, and sometimes all of the acidity in mine drainage is neutralized while it is still ground water and before it enters the surface streams. A study of 18 underground mines in western Maryland by Hollyday and McKenzie (1973, p. 25, 30) showed that an average of 70 percent of all acid produced is neutralized underground, and in some mines all of it is neutralized. Part of this neutralization occurs when crystalline carbonates (mainly calcite and dolomite) dissolve in the acid waters (as suggested by Hollyday and McKenzie, 1973, p. 24, 26). But it seems probable, that most of the neutralization occurs when hydrogen ions from the water replace exchangeable calcium, magnesium, sodium, and potassium ions in the soils, spoils, and aquifer materials contacted by the acid water. The acid in the water is thus replaced by the common cations or bases from the soil and aquifer materials, which in turn become more acid as they gain exchangeable hydrogen ions.

The potential of soils, spoil materials, or aquifer materials to neutralize acid water is hereinafter referred to as the neutralization potential. It may be computed, in terms of chemical equivalents, as the sum of all carbonates plus the sum of all exchangeable bases contained in these materials. Von Demfange and Warner (1975, p. 141) defined neutralization potential as an estimate of the quantity of acid that calcium and magnesium minerals (both soluble and exchangeable) were capable of neutralizing, but it is known exchangeable sodium and exchangeable potassium are also effective in neutralizing acid waters. Except for the carbonates no common soluble salts are effective in neutralizing acid water. It may be inferred from the chemistry of the drainage water from disturbed land that calcium and magnesium are the dominant cations in most Appalachian spoils; so the neutralization potential as determined by Von Demfange and Warner would still be a reasonable estimate, though generally less than the true value. They observed (p. 141-142) that some spoils with a more than adequate neutralization potential still produced acid waters. This can readily be explained if very much of the acid water takes flow paths bypassing those sites with the greatest potential for neutralizing acid.

Most of the ground water in the study area is still similar in chemical characteristics to that found under pristine conditions, but wherever mining activities have occurred, ground water in the disturbed areas will have changed in chemical characteristics, and likewise all ground-water downgradient in the flow path from these mines will eventually change if it hasn't already. This may be deduced from base flow observations in disturbed and undisturbed areas and from fundamental concepts of soil chemistry. During much of the year the flow of the small streams is sustained entirely by ground-water discharges at springs and seeps, so samples collected for these streams when they are not muddied by overland-flow runoff should be representative of the ground water which sustains the stream. The dissolved-oxygen level in acid streams may increase causing oxidation and precipitation of iron, aluminum, and other trace elements; but the concentrations of sulfate, chloride, and other major dissolved constituents are not likely to change appreciably as a consequence of flowing as surface water for a mile or two in a stream channel.

No direct measurements on ground water affected by mine drainage were made during the course of the present study with the exception of drainage from a deep mine at Harveyton (site 255, table 9, part 2) and a spring in the headwaters of the South Fork of Quicksand Creek (site 390, table 8). Data from several additional samples of deep mine drainage from within the study area were found in the files of the U.S. Geological Survey and are also presented in table 9, (part 2). It is believed that deep mine drainage contributes an appreciable portion of the low flow to many small streams in the headwater reaches of the study area.

The drainage discharging from deep mines may be almost directly proportional to the area of the workings. A fairly consistent relation of 0.25 $(ft^3/s)/mi^2$ of mine workings was observed in western Maryland during the summer of 1970 when mine discharges were approximately in low flow condition (Hollyday and McKenzie, 1973, p. 11).

Deep mines, auger mines, and to a lesser extent, strip mines cut into and drain portions of the aquifers. Much of the water thus drained may be considered as "mined water," or water not likely to be replaced in the aquifer. Drainage of an aquifer to a more or less stable, or equilibrium condition may not occur for months or even years after the mine openings have been cut into the ground water body.

Surface Water

Discharge

Coal-mining activities generally affect both the discharge of streams and the seasonal distribution of this discharge. No attempt was made during this study to ascertain the effects of mining on stream discharge, but other studies indicate that small streams originating in mined areas have a continuous flow, whereas before mining they were intermittent (May and Striffler, 1966, p. 663). They also observed that areas with 10 percent of the surface disturbed had slightly higher stream discharges than adjacent forested watersheds. Agnew (1966, p. 38-40) found that surface mined areas in Pike County, Indiana acted like a sponge thus damping out extremes of flood and drought. On one occasion the flood crest in the mined area was only 38 percent of that in the nearby unmined area. When streams in the unmined areas dried up, those in the mined areas were still yielding more than 0.25 $(ft^3/s)/mi^2$ of drainage area. Corbett (1968, p. 183) observed in southern Indiana that watersheds with substantial surface mining remain more nearly saturated with water and thus produced storm runoff from heavy rains following extended droughts when adjacent creeks draining unmined watersheds remained dry.

Curtis (1972A, p. 357) reported that peak-flow rates in eastern Kentucky watersheds (upstream from Bear Branch, site 324 and Leatherwood Creek, site 396) increased by a factor of threefold to fivefold immediatley after surface mining. Lag time was reduced, thus effecting an increase in the rate at which flood peaks move downstream. He further noted that peak flow is directly and positively correlated with the percent of the area disturbed during the surface mining. Abandoned haul roads are also known to be a factor in increasing surface runoff in mined areas. In a later study after reclamation of these watersheds, Curtis (1977B, p. 4) observed a reduction in peak flow and runoff. Runoff on April 4, 1977, following a 2.98 inch rainfall, totalled 2.61 inches on the unmined watershed compared to 1.26 and 1.43 inches runoff on the two partially strip mined but reclaimed watersheds. Further computations showed that the disturbed portions of the strip mined watersheds yielded only 0.05 to 0.15 inches of runoff, a average of only about 4 percent that of the unmined watershed runoff. Following this initial runoff, discharge was somewhat greater in the mined watersheds than in the unmined watersheds, thus stream discharges became more stable following reclamation of mined areas than they had been prior to mining, or during mining. Accumulative runoff from the mined watersheds after this storm was far lower than that from the unmined watershed, thus indicating that the mined sites had not yet attained a long term hydrologic equilibrium. It is evident that the deep spoils on these mined watersheds were still in the process of being wetted from the top and were not producing significant seepage several years after mining had ceased.

Underground mines may extend deep into the mountains where they intersect small but relatively constant trickles of deep percolating water. Discharges from these mines tend to produce a more uniform flow in the receiving streams. Strip mines may produce either a more variable runoff or a more stable runoff. They sometimes increase flood danger and sometimes reduce it. The exact effect of any strip mine on stream flow depends upon many things such as location (whether on a ridge top or on a slope or on level land), technique of strip mining (whether the overburden is back filled on the bench, dumped in the head of the hollow, or simply pushed over the edge), and degree of compaction of the spoil.

Unvegetated strip-mine areas lose less water to the atmosphere by evapotranspiration than will the adjoining vegetated areas but this will not necessarily produce a corresponding increase in runoff. The low flow of streams draining bare spoils may either be higher or lower than it had been prior to removal of vegetation depending on the permeability and water holding characteristics of the spoil materials.

Sediment

Sediment originating in strip mines may have a profound effect on quality of water in streams draining the area. Sediment yields from a strip-mined watershed depend upon the proximity of the disturbed areas to the main channel, the degree of channeling of the disturbed area, and the presence of landslides or road disturbances (May and Striffler, 1966, p. 667). Branson and Batch (1971, p. 508) observed that strip mining increased siltation by 15 to 30 times that present in non-affected streams in east central Kentucky. Curtis (1973, p. 152-153) reported that suspended sediments in one tributary to Leatherwood Creek (a tributary to the South Fork of Quicksand Creek) exceeded 47,000 mg/L.

Three major sources of sediment in strip-mined areas have been recognized. These are (1) spoil bank slides, (2) coal-haul roads, and (3) the mined area itself (May and Striffler 1966, p. 666-667). Preliminary results from a survey in eastern Kentucky indicated that about 12 percent of outslope areas were in slides (Weigle, 1966B, p. 67). These slide areas can be very productive of sediment -- especially when they slide into a stream. Abandoned coal haul roads account for only 5 percent of the disturbed land in strip mined areas in the study area (Plass, 1967, p. 5-6); nevertheless they may be the source of as much sediment as the strip mines themselves. Weigle (1966A, p. 98) has found that erosion from these abandoned roads varied from 2.6 to 5 inches per year (or about 430 to 835 tons of sediment per acre per year). The construction of silt retention dams can in itself generate a considerable amount of sediment. It is believed that in some cases sediment caused by construction of these dams is greater than the amount controlled (White, 1975, p. 10).

Depth of visibility was estimated at most stream sites visited (see table 8), thus giving some indication of turbidity and the presence or absence of significant quantities of suspended solids. Highly turbid waters were observed only in watersheds subjected to strip mining, road construction, or other earth-moving operations. Streams that carried heavy silt loads at one time, might be perfectly clear a few hours later, or vice versa, even though discharge may remain nearly constant. Occasional sediment samples on such streams tell little about the total sediment load produced by the mining operation, consequently the few sediment samples which were taken were not submitted for analysis.

The minimum acceptable standards for construction of debris basins in strip-mine areas in eastern Kentucky once required at least 0.2 acre feet of storage for each acre to be stripped (Davis and Hines, 1973, p. 261, 264). It was assumed this would generally be adequate for storage of sediment for 3 years, by which time reclamation and revegetation of the spoil banks should have reduced sediment production to acceptable levels. More recent standards (Office of Surface Mining Reclamation and Enforcement, 1979, p. 15400) require that sediment ponds plus other measures provide for storage of at lease 0.1 acre foot of sediment volume -- or more if the Universal Soil Loss Equation or other techniques should so indicate.

Silt-retention dams are now required on most strip-mining operations and are normally constructed near the heads of the branches. The water below these dams may be perfectly clear even when it is quite turbid above. On rare occasions these dams may be breached by the heavy runoff following a cloudburst. In terms of downstream destruction the consequences of the dam being over-topped may be near catastrophic as was the case on Rockhouse Branch at Talcum on May 23, 1975 (site 314), when a torrent from a breached dam blocked the highway at the mouth of the branch with logs, mud, and boulders.

A small earth-moving operation on a small branch can muddy a major stream for several miles. An example of this was observed on February 26-27, 1975. Earth was being moved by bulldozer in connection with the opening of a new deep mine on Beaverdam Branch of Rockhouse Creek. At the mouth of this branch (site 77) the water was so turbid that the depth of visibility was no more than 0.25 inch below the water surface. Above this branch the waters of Rockhouse Creek were clear with visibility of about 16 inches. Below this juncture Rockhouse Creek was muddy (visibility 2 to 3 inches) all the way to its mouth -- a distance of about 10 stream miles.

Sulfate

Essentially all the adverse effects of coal mining on downstream water chemistry relate either directly or indirectly to the acid mine drainage produced by the oxidation of iron disulfides. It is commonly assumed that all of the sulfate observed in acid mine drainage arises from the oxidation of sulfide minerals and that it may be used to approximate the total acidity produced regardless of how much acidity may have since been neutralized (Caruccio, 1968, p. 119). Any sulfate dissolved in the streams over and above the small amounts carried in by precipitation and by man, or that sulfate attributable to the slow geological processes for dissolution of sulfide minerals, must be attributed to the mining or earth-moving activities of man which expose sulfides to accelerated weathering and oxidizing processes.

A map depicting sulfate concentrations in the small streams of the study area would pictorially illustrate those areas wherein water quality has been most significantly affected by mining -- and in a few instances by other activities of man. The sulfate data in tables 8 and 9 were mostly from spot samples collected only once or twice at a given location and thus may not likely be very representative of mean annual concentrations. A long record of sulfate concentrations (both measured and synthesized data) are available for the station North Fork Kentucky River at Hazard (see section entitled: "Water Quality of the North Fork Kentucky River at Hazard, 1963-1973") and repeated measurements of sulfate concentrations are available at a number of other stations within the basin (see table 8). By relating sulfate data at any given site to corresponding data for that time at Hazard or other nearby stations for which more complete data were available, it was possible to estimate mean 1975 water year sulfate concentrations based on each individual measurement. Estimates of mean sulfate concentrations in individual streams made in this way for the 1975 water year are plotted on plate 1.

It is immediately apparent from this illustration that mean sulfate concentrations in numerous streams are now many-fold more than the 8 mg/L believed to have been representative of the pristine streams of the area or the 12 mg/L believed to prevail in streams draining present day undeveloped watersheds. It is estimated that the mean sulfate concentration of the North Fork Kentucky River at its confluence with the Middle Fork is about 50 mg/L or more than six-fold greater than the 8 mg/L believed present prior to 1912 when large-scale commercial coal mining was begun in the basin.

Most of the streams with high sulfate concentrations are located in an area of approximately 100 square miles centered at Cordia (about 5 miles east of Hazard) on the Lotts Creek watershed. Lotts Creek at the mouth (estimated from sites 247 and 251) averages about 360 mg/L sulfate, while the tributary Jacks Branch at Cordia (site 240) had the highest mean concentration of sulfate -- about 1,300 mg/L. The bulk of the sulfate in the Lotts Creek area originates from strip mines on the Hazard Number 9 coal seam. Most of these mines have been worked out and abandoned for many years -- some for as long as 30 years. The Hazard Number 7 coal seam has also been worked over much of the area, generally by auger, but contributes little to the total observed sulfate concentration.

South of Hazard another cluster of high sulfate streams emanates from the ridges between the Right Fork of Maces Creek, the headwaters of Big Creek, and the headwaters of Wooten Creek. Geologically, this area is a continuation of the Lotts Creek area discussed above and chemically the drainage waters are similar. The highest sulfate concentrations (estimated annual mean of 800 mg/L) were observed in Big Branch, tributary to the Right Fork of Maces Creek (site 189), while the auger or underground mine drainage (from the Hindman or Hazard No. 9 coal seam at site 188) feeding Big Branch may average 4,000 mg/L sulfate. Here again the highly acid waters and high sulfate appear to originate in the Hazard Number 9 coal seam, though other seams have been mined.

A third area of sulfate drainage is centered along the divide between Rockhouse Creek and the headwaters of the North Fork Kentucky River in Letcher County. Streams draining from this area average about 150 mg/L sulfate.

An isolated occurence of high sulfate water was observed in Razorblade Branch at Deane (site 72). The mean sulfate concentration for the year probably averaged about 1,100 mg/L. Most of the sulfate originates as drainage from a coal-washing operation rather than as waste from the mines on the watershed.

An isolated puddle of high sulfate water (6,000 mg/L) was observed in the headwaters of Dixon Branch on Dixon Knob. Similar puddles of highly acid water appear to be common in areas where the Hazard Number 9 seam has been strip-mined. Essentially all of this sulfate will eventually drain into the streams of the area and alter the quality of the water.

Data collected by the Federal Water Pollution Control Administration (1969, p. 210, 213-216) in 1966 indicate that water samples collected from Quillen Fork at Hemphill, Yellow Creek at Sassafras (site 215), Stacy Branch at Vicco (site 216), Raccoon Creek at Glowmar, Lotts Creek above Trace Fork at Darfork (site 247), Jakes Branch at Bulan (site 250), and Big Creek above Browns Fork near Typo (at or near site 252) contained more than 500 mg/L sulfate on at least one occasion in 1966. The above stations with site numbers listed were resampled as part of the present study and the data are given in table 8. More recent data for those sites which were resampled as part of this study show lower sulfate concentrations, but this could have been caused by differences in discharge and season of sampling.

Chloride

Estimates of mean chloride concentrations for the 1975 water year are plotted on plate 2. Extremely low levels of chloride (less than 5 mg/L) predominate over most of the area. The only major streams with higher concentrations are in the extreme eastern end of the area, namely the North Fork Kentucky River upstream from Roxana and Rockhouse Creek upstream from Jeremiah, and even here chloride concentrations are in part due to road salting and waste discharges from the relatively dense human population, but most is probably attributable to geologic factors and perhaps to underground coal mining in deeper seams.

Chloride concentrations exceeding 20 mg/L were observed in the headwaters of Little Cowan Creek above Ovenfork B near Whitesburg (site 27), in Bowmans Branch near Dice (site 341), and in Walker Creek at mouth (site 415). The relatively high chloride level on Little Cowan Creek could be caused by salt applied for controlling snow and ice on U.S. Highway 119 which climbs up Pine Mountain on this watershed. The extremely high chloride concentration (2,400 mg/L) observed in Bowmans Branch near Dice (site 341) during a low-flow period on July 23, 1975 can be attributed to a gas well which was being drilled on the watershed and which intercepted and discharged salt water into the stream. The discharge, although small (0.03 ft^3/s), was enough to increase the chloride concentration in Lost Creek appreciably all the way to its mouth. Walker Creek (site 415) at the western extremity of the study area almost certainly obtains its relatively high chloride concentration from the numerous oil and gas wells on the watershed.

Mean chloride concentrations are believed to exceed 10 mg/L for headwaters of the North Fork Kentucky River (sites 1 and 2), for Yonts Fork at Neon (site 4), for Wright Fork at mouth at Neon (site 3), for Little Colly Creek at Ison (site 84), for Blair Fork (Head of Leatherwood Creek) at Tilford (site 134), and for Buffalo Branch at Fourseam (site 225). Though higher than most, these concentrations are still so low that they do not significantly degrade the quality of the water. Some of this chloride is probably derived from domestic and industrial wastes.

There is no relation at all between the concentrations of distribution of sulfate and chloride as plotted on plates 1 and 2. The chloride concentrations observed are almost totally unrelated to coal-mining activities and do not appear to be correlated with either the type of coal or method of mining. If shaft mining is ever introduced into the area to remove coal from within the zone of salt water then it could be anticipated that large quantities of high chloride waters might be pumped into the streams.

The mean annual chloride concentration of the North Fork Kentucky River at its mouth has increased from about 1.5 to 2.3 mg/L as a result of coal mining and other activities of man on the watershed, a negligible increase.

Acidity, Alkalinity, pH, and Neutralization

The concepts of gross acidity, gross alkalinity, and neutralization ratio provide a system of evaluating neutralization of acid mine drainage (Hollyday and McKenzie, 1973, p. 24-25). Gross acidity is defined as the potential acidity prior to any neutralization and is measured as equivalents of sulfate ion dissolved in the water sample. Gross alkalinity is defined as the alkalinity removed plus the alkalinity remaining and is measured as the sum of the equivalents of calcium, magnesium, sodium, and potassium dissolved in the sample minus the sum of the equivalents of chloride, fluoride, and nitrate in solution. The neutralization ratio describes the degree of completeness of the neutralization process and is computed by dividing the equivalents of gross alkalinity by the equivalents of gross acidity. The ratio is unity when the gross alkalinity produced during formation and neutralization of mine drainage is equal to the gross acidity produced during formation of mine drainage. Ratios less than one means that neutralization is incomplete and the water is acid while ratios greater than one indicate neutralization is not only complete but that the water is capable of neutralizing more acid.

A review of all the available data from the study area shows that while much acid-drainage water is produced in coal mining operations, the bulk of it is apparently neutralized before it enters the streams. Neutralization ratios evaluated in this study ranged from 0.63 (site 189, Big Branch near Viper) to 2.98 (site 5, Potters Fork at Neon Junction) in waters affected by mine drainage (table 9).

When gross acidity exceeds gross alkalinity acid water is the result and it should have an acidity approximately equal to or slightly more than the gross acidity minus the gross alkalinity. The acidities listed in table 9 were all determined in accordance with the procedure given by Brown, and others (1970, p. 39-40).

Acid surface waters are rare within the watershed of the North Fork Kentucky River. The only surface waters observed to have pH values less than 5.0 units during the course of this investigation were: A puddle at the head of Dixon Branch near Fusonia (site 173), Big Branch near Viper (sites 188 and 189), Right Fork Maces Creek near Viper (sites 190 and 192) with acid traceable to Big Branch (sites 188 and 189), Lotts Creek above Trace Fork at Darfork (site 247), several of its tributaries (sites 231, 233, and 240), and Bowmans Branch near Dice (site 341). Acid observed at all these sites except the last can be attributed to surface mines on the Hazard Number 9 coal seam. The acid at site 341 probably originates in underground mines.

Acid water which accumulates in puddles on strip-mine benches (such as at site 173) probably maintains its acidity thoughout the year. It is believed that Big Branch near Viper (sites 188 and 189) is highly acid at all times since the source of this acid is fairly constant drainage from an abandoned underground mine and auger tunnels. This acid water enters the stream largely from point sources so, unlike that in most other streams sampled, it has little contact at any time of the year with soils or near-surface aquifer materials that have potential for neutralizing the acid. It is doubtful that any of the remaining streams sampled maintain their acidity throughout the year. Lotts Creek above Trace Fork at Darfork (site 247) and tributaries were highly acid during the spring from about February through May, but were near neutral in reaction the remainder of the year.

During the spring of 1975 Lotts Creek above Trace Fork and most of its tributaries had pH values ranging from 3.5 units on Lotts Creek above Trace Fork at Darfork (site 247) to 3.2 units on Youngs and Kelly Forks (sites 231 and 222). During the remainder of the year the acidity associated with sulfate had been neutralized and most of the streams were near neutral. Kelly Fork with a pH of 3.5 units and possibly Youngs Fork, were still acid in July 1975. During the heavy runoff season it is postulated that on these watersheds the acid mine drainage from strip mine spoils is transported to streams with a minimum of interaction with the soil, subsoil, and substratum, thus relatively little acid is neutralized. During dryer seasons most of the acid mine drainage would slowly move underground through materials containing exchangeable bases for some distance before seeping into streams and thus much or all of the acidity would be neutralized.

Seasonal releases of acid water, such as observed on Lotts Creek and its tributaries in the spring of 1975, can under some circumstances be very brief. An example would be the "flushout" described in detail by Agnew and Corbett (1973, p. 167-171) wherein discharge, acidity, and total iron all increased more than sixfold in an hour in a small southern Indiana stream.

Small streams with extreme acidity may seriously affect the quality of water in larger streams for a considerable distance. An example would be Big Branch near Viper (site 189), where pH values ranged from 2.6 to 2.9 units. This small flow of water was sufficient to produce acid waters in the Right Fork Maces Creek at Viper all the way to its mouth (site 192) most of the year, and presumably at times, all the way to the mouth of Maces Creek at Viper.

The occasional occurrences of highly acid water reported in the North Fork Kentucky River at Hazard until June 1966 (U.S. Geological Survey, 1949-75) almost certainly were caused by sudden surges of acid water released from ponds or from underground mines. During low-flow periods small releases of highly acid water could seriously affect the quality of much of, or conceivably all of, this river. If the acid had been released during high-flow periods the harmful effects on water in the river would probably have extended only for short distances, or the acid more likely would not have been detectable at all. Since 1966 mine operators have either refrained from releasing large quantities of acid water during low flows, or else mining operations have changed so there is no need to release large flows all at once. Daily observations by personnel at the Municipal Water Plant in Hazard confirmed that no acid water has appeared at this point for quite a number of years although it once had been common (Cleon Begley, oral commun., 1975).

No attempt was made during the course of the study to investigate the sources of these large releases of acid water a decade or more ago into the North Fork Kentucky River; however, Braley (1954, p. 128-133) describes in some detail the causes and effects of a "breakout" of acid water from an underground mine in Pennsylvania. Braley (p. 174, 181) also discusses the holding of acid water in a lagoon so that its release can be timed to coincide with high flow in the stream thus taking advantage of dilution.

Underground mine or waste discharges with high concentrations of ferrous iron have the potential for becoming more acid once they drain into a surface stream and the ferrous iron is oxidized to the ferric state (see equations 2 and 3 in section on oxidation of ferrous sulfide). As an example the sample collected from Razorblade Branch on February 26, 1975 (site 72) contained 37,000 ug/L of ferrous iron when sampled, and calculations show that this iron, when oxidized, had the potential for lowering the pH value of the sample from the 5.1 units observed at streamside to about 2.9 units, provided there was little or no buffering effect from other dissolved constituents. The pH value of this sample declined to 3.3 units when it was allowed to set four weeks in the laboratory. Other examples are given in table 9, part 1. A similar decline in pH from 7.2 units on June 11, 1974 in the field to 4.2 units in the laboratory a few weeks later was observed in a sample collected from Camp Branch at Colson (site 80). Water from these two tributaries normally does not affect the quality of water in Rockhouse Creek very far downstream but heavy yellow deposits of ferric hydroxide were observed downstream from Razorblade Branch as far as Loves Branch (station 74), a distance of more than 2 miles.

Not all streams containing acid water in the study area were sampled as a part of the present investigation. The Federal Water Pollution Control Administration (1969, p. 210, 213-216) cites eight streams in the study area with pH values equal to or less than 4.2 units in 1966. These streams include Quillen Fork at Hemphill, Sassafras Creek at mouth (site 206), Yellow Creek at Sassafras (site 215) Stacy Branch at Vicco (site 216), Raccoon Creek at Glowmar, Lotts Creek above Trace Fork at Darfork (site 247), Jakes Branch at Bulan (site 250) and Big Creek near Typo (at or near site 252). Those with site numbers were resampled as part of the present study, but not always for pH. Since 1966 the general trend of pH seems to have been upward. This was especially true of Sassafras Creek where a pH value of 8.0 units was measured on August 20, 1975. The pH of Yellow Creek at Sassafras ranged from 4.8 to 7.1 units during the 1974-75 sampling period. Lotts Creek in 1975 ranged from acid at a pH at 3.6 units to alkaline with pH values as high as 7.8 units.

Trace Elements

The term "trace elements," as used in this report, includes boron and all the trace metals (metals other than calcium, magnesium, sodium, and potassium). The occurrence of trace elements normally associated with acid mine drainage has already been discussed in some detail in the section entitled: "Origins and Characteristics of Drainage from Coal Mines." Trace-elements data for the North Fork Kentucky River and tributaries are presented in table 9, part 1. A number of samples were observed to be high in dissolved iron (concentrations ranging up to 82,000 ug/L) and in dissolved manganese (concentrations up to 22,000 ug/L). These two elements are abundant in most soil and spoil materials. They are relatively soluble in an acid environment so appreciable concentrations must be expected in acid mine drainage.

Both iron and manganese in mine drainage waters commonly exceed the 300 and 500 ug/L respective maximum limits assigned in the drinking water standards (U.S. Environmental Protection Agency, 1976, p. 78, 95). Much larger quantities of these two metal in drinking water may not be harmful to human health, but they do give the water a bad taste and tend to form stains or deposits on kitchen utensils and other containers.

The only sample with high concentrations of other trace elements was from Big Branch near Viper (site 189). This sample was high in aluminum, cobalt, copper, iron, lead, magnesium, nickel, and vanadium. None of these concentrations were sufficiently high to be toxic to man or animals although the 1,200 ug/L of nickel may, after extended contact, be toxic to certain species of fish and shellfish (Committee on Water Quality Criteria, 1974, p. 181, 182). The limited data collected on trace elements in the study area gave no indication that any of the elements tested, other than iron and manganese, could be a problem in the concentrations observed, even for drinking water.

Specific Conductance and Dissolved Solids

Specfic conductance does not give a direct measure of any specific chemical constituent dissolved in a natural water sample; nevertheless, it is a quick inexpensive measurement which can give a good estimate of the dissolved-solids content of the water and frequently much more also. The U.S. Salinity Laboratory Staff (1954, p. 157) suggests that specific conductance in umhos/cm multiplied by the factor 0.64 will give a reasonable estimate of dissolved solids in parts per million (essentially equivalent to milligrams per liter) when conductivity is in the range of 100 to 5,000 umhos/cm. Hem (1970, p. 99) observed that the dissolved solids concentrations (in milligrams per liter) in natural waters were generally between 0.55 ad 0.75 of the specific conductance (in umhos/cm). Hill (1972, p. 104) states that in many cases specific conductance can be used as an indirect measure of other parameters; and Curtis (1972B, p. 24) notes that specific conductance may be a reliable test for indicating the degree of mine pollution. The exact relations between specific conductance and other parameters will certainly vary from watershed to watershed, but within a given area the relations may be well defined.

Plass (1975B, p. 180, 184) reported that prior to mining, the specific conductance of water flowing from a small watershed near Beckley, West Virginia averaged 58 umhos/cm and bore no relation to any of the other parameters measured: calcium, magnesium, potassium, sulfate, alkalinity, pH, temperature, turbidity, aluminum, iron, manganese, or zinc. After coal was strip mined from the watershed the specific conductance rose to an average value of 193 umhos/cm and showed a positive correlation with both sulfate and calcium ions in solution. Plass (1975A, p. 163) notes that sulfate, calcium, and magnesium accounted for most of the increase in specific conductance after areas had been strip-mined. On tributaries to the Clarion River in western Pennsylvania Gang and Langmuir (1974, p. 62) reported good correlations between the logarithm of specific conductance and the logarithms of discharge, iron, manganese, and zinc.

A very high level of correlation (correlation coefficient $r = 0.986$) was observed in the curvilinear regression between specific conductance and sulfate in samples from the North Fork Kentucky River at Hazard for the time period 1949 through 1974 (fig. 3).

On the watershed of the North Fork Kentucky River, specific conductance is still a reliable indicator of which streams have been seriously affected by coal-mine drainage, oil and gas well drainage, municipal wastes, or road salt even though the base level of conductance in unmined areas is higher at the extreme upper and lower ends of the watershed than in the remainder of the watershed. A review of the data collected from throughout the study area shows that a very close relation exists between specific conductance and sulfate, and a somewhat lesser degree of relation with calcium and magnesium. Much of the sulfate-distribution pattern illustrated in plate 1 was estimated from field measurements of specific conductance using the curve developed in figure 2 for the North Fork Kentucky River at Hazard.

Estimates of mean specific conductance for the 1975 water year were used to construct the dissolved solids map on plate 3. It was assumed that the dissolved solids in milligrams per liter was approximately two-thirds the value of specific conductance measured in micromhos per centimeters as determined from the sites listed in table 9.

The mean annual specific conductance of the North Fork Kentucky River at its mouth is now about three fold what it had been prior to the introduction of large-scale commercial coal mining on the watershed -- an increase from about 75 to about 225 umhos/cm. From this it may be deduced that mean annual dissolved solids concentrations on the watershed have increased from about 50 to 150 mg/L during the same time period.

EFFECTS OF DIFFERENT METHODS OF MINING ON WATER QUALITY

A detailed, rigid, and fully-documented evaluation of the relative downstream effects of the different methods of mining on water quality is beyond the scope of this investigation; nevertheless, a limited assessment of these effects can be made from the information gathered during the course of the study and from selected historial data. Mining methods have changed gradually over the years. No attempt will be made to assess the effects of increased mechanization, although this undoubtedly has had some effects on the pattern of waste releases. The relative importance of the different seams of coal mined has changed from year to year, thus complicating the process of associating causes with effects.

The major mining methods are (1) underground or "deep" mining, (2) strip or surface mining, and (3) auger mining. In underground mining the production of acid mine drainage is fairly constant and while many control measures have been tried, most have little or no effect on production of acid. Sealing abandoned mines against entry of oxygen has generally not proved practical, although it may slightly reduce the production of acid. Flooding mines with water is sometimes feasible and since this does permanently cut off most of the oxygen supply, it effectively controls production of acid.

Auger mining was first introduced into the study area in 1949. These mines are essentially a series of short parallel underground mines, so most of the comments given for underground mines are also applicable to auger mines.

Strip mining was introduced into the area in 1944 and it is generally recognized that over an extended period these mines are less productive of acid drainage per unit of coal produced than are underground mines. This is in some measure due to the fact that the acid-abatement measures used on strip mines, especially in recent years, are more effective than those used in underground mines. Braley (1954, p. 235) suggests that the acid potential of outcrop strip mines is less than that of underground mines because the coal and associated overburden in the former have been subjected to a certain amount of weathering over the years. The most effective means of avoiding excessive acid drainage from strip mines is to bury the acid-producing portion of the overburden under spoil materials which do not produce acid drainage. Despard (1974, p. 1-4) suggests that core samples of the overburden be analyzed prior to mining so that the potentially toxic strata may be identified and reburied at a low level.

Von Demfange and Warner (1975, p. 142) found that after 16 years of exposure to a moderate, temperature climate most of the acid production still occurred in the top 2 feet of spoil, and this illustrates the effectiveness of even shallow burial of toxic spoils in reducing acid production. They also found that the loss of acid from exposed spoils can be a fairly rapid process since in all the samples they examined, over 90 percent of the pyrite had been oxidized after 8 to 16 years. Production of acid from underground mines does not normally decline so quickly unless they are flooded.

Evidence has been presented earlier in this report which would seem to indicate that the acid discharge periodically associated with deep mining prior to 1964 in the area upstream from Hazard have almost ceased (see the section entitled "Water Quality of the North Fork Kentucky River at Hazard, 1963-73"). This decline in acid discharge may be attributable to either a decline in deep mining or to an improvement in mining methods. In the area upstream from Hazard the production of acid mine drainage has tended to decrease somewhat as deep mining declined, even though production of coal by strip mining increased by a corresponding amount.

DEPENDENCE OF WATER QUALITY ON TYPE OF COAL MINED

One of the objectives of this study was to evaluate the different coal seams of the study area in regard to their potential for producing acid mine drainage so that problems associated with acid mine drainage might be assessed prior to mining in new areas. It has long been known that certain coal seams in the area such as Hazard Number 9 were high in sulfur and were likely to produce large quantities of acid and dissolved solids when mined; while other coal seams such as Hazard Number 7, Fire Clay, and Leatherwood generally produced drainage water near neutral in pH and low enough in dissolved solids to be suitable for domestic supplies.

Some of the streams on strip and auger mined watersheds show little change in water quality due to mining. These have been tabulated by coal seam mined in the section entitled "Stream Chemistry Reconnaissance, 1975 water year." Water from several of the underground mines listed in table 9 (part 2) were of such high quality that they were used as municipal or domestic supplies. Most acid mine drainage problems in the study area are associated with mining of the Hazard Number 9 coal seam. Sites affected by acid mine drainage from this seam are discussed in the section "Downstream Effects of Mine Drainage" under two subheadings: (1) "Sulfate," and (2) "Acidity, Alkalinity, pH, and Neutralization."

Any assessment of the acid producing potential of different seams of coal must be somewhat empirical. Some of these seams cover huge geographical areas, in some cases most of Appalachia from Pennsylvania to Alabama (Pocahontas Land Corporation, 1971). The quantity of sulfur or any other element associated with the coal and its overburden cannot reasonably be expected to remain constant over such a wide area. In addition, not all pyrite in a given seam is equally stable. Caruccio and Ferm (1974, p. 6) observed that the framboidal pyrite (associated mainly with back barrier and lower delta deposits) is very reactive and quickly releases large quantities of acid when exposed to weathering; while the coarse-grained pyrite (associated mainly with upper delta and alluvial plain deposits) is relatively stable and releases little acid.

With so many controllable and uncontrollable variables affecting the release of acid and sulfate wastes, it is not easy to predict pollutant concentrations entering streams as a consequence of the mining of a given quantity of coal from a given seam. About all that can be done is to evaluate the pollution potential of different seams on a relative basis. A listing of coal seams of eastern Kentucky grouped according to acid-producing potential has been published by R. L. Kimball (1974, p. 29-30). Because of the variability within some seams, the incomplete mapping of coal seams, and the inconsistent names applied to many seams a more refined assessment and comparison of seams is not justified at this time.

The most direct method for evaluating the pollution potential of different coal seams and their overburdens would be through the analysis of numerous core drillings for both framboidal pyrite and substances capable of neutralizing acid produced from the pyrite.

SUMMARY AND CONCLUSIONS

The watershed of the North Fork Kentucky River above its confluence with the Middle Fork covers a total of 1,319 square miles. This long narrow watershed cuts diagonally across most of the Appalachian coal fields of eastern Kentucky. Water samples collected at a total of 415 sites made it possible to delineate areas where waters are high in dissolved solids, highly acidic, and contain excessive sediment, and to evaluate the overall water-quality status of the streams of the basin.

Commercial coal production began on a small scale in the study area in 1891 but did not become important until 1912. Total coal production reached a peak after World War II in 1948, declined, and then increased to a somewhat higher peak in 1970. All production was by underground mines until 1944 when strip mining was introduced into the area. Auger mines were introduced in 1949. Production by strip and auger mines by 1975 was 162 percent that of the underground mines, which then produced less than half as much coal as during the peak year of 1948.

The mean annual dissolved-solids concentration of the North Fork Kentucky River above its juncture with the Middle Fork is now about threefold what it had been prior to the introduction of large-scale commercial mining, an increase from about 50 to 150 mg/L. During this same time span, mean sulfate concentrations increased about sixfold, from 8 to 50 mg/L. The corresponding increase in chloride concentrations has been negligible, from about 1.5 to 2.3 mg/L.

Observations by the author and others indicate that the worst and most immediate water-quality problem attributable to surface mining in the study area in 1975 is the increase in sediment. Sediment can smother or bury the aquatic plant life at the base of the food chain thus starving most higher forms of aquatic life. The construction of silt-retention dams is now required by law as part of most new surface-mining operations and these have cleared most sediment from the downstream waters, thus greatly improving water quality over what it otherwise would have been; nevertheless, earth-moving operations associated with the construction of coal-haul roads and even construction of the silt-retention dams still keep many streams very silty much of the time.

Considering the large tonnage of coal produced in the study area, the adverse effects of acid mine drainage on quality of water in the streams have been surprisingly small. Acid mine drainage is far more prevalent in mined areas of western Kentucky or western Pennsylvania. Reasons for this difference are (1) a lower rate of acid production in the study area per ton of coal produced (as estimated from sulfate levels in downstream waters) and (2) neutralization or removal of these acids by soils or aquifer materials before mine-drainage reaches the streams. Acid waters were observed in several small creeks and branches, but these were generally not acid all year. The most acid sample collected during the study had already lost 63 percent of its original acidity through neutralization by carbonate minerals and removal through cation exchange processes.

The quality of water in the North Fork Kentucky River at Hazard was most severely affected by mining during or shortly before the 1963 water year when the average concentration of sulfate was about double its 1975 level. The highest concentrations of sulfate in 1963 were observed at irregular intervals. Slugs of acid water were occasionally observed at this site until 1966 and are believed to have resulted mainly from the periodic pumping of highly acid waters from deep mines or from sudden releases of water from coal-washing ponds. The reduction in sulfate and acidity at this site is attributed mainly to improved mining practices and partly to a shift of emphasis from underground mining to strip mining on the watershed. The reduction of sulfate and acid at this station cannot be attributed to changes in total coal production on the watershed since coal production has remained almost constant for the period in question.

A disproportionate amount of the sulfate and acid produced in the study area is traceable to mining of the Hazard Number 9 coal seam. Relatively little coal is now produced from this seam since the more accessible portions were mined before 1970 and there is almost no market for the high sulfur coal it generally produces; nevertheless, the unreclaimed strip and auger mines in this seam dating back to 1965 or before still produce large quantities of sulfate and acid drainage, especially in the areas just north, east, and south of Hazard. Many of the spoilbanks are still bare of vegetation.

Most coal seams produce far less sulfate and acid drainage than the Hazard Number 9 seam. This is especially true of the Fire Clay and Leatherwood seams, where, within a few years after cessation of mining, the quality of the drainage water is sometimes scarcely distinguishable from that in unmined areas.

Ground water in most of the study area has not been affected by mining, but immediately downslope from any mine it may be severely affected. Nearly all mine drainage is ground water for at least a short period of time before it leaves the mine or before it enters a stream through a spring or seep. It is as ground water that most or all of the acidity in acid drainage will be neutralized. Large quantities of water accumulate in some abandoned mines during the winter and spring, then slowly drain from the mine opening during the warmer months. This water is frequently of good quality and sometimes is used as a domestic supply.

Several samples of water affected by acid mine drainage were shown to have unusually high concentrations of a number of trace elements, but in no case were these concentrations sufficiently high to be hazardous to human health. The concentrations of iron and manganese in several samples were high enough to impart a bad taste to the water and to stain containers.

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Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
1	North Fork Kentucky River at Payne Gap	370924 0823926 00	0.20	07-25-75	1020	0.08	31	29	405	8.0	20.5	Small fish observed
2	North Fork Kentucky River above Boone Fork at Kona	370923 0824425 00	10.0	06-11-74	1435		120		501	8.6	22.0	
				01-15-75	1540	10	88	13	425		4.5	
3	Wright Fork at mouth at Neon	371128 0824247 00	6.96	01-15-75	1420	5	140	10	587		6.0	
4	Yonts Fork at Neon	371128 0824247 01	5.77	01-15-75	1430	4.5	160	7.7	602		8.0	
5	Potter Fork at Neon Junction	371044 0824241 00	4.29	01-15-75	1515	5.0	120	2.9	707		7.5	
				07-25-75	1135	2.3	130	7.3	715	8.1	20.0	
6	Boone Fork at Kona	370925 0824424 00	19.5	06-11-74	1440		170		757	8.2	19.5	
				01-15-75	1555	20	150	6.2	602		5.5	
7	Millstone Creek at Millstone	371004 0824512 00	9.08	01-15-75	1630	6	190	3.5	718		7.5	Silty
8	Thornton Creek at Sergent	370907 0824555 00	3.71	01-15-75	1225	4.4	210	2.2	531		5.0	
9	Bottom Fork at mouth at Mayking	370801 0824549 00	3.16	01-15-75	1125	4.0	120	2.1	358		3.0	
10	Pine Creek at Mayking	370802 0824549 00	2.26	01-15-75	1115	2.5	33	1.4	159		2.0	
11	Cram Creek at Mayking	370726 0824609 00	2.72	01-15-75	1155	2.5	30	1.3	152		3.0	
12	Crafts Colly Creek at Ermine	370710 0824737 00	6.93	01-15-75	1040	3.0	150	1.8	362		2.0	
13	North Fork Kentucky River at Whitesburg (03277300)	370703 0824929 00	66.4	01-15-75	0910		130	5.4	488		.5	Water clear
				01-15-75	1815				498		2.5	
				01-16-75	0845				493		3.0	
				04-30-75	0900		120	2.4	451	8.0	15.5	Dirty gray, 6 inches visibility
				05-01-75	0850				450		15.5	Dirty gray, 6 inches visibility
				07-25-75	0855		150	20	490	7.8	27.0	1 inch visibility
14	Sandlick Creek at Whitesburg	370724 0825014 00	4.86	01-15-75	0950	2.5	160	5.6	438		2.0	
				01-15-75	1720	5.0			537		5.5	Silty
				01-16-75	0900	2.6			472		4.0	Clear
15	Cowan Creek above Sturgill Branch at Day	370403 0825127 01	1.68	01-29-75	1735	2.3			117		11.0	Murky
16	Sturgill Branch at Day	370403 0825127 00	.29	01-29-75	1730	.4	81	.8	219		10.5	Murky
17	Cowan Creek Unnamed Tributary No. 1 at Day	370409 0825102 00	.021	01-29-75	1715	.01			23			Clear
18	Cowan Creek Unnamed Tributary No. 2 at Day	370412 0825100 00	.14	01-29-75	1710	.2			133		11.0	Clear
19	Long Branch at Day	370421 0825045 00	.38	01-29-75	1700	.4			71		11.0	Murky
20	Blair Hollow at Day	370438 0825010 00	.44	01-29-75	1640	.25	14	.8	147		10.5	Almost clear
21	Bartesta Branch at Day	370452 0825000 00	.78	01-29-75	1555	.5	16	1.9	79		10.5	Almost clear
22	Cowan Creek Unnamed Tributary at Dongola	370503 0825000 00	.12	01-29-75	1605	.04	15	.6	46		11.0	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi²)	Date	Time	Estimated discharge unless noted (ft³/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
23	Grapevine Branch at Dongola	370527 0825024 00	0.29	01-29-75	1620	0.15			129		11.0	Dirty and stinking
24	Cowan Creek above Little Cowan Creek at Dongola	370542 0825036 01	6.15	01-29-75	1200	8.4	18	2.0	118		11.0	Clear
25	Little Cowan Creek near Whitesburg	370538 0824759 01	.42	01-29-75	1530	.5			185		10.0	Clear
26	Little Cowan C Unnamed Trib near Whitesburg	370538 0824759 00	.19	01-29-75	1525	.04			326		10.0	Murky
27	Little Cowan Creek above Ovenfork B near Whitesburg	370523 0824835 00	1.09	01-29-75	1455	1.2	18	23	237		11.0	Murky
28	Ovenfork Branch near Whitesburg	370524 0824836 00	.22	01-29-75	1445	.1			59		9.5	Murky
29	Little Cowan C Unnamed Trib 1 near Dongola	370520 0824901 00	.28	01-29-75	1425	.2	54	1.2	172		10.5	Muddy
30	Little Cowan C Unnamed Trib 2 near Dongola	370536 0824919 00	.10	01-29-75	1420	.01			55		10.0	Clear
31	Little Cowan C Unnamed Trib 3 near Dongola	370542 0824926 00	.22	01-29-75	1330	.2			85		10.0	Clear
32	Little Cowan C Unnamed Trib 4 near Dongola	370540 0824929 00	.087	01-29-75	1335	.05			46		9.5	Clear
33	Little Cowan C Unnamed Trib 5 near Dongola	370551 0824938 00	.21	01-29-75	1315	.2			126		10.0	Somewhat murky
34	Little Cowan C Unnamed Trib 6 near Dongola	370555 0824955 00	.13	01-29-75	1305	.2			90		9.5	Somewhat murky
35	Johnson House Branch at Dongola	370552 0825015 00	.50	01-29-75	1255	.5	77	.8	202		10.0	Somewhat murky
36	Little Cowan Creek at Dongola	370542 0825036 00	3.76	01-29-75	1155	5.3	28	9.8	176		10.5	Somewhat murky
37	Day Branch at Dongola	370556 0825050 00	.25	01-29-75	1125	.25			79		10.0	Almost clear
38	Hampton Branch at Dongola	370547 0825103 00	.42	01-29-75	1110	.25			110		10.0	Somewhat murky
39	Cowan Creek at Ice	370618 0825136 00	11.1	01-15-75	1740	10	27	11	169		3.5	Silty
				01-29-75	1050	14	22	4.6	144		10.0	Somewhat murky
				05-01-75	0930	20	25	2.6	147	7.9	14.5	16 inches plus visibility
40	Brown Branch at Ice	370617 0825136 00	.56	01-29-75	1140	.30			111		10.5	Almost clear
41	Dry Fork near Ice	370716 0825229 00	5.27	01-16-75	0930	3	160	3.0	411		3.5	Murky
42	Kingdom Come Creek above BO Fork near Oscaloosa	370425 0825241 00	.81	05-01-75	1040	1.7	40	.9	120	7.7	15.0	Murky, surface mined about 1969

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
43	BO Fork of Kingdom Come Creek near Oscaloosa	370425 0825242 00	2.31	05-01-75	1030	2.5	59	[illegible].1	184	7.7	15.0	Murky, surface mined about 1972
44	Cottonpatch Branch near Oscaloosa	370501 0825250 00	.65	05-01-75	1125	.67			88	7.7	17.0	Muddy, 1/4 inch visibility, active surface mine
45	Poplar Log Hollow at Oscaloosa	370535 0825314 00	.40	05-01-75	1140	.67			140	7.7	16.0	Clear
46	Kingdom Come Creek near Hot Spot	370648 0825419 00	7.62	01-16-75	1005	9	41	[illegible].4	137		2.5	Clear
				05-01-75	1200		39	[illegible].0	129	7.8	18.0	Muddy, 2 inches visibility
47	Smoot Creek at Hot Spot	370709 0825508 00	8.70	01-16-75	1040	5	130	[illegible].0	363		3.0	Very silty
				06-12-75	1930	6.5			529	7.9	21.5	Muddy, 1/2 inch visibility
48	Birchfield Branch at Hot Spot	370648 0825532 00	.35	05-01-75	1250	1.7	93	[illegible].0	284	7.8	21.0	Clear, (below 2 ponds)
				06-12-75	1915	.05			270		20.5	Clear
49	Left Fork Kings C (Head of Kings C) at Kings C	370237 0825441 00	1.41	05-01-75	1440	1.3	14	[illegible].0	75	8.4	18.5	Clear
				06-12-75	1540	.42			102	7.7	22.0	Clear
50	Right Fork Kings Creek at Kings Creek	370236 0825444 00	1.37	05-01-75	1450	.56	13	[illegible].2	82	7.8	18.0	Clear, mined about 1973
				06-12-75	1530	.28			125	7.5	21.5	Murky, 5 inches visibility
51	Kings Creek Unnamed Tributary at Kings Creek	370308 0825456 00	.15	06-12-75	1550	.01			68		22.0	Clear
52	Fugate Branch at Kings Creek	370314 0825454 00	.45	06-12-75	1600	.01			99	7.5	24.0	Clear
53	Lick Branch at Kings Creek	370356 0825504 00	.69	06-12-75	1610	.08			155	7.5	25.0	Clear
54	Ike Branch near Kings Creek	370407 0825520 00	.44	06-12-75	1625	.07			153	7.8	21	Muddy, 2 inches visibility
55	Carrion Branch near Kings Creek	370414 0825527 00	.52	06-12-75	1640	.08			163	8.3	24.5	Clear
56	Lynn Branch near Kings Creek	370453 0825508 00	1.07	06-12-75	1700	.2			261	8.0	23.0	5 inches visibility
57	Right Fork Lynn Branch near Kings Creek	370454 0825508 00	.27	06-12-75	1705	.11	130	[illegible].5	393	8.0	20.5	Clear
58	Muddy Branch near Roxana	370517 0825525 00	.45	06-12-75	1735	.18			228	7.7	21.0	Murky, 9 inches visibility
59	Big Bottom Branch near Roxana	370522 0825514 00	.30	06-12-75	1750	.12			310	8.0	20.5	Murky, 5 inches visibility
60	Lucky Branch near Roxana	370538 0825525 00	.68	06-12-75	1805	.47			210	8.1	21.0	Muddy, 1/2 inch visibility
61	Pacies Branch near Roxana	370552 0825602 00	.92	06-12-75	1830	.44	130	2.6	361	7.9	21.0	5 inches visibility
62	Kings Creek Unnamed Tributary near Roxana	370600 0825604 00	.17	06-12-75	1850	.03			76		21.0	5 inches visibility
63	Kings Creek at Roxana	370616 0825631 00	11.3	01-16-75	1125	8.6	42	2.7	147		3.0	Clear
				05-01-75	1320	10	40	1.2	141	8.7	18.5	Clear
				06-12-75	1820				206	8.0	22.0	Muddy, 1 inch visibility

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
64	Rise Branch at Roxana	370616 0825647 00	0.29	06-12-75	1900	0.04			84		19.0	Murky
65	Tolson Branch at Roxana	370641 0825736 00	1.76	05-01-75	1350	.5	83	.9	253	8.1	21.0	8 inches visibility, gray silt on bottom
66	North Fork Kentucky River	370743 0825827 00	131	06-11-74	1720		150		540	8.1	23.0	
	at Blackey (03277340)			09-26-74	1445	1/31	160	7.2	574		18.5	
				01-16-75	1240		100	8.4	380		2.5	
				02-12-75	1230				221		7.5	Muddy
				02-27-75	1440		120	3.4	435	7.8	9.0	Clear
				04-30-75	1030		97	2.2	354	7.7	18.0	Murky, 5 inches visibility
				07-10-75	1535		170	7.6	595	8.2	27.0	1 inch visibility
67	Rockhouse Creek above Stephens Fork at Deane	371438 0824417 01	2.36	02-26-75	1200	3.0			172		5.0	12 inches visibility, yellowish silty bottom
68	Stevens Fork Rockhouse Creek near Deane	371438 0824417 00	1.12	02-26-75	1150	1.5			115		6.0	Clear
69	Rockhouse Creek above Mill Creek at Deane	371418 0824630 00	6.66	02-26-75	1110	6.5	110	4.1	392		5.0	Clear, 24 inches visibility
70	Mill Creek at Deane	371418 0824631 00	2.86	02-26-75	1105	2.0			115		4.5	Clear, yellowish bottom
71	Rockhouse Creek above	371418 0824645 00	9.67	02-26-75	1305				368	8.0	7.5	Clear
	Razorblade Branch at Deane			08-19-75	1100	.15	310	11	1,060	7.2	21.0	Small fish observed
72	Razorblade Branch at Deane	371419 0824645 00	.89	02-26-75	1230	1.0	1,100	15	1,750	5.1	10.0	Heavy yellow boy
				08-19-75	1045	.13	1,200	24	2,200	6.8	18.5	Yellow boy
73	Big Branch at Democrat	371400 0824814 00	1.24	02-26-75	1400	2.0	16	1.9	70		9.5	Clear
74	Rockhouse Creek above Loves Branch at Democrat	371257 0824852 00	13.4	02-26-75	1445				510	7.1	9.0	16 inches visibility, yellow boy
				08-19-75	1200	.30	530	14	1,340	8.2	23.0	Small fish observed
75	Loves Branch at Democrat	371357 0824853 00	1.42	02-26-75	1430	1.0	13	.1	55	7.0	10.0	Clear
				08-19-75	1200	.00						
76	Indian Creek near Democrat	371327 0824855 00	2.22	06-11-74	1545				333	8.8	22.0	
				02-26-75	1455	1.4			240		8.0	20 inches visibility
77	Beaverdam Branch near Colson	371341 0824952 00	2.41	02-26-75	1520	1.7			109	6.9	11.0	Extremely silty, 1/4 inch visibility
78	Buck Creek at Colson	371332 0825110 00	1.89	02-26-75	1535	1.2			276		14.0	Murky, 3 inches visibility
79	Trace Fork at Colson	371327 0851190 00	1.70	02-26-75	1545	1.3			155		11.5	Murky, 5 inches visibility
80	Camp Branch at Colson	371244 0825107 00	6.34	06-11-74	1610		340		903	7.2	21.0	
				02-26-75	1600	4.0	200	4.3	455	7.1	11.0	Muddy, 1 inch visibility
				08-19-75	1250	.23	820	19	1,620	8.00	23.5	Clear water, muddy bottom
81	Millstone Branch near Sackett	371232 0825201 00	.44	02-26-75	1625	.25	61	.7	190	7.4	11.0	Clear

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
82	Daniels Branch at Sackett	371226 0825250 00	1.25	02-26-75	1700	0.75	100	1.1	363	8.0	11.0	Murky, 6 inches visibility
83	Rockhouse Creek above	371117 0825345 00	37.1	02-26-75	1740		150	4.5	419	7.2	8.0	Muddy, 2 inches visibility
	Little Colly C at Isom			02-27-75	1010				410		6.0	Muddy, 2 inches visibility
84	Little Colly Creek at Isom	371117 0825344 00	3.48	02-26-75	1730	3.8	180	11	500	9.3	10.5	Clear, over 24 inches visibility
				08-19-75	1340	.19	390	19	1,170	8.2	29.5	Many small fish
85	Stampers Branch at Isom	371116 0825358 00	1.04	02-26-75	1825	.5			195	7.7	9.5	Muddy, 3 inches visibility
86	Garner Creek at Isom	371106 0825425 00	.70	02-26-75	1840	.4			260		9.5	Muddy, 3 inches visibility
87	Blair Branch near Isom	371021 0825511 00	1.76	02-27-75	1025	.8	34	2.4	130	7.3	5.5	Clear
88	Adams Branch near Isom	371030 0825527 00	.71	02-27-75	1055	.4	36	1.5	130	7.4	5.5	Clear
89	Doty Creek near Carbon Glow	371102 0825610 00	.58	02-27-75	1145	.22	98	1.8	390	9.0	8.0	Clear
90	Doty C Unnamed Tributary near Carbon Glow	371101 0825608 00	1.08	02-27-75	1155	.2			111	7.1	6.0	Murky, 6 inches visibility
91	Doty Creek near Jeremiah	371029 0825548 00	2.06	02-27-75	1115	1.2			235	9.1	6.5	Clear
92	Spring Branch at Jeremiah	370946 0825515 00	.67	02-27-75	1225	.65			233	7.7	8.0	Clear
93	Perkins Branch at Jeremiah	370912 0825605 00	.61	02-27-75	1245	.17			143		9.0	Clear, clean
94	Caudill Creek at Letcher	370909 0825705 00	1.84	02-27-75	1300	2.1	100	2.4	333	8.0	10.0	Silty, 1 inch visibility
95	Crases Branch at Letcher	370842 0825732 00	.72	02-27-75	1325	.22			111	7.5	10.0	Clear, clean
96	Pratts Branch at Letcher	370835 0825744 00	.62	02-27-75	1345	.50			275	9.0	9.5	Clear
97	Rockhouse Creek at mouth	370824 0825823 00	56.1	06-11-74	1700		180		537	8.0	21.5	
	near Letcher (03277362)			01-16-75	1220		90	6.5	306		3.0	
				02-12-75	1250				127		7.0	Muddy
				02-27-75	1410		120	3.8	380	7.0	8.5	Muddy, 2 inches visibility
				04-30-75	1010		75	1.9	245	7.6	16.5	
				07-10-75	1605		250	9.3	720	8.5	27.5	10 inches visibility small fish and tadpole
				08-19-75	1435		270	12	765	8.8	26.5	3 inches visibility
98	Elk Creek at Blackey	370819 0825921 00	3.29	02-27-75	1505	2.2	88	1.8	351	9.0	10.5	Clear
99	Orchard Branch near Blackey	370802 0830034 00	.70	02-27-75	1535	.5			338		9.0	Clear
100	Talent Branch near Ulvah	370828 0830104 00	.47	02-27-75	1550	.13			71	7.8	10.0	muddy, 1/2 inch visibility
101	Line Fork above Bear Branch at Gilley	365825 0830642 00	2.86	06-11-75	1545	.67	6.8	1.1	93	8.0	19.5	Clear
102	Bear Branch at Gilley	365830 0830642 00	1.50	06-11-75	1525	.33	6.2	.7	52	8.1	18.5	Muddy, 3 inches visibility
103	Line Fork above Jakes Creek	365858 0830512 00	5.50	04-30-75	1905	5.6	7.8	.7	65	7.9	16.5	Clear
	near Gilley			06-11-75	1620	.83			98		19.5	Murky, 5 inches visibility
104	Jakes Creek near Gilley	365858 0830513 00	1.89	04-30-75	1855	.53	34	.5	129	7.8	16.0	Muddy, 2 inches visibility
				06-11-75	1625	2.5			242	8.0	19.0	Clear
105	Koyle Branch near Gilley	365912 0830431 00	1.15	06-11-75	1650	.33			233	8.0	18.0	2 inches visibility
106	Long Branch near Gordon	365916 0830326 00	1.60	06-11-75	1710	.25			143	7.5	18.0	Clear
107	Laurelpatch Branch near Gordon	365931 0830254 00	.42	06-11-75	1730	.14			166	7.6	17.0	Clear

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
108	Little Laurelpatch Branch near Gordon	365943 0830226 00	0.21	06-11-75	1805	0.01			89		17.0	Clear
109	Trace Branch at Gordon	365956 0830156 00	2.68	06-11-75	1815	.35	78	3.1	273	7.8	19.0	Clear, 12 inches visibility, silt on bottom
110	Valley Branch at Gordon	365930 0830131 00	.32	06-11-75	1855	.05			209		18.0	Muddy, 1 inch visibility
111	Piney Branch at Gordon	365930 0830126 00	.63	06-11-75	1840	.11	14	4.5	258	8.1	15.5	Clear, 24 inches visibility
112	Pitcher Branch near Gordon	370006 0830035 00	.79	06-11-75	1920	.20			171	7.9	17.5	Clear, 24 inches visibility
113	Ingram Branch near Gordon	370014 0830021 00	.44	06-11-75	1930	.03			70		18.0	Clear
114	Dee Holcomb Branch near Linefork	370024 0825928 00	.38	04-30-75	1940	.50	34	.8	135	7.7	17.0	Muddy, 1/4 inch visibility, surface mined 1974
				06-11-75	1940	.07			253		20.0	Clear
				06-12-75	1350	.22			168	7.5	20.5	Muddy, 1 inch visibility
				08-19-75	1845	.01	36	1.8	330	8.3	27.0	
115	Limestone Branch near Linefork	370031 0825856 00	.11	06-11-75	2000	.2			194	8.0	16.5	Clear
				06-12-75	1410	.25			174	7.6	16.5	Clear
				08-19-75	1915	.02	12	1.0	242	8.2	21.5	
116	Big Branch (Bugg Holcolm Branch) near Linefork	370034 0825852 00	.30	06-11-75	1945	.03			203		19.5	Clear
				06-12-75	1425	.12			157	7.7	21.0	Muddy, 2 inches visibility
				08-19-75	1925	.01			281	8.4	24.5	
117	Jerd Holcomb Branch near Linefork	370046 0825826 00	.27	06-11-75	2010	.05			80		19.0	Clear
				06-12-75	1450	.13			67	7.7	19.0	Clear
				08-19-75	1945	.01	15	2.0	145	8.5	22.5	Sampled outflow from pipe, stream was dry
118	Line Fork above Dry Fork at Linefork	370118 0825732 00	23.4	04-30-75	1745		19	1.1	122	8.2	17.5	Muddy, 3 inches visibility
				06-11-75	2025	.7	30	1.8	189	8.0	20.0	Clear
				06-12-75	1500				150	7.7	20.0	Muddy, 1/4 inch visibility
119	Dry Fork at Linefork	370128 0825725 00	3.14	04-30-75	1720	1.8	18	1.2	89	7.7	18.0	6 inches visibility
				08-19-75	1810	.17	25	5.6	215	8.5	25.0	
120	Ingram Branch at Linefork	370224 0825756 00	3.25	04-30-75	1700	2.5	28	1.0	124	7.7	19.0	Silty, 2 inches visibility
121	Line Fork above Defeated Creek at Defeated Creek	370313 0825921 00	33.70	08-19-75	1735		48	5.1	230	8.5	25.0	
122	Defeated Creek at mouth	370313 0825921 00	7.07	04-30-75	1625	6.5	44	1.1	171	8.0	18.0	Murky, 8 inches visibility
				08-19-75	1715	.7	62	5.8	270	8.0	27.5	
123	Big Branch at Skyline	370439 0825901 00	3.42	04-30-75	1545	4.0	69	.9	214	8.1	19.5	Clear
				08-19-75	1635	.7	85	1.7	253	8.3	25.0	
124	Whitaker Branch near Skyline	370510 0825935 00	1.02	04-30-75	1515	6.8	28	1.0	109	8.0	19.0	Clear
				06-12-75	1310	1.2			180	7.1	19.5	Muddy, 1/2 inch visibility
125	Turkey Creek at Hallie	370601 0830103 00	7.90	04-30-75	1430	6.0	13	1.9	66	7.9	19.5	Murky, 4 inches visibility
				08-19-75	1555		18	3.9	100	8.7	29.0	1/2 inch visibility
126	Long Branch at Hallie	370626 0830136 00	1.24	04-30-75	1400	.9	24	1.2	95	7.9	17.5	Muddy, 2 inches visibility

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
127	Campbell Branch at Hallie	370642 0830136 00	0.91	04-30-75	1335	1.8	17	0.9	78	7.3	16.5	Muddy, 3 inches visibility
128	Muriel Branch near Hallie	370705 0830145 00	.38	04-30-75	1315	.11			110	7.3	16.0	Clear
129	Line Fork Unnamed Tributary	370722 0830309 00	.012	02-12-75	1140	.01			60		6.5	6 inches visibility
	No. 1 near Ulvah			02-27-75	1640	.001			130		6.0	Clear
130	Line Fork at Ulvah	370724 0830310 00	64.0	06-11-74	1035		35		202	8.6	20.5	
				01-16-75	1315		26	2.4	124		2.5	
				02-12-75	1125		20	1.9	81		7.5	Muddy
				02-27-75	1615		28	2.4	140	7.8	10.0	12 inches visibility
				04-30-75	1125		25	1.3	122	8.0	17.0	Murky, 6 inches visibility
				07-10-75	1450	1.2	38	6.6	245	7.6	27.0	5 inches visibility, small fish
				08-19-75	1525		31	2.8	135	8.3	27.0	Zero visibility, muddy, brown
131	Line Fork Unnamed Tributary	370726 0830309 00	.007	02-12-75	1140	.1	37	2.1	150		7.0	6 inches visibility
	No. 2 near Ulvah			02-27-75	1630	.002			225		11.0	Clear
132	Line Fork Unnamed Tributary	370728 0830310 00	.006	02-12-75	1140	.1			103		6.5	6 inches visibility
	No. 3 near Ulvah			02-27-75	1635	.002			192		8.5	Clear
133	Bull Creek at Cornettsville	370822 0830357 00	6.33	02-27-75	1700	3.5	24	1.0	101	7.5	7.5	18 inches visibility
134	Blair Fork (Head of	370142 0830401 01	.58	02-25-75	1915	.35	160	10	440		8.0	Clear, clean
	Leatherwood C) at Tilford			06-11-75	1425	.21			495	7.9	19.0	Clear
135	Blair Fork Unnamed	370142 0830401 00	.51	02-25-75	1910	1.0			343		9.5	Clear, clean
	Tributary No. 1 at Tilford			06-11-75	1415	.33			456		17.0	Murky
136	Jim Polly Branch at Tilford	370145 0830411 00	.38	02-25-75	1930	.33			87		7.0	Murky, 9 inches visibility
137	Blair Fork Unnamed	370133 0830435 00	--	06-11-75	1355	.17	140	1.9	450	8.0	17.5	Clear, mine drainage, coal sand
	Tributary No. 2 at Tilford											
138	Blair Fork above Horn	370144 0830508 00	1.99	02-25-75	1855	1.8			370		9.0	Murky, 3 inches visibility
	Branch at Delphia											
139	Horn Branch at Delphia	370145 0830509 00	.67	02-25-75	1850	.25	8.7	1.2	37		8.5	Murky, 9 inches visibility
140	Barkcamp Branch (Head of	370128 0830518 00	.90	02-25-75	1840	1.2			343		9.5	Almost clear, 8 inches visibility
	Whitaker F) at Delphia											
141	Ax Handle Branch at Delphia	370128 0830519 00	.35	02-25-75	1835	.06			76		7.5	Clear, clean
142	Beech Rock Branch at Delphia	370214 0830550 00	.38	02-25-75	1810	.2	13	.9	47		7.0	Clear, clean
143	Stony Fork near Delphia	370148 0830707 00	3.97	02-25-75	1755	3.5			195		7.5	Murky, 6 inches visibility
144	Oldhouse Branch near Delphia	370152 0830720 00	1.50	02-25-75	1740	1.7			253		9.0	Clear, 10 inches visibility
145	Lynn Fork near Leatherwood	370220 0830739 00	2.85	02-25-75	1720	.4			232		9.0	Clear, 18 inches visibility
146	Leatherwood C above Clover	370245 0830735 00	15.3	06-11-74	1135				377	8.8	22.0	
	Fork near Leatherwood			02-25-75	1705	10	67	1.8	243		10.0	Murky, 8 inches visibility
				06-11-75	1325	5.4			313	8.7	21.5	Clear
147	Clover Fork near	370256 0830823 01	3.91	02-25-75	1540	2.6	64	3.1	256		9.0	Black and murky,
	Leatherwood											3 inches visibility
				06-11-75	1310	1.0			342	8.2	19.5	Clear

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
148	Right Fork Clover Fork near Leatherwood	370256 0830823 00	1.93	02-25-75	1535	2.3	95	1.3	372		9.5	Silty, 6 inches visibility
149	Clover Fork at mouth near Leatherwood	370252 0830738 00	6.15	06-11-74	1130				372	8.9	20.0	
				02-25-75	1700	5.0			320		9.5	Dark and murky, 4 inches visibility
150	Beech Fork near Slemp	370403 0830723 00	3.83	02-25-75	1510	2.7			87		10.0	Silty, 2 inches visibility
151	Owens Branch at Slemp	370447 0830648 00	2.82	02-25-75	1455	1.3			110		8.5	Clear, 9 inches visibility
152	Beehive Branch at Slemp	370452 0830625 00	4.12	02-25-75	1425	1.3			83		10.0	Murky, 4 inches visibility
				06-11-75	1250	.22			133		21.0	3 inches visibility
153	Puncheoncamp Branch at Slemp	370526 0830626 00	.88	02-25-75	1440	.55			90		9.0	Clear, 5 inches visibility
154	Deephole Branch near Daisy	370603 0830518 00	1.23	06-11-75	1215	.08	23	1.8	128		20.0	Clear
155	Hicks Branch at Daisy	370647 0830549 00	1.06	02-25-75	1410	.65			77		9.0	
156	Right Fork Hicks Branch at Daisy	370648 0830549 00	1.15	02-25-75	1405	.50			76		10.0	Murky, 5 inches visibility
157	Leatherwood C above Little Leatherwood C at Daisy	370716 0830519 00	41.4	01-16-75	1350		44	1.6	170		3.5	Silt on rocks
				02-12-75	1055				90		7.5	Muddy, 1 inch visibility
				02-25-75	1200	22	53	2.6	220		6.5	Murky, 4 inches visibility
				02-27-75	1735				227	8.3	10.5	18 inches visibility
				06-11-75	1130	15	64	2.6	278	7.5	21.5	12 inches visibility, clear
				07-10-75	1355		77	3.9	310	7.3	26.0	2 inches visibility, small fish
158	Little Leatherwood C above Straight F at Wentz	370455 0830355 00	2.72	02-25-75	1305	1.4			115		6.0	Gray silt, 1/2 inch visibility
159	Straight Fork Little Leatherwood C at Wentz	370455 0830354 00	1.81	02-25-75	1300	1.3			175		9.0	Murky, 3 inches visibility
160	Andy Branch at Wentz	370518 0830334 00	.29	02-25-75	1330	.17			82		7.5	Clear
161	Bent Branch near Wentz	370606 0830339 00	.29	02-25-75	1340	.25			70		9.5	Murky, 3 inches visibility
162	Little Leatherwood Creek at Daisy	370717 0830516 00	8.19	01-16-75	1400	7.0			106		4.0	
				02-12-75	1100				78		7.0	Muddy, yellow
				02-25-75	1220	4.7	26	2.4	126		6.5	Murky, 3 inches visibility
				02-27-75	1745				126	8.1	9.5	Murky
				06-11-75	1150	.83			180	7.7	20.5	Muddy, 2 inches visibility
				07-10-75	1350	.16			250	7.8	25.5	3 inches visibility
163	Bear Branch near Cornettsville	370807 0830553 00	.77	02-27-75	1800	.28	11	.3	45	7.6	6.5	Clear and clean
164	Campbell Branch near Cornettsville	370824 0830559 00	.73	02-27-75	1855	.22			73		6.0	
165	Schoolhouse Branch near Cornettsville	370848 0830550 00	.29	02-27-75	1815	.08			37		7.5	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
166	Dykes Branch near Fusonia	370917 0830520 00	0.72	02-27-75	1845	0.28			105		7.0	
167	Fort Branch near Fusonia	370929 0830508 00	1.35	02-27-75	1910				97		6.0	Murky, 6 inches visibility
				08-20-75	1720	.01	18	7.4	302	8.3	24.0	
168	Big Branch at Fusonia	371031 0830230 00	.47	02-24-75	1755	.5			88		9.5	Clear
169	Big Branch Unnamed Tributary No. 1 near Fusonia	371030 0830230 00	.27	02-24-75	1800	.3	22	1.8	61		9.5	Clear
170	Firescald Branch near Fusonia	371033 0830238 00	.33	02-24-75	1810	.2			145		10.0	Murky, 4 inches visibility
171	Puncheoncamp Branch near Fusonia	371025 0830323 00	.25	02-24-75	1820	.2			230		7.5	
				07-25-75	1535	.02	82	0.8	210	8.1	21.5	
				08-20-75	1615	.01	94	1.2	230	7.3	23.0	
172	Big Branch above Dixon Branch near Fusonia	371024 0830358 00	2.11	07-25-75	1510	.05			315	8.0	22.0	
173	Dixon Branch at Head (Puddle) near Fusonia	370933 0830307 00	--	08-20-75	1920	.000	6,000	2.6	5,720	2.5	29.0	Red color
174	Dixon Branch near Fusonia	371025 0830359 00	.54	02-24-75	1840	.65			455		8.0	Silty, 1 inch visibility
				08-20-75	1650	Dry						
175	Hurt Fork near Fusonia	371036 0830424 00	.48	02-24-75	1900	.30			110		8.0	Clear
176	Big Branch Unnamed Tributary No. 2 at Fusonia	371031 0830450 00	.17	02-24-75	1910	.07			99		8.5	Clear
177	Big Branch Unnamed Tributary No. 3 at Fusonia	371024 0830504 00	.29	02-24-75	1915	.08			60		8.0	Clear
178	Big Branch at Fusonia	371023 0830525 00	4.23	02-12-75	1030		32	1.2	100		7.0	Muddy, 3 inches visibility
				02-24-75	1925	3.5	52	2.3	170		9.0	Murky, 5 inches visibility
				02-27-75	1830	.65			172	7.3	8.5	
				07-25-75	1430	.3	95	5.9	340	8.0	23.0	
				08-20-75	1705		120	9.5	435	8.6	30.5	
179	Middle Fork Maces C (Head of Maces C) near Vicco	371012 0830851 00	8.82	12-19-74	1150				63		5.0	Clear
				07-25-75	1625	.13	22	102	163	7.4	25.5	
180	Left Fork Maces Creek above Middle Fork near Viper	371008 0830843 00	6.55	12-19-74	1140				75		5.0	Clear
181	Left Fork Maces Creek above Right Fork at Viper	371050 0830858 00	15.8	12-19-74	0920				77		4.0	Slightly murky
				01-16-75	1430	13	15	1.6	75		4.0	
				02-12-75	0950		12	1.2	55		7.0	Muddy
				06-12-75	1125				140	6.3	19.5	Muddy, 2 inches visibility
				06-12-75	2120				123	6.4	20.5	Muddy, 2 inches visibility (stage 4 inches lower than it was at 11:25
				07-10-75	1040	.78	23	5.2	190	8.2	24.5	6 inches visibility
182	Stratton Fork (Head Right Fork Maces C) at Farler	370844 0831134 00	2.50	12-19-74	1110				36		5.5	Clear

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi²)	Date	Time	Estimated discharge unless noted (ft³/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper-ature (°C)	Remarks
183	Fields Fork of Right Fork Maces Creek at Farler	370844 0831134 00	2.06	12-19-74	1110				169		5.5	Clear
184	Wells Fork of Right Fork Maces Creek at Farler	370910 0831149 00	1.20	12-19-74	1055				527		5.5	Slight yellow boy
185	Talp Hollow near Farler	370948 0831125 00	.51	12-19-74	1030	.2			284		5.0	Clear
186	Wooten Branch near Farler	370952 0831124 00	.67	12-19-74	1025	.2			498		6.0	Murky
187	Right Fork Maces Creek above Big Branch near Viper	371017 0831028 00	8.87	06-12-75	2055	2.8			360	5.6	20.5	Muddy, 1 inch visibility
188	Big Branch at Head near Viper	371043 0831108 00	--	08-21-75	1135	.01	4,200	6.2	5,000	3.1	30.0	
189	Big Branch near Viper	371018 0831029 00	.44	12-19-74	1000	.2			1,390		5.5	Yellow boy
				06-12-75	1110	.9			1,170	2.9	19.0	Muddy, 1/2 inch visibility
				06-12-75	2045	.14			1,800	2.8	18.5	Clear, yellow boy
				07-10-75	1215	.08	1,400	1.8	2,580	2.8	23.0	Yellow boy
				07-25-75	1655	.08	1,400	3.4	2,500	2.6	24.0	
190	Right Fork Maces Creek above Stillhouse B near Viper	371018 0830930 00	9.88	07-10-75	1140	.19	370	1.8	745	3.8	25.0	6 inches visibility, iron stains
191	Stillhouse Hollow at Viper	371050 0830911 00	.43	12-19-74	0950	.2			453		5.0	Slight yellow boy
				06-12-75	1030	1.3	120	.6	297	5.6	17.5	Muddy, 1/4 inch visibility
				06-12-75	2025	.22	230	.7	489	7.2	18.0	Clear
192	Right Fork Maces Creek at Viper	371051 0830900 00	10.7	12-19-74	0925				266		4.0	Slight yellow boy
				01-16-75	1440	12.0			279		4.0	
				02-12-75	1005				190		7.0	Very muddy
				06-12-75	1140				579	3.7	20.0	1 inch visibility
				06-12-75	2115				375	5.5	21.0	Muddy, 1 inch visibility
				07-10-75	1025	.3	320	2.6	640	4.3	23.0	Muddy, 1 inch visibility
193	Carr Fork above Collins Branch at May	371619 0825145 00	3.97	01-28-75	1325	5.6	16	1.4	67		9.0	Clear
				08-20-75	1330	.05	22	4.7	165	8.7	30.5	
194	Collins Branch at May	371619 0825145 01	1.45	01-28-75	1335	2.4	42	.9	144		9.5	Muddy
				08-20-75	1315	.02	140	5.0	450	8.1	29.5	
195	Nealy Branch at May	371626 0825204 00	1.52	01-28-75	1415	3.0	20	.7	75		9.5	Murky
196	Willard Branch at Pinetop	371612 0825240 00	1.01	01-28-75	1440	2.3	56	.9	182		9.5	Slightly murky
197	Mallet Branch at Pinetop	371631 0825325 00	1.62	01-28-75	1515	3.5	21	1.1	90		10.0	Clear
198	Carr Fork above Branhams Branch near Pinetop	371628 0825356 01	11.3	01-28-75	1300		26	1.2	104		8.0	Muddy
199	Branhams Branch near Pinetop	371628 0825356 00	2.04	01-28-75	1250	2.4	20	1.7	88		8.5	Clear
200	Smith Branch at Spider	371534 0825512 00	1.79	01-28-75	1545	2.5	22	.7	82		11.0	Milky white

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
201	Betty Troublesome Creek at Littcarr	371507 0825643 00	3.66	01-28-75	1610	5.0	80	20	253		11.0	Black, very silty
202	Little Carr Fork at Littcarr	371433 0825635 00	7.44	01-28-75	1630	9.5	59	14	206		10.5	Milky white
				08-20-75	1230	.15	140	57	500	8.0	30.0	
203	Breeding Creek at mouth	371320 0825844 01	5.68	01-28-75	1710	5.0	33	25	154		11.0	Murky gray
				02-12-75	1335				105		6.0	Muddy
204	Defeated Creek at Cody (03277439)	371320 0825843 00	3.35	01-28-75	1700	3.0	49	11	194		11.0	Milky white
				02-12-75	1330				120		6.0	Muddy
				08-20-75	1150	.16	84	22	365	8.7	28.5	
205	Irishman Creek at mouth	371405 0830002 00	10.0	01-28-75	1135		100	10	272		6.5	Slightly muddy
				02-11-75	1545				334		7.5	Black and silty
206	Sassafras Creek at mouth	371400 0830202 00	2.15	02-11-75	1445	1.7	154	22	350		7.0	Muddy and very dirty
				08-20-75	1445	.05	190	32	428	8.0	32.0	
207	Red Oak Branch at Sassafras	371320 0830238 00	2.04	01-28-75	1730	4			260		10.0	Murky
208	Yellow Creek at Anco	371518 0830315 00	.24	12-17-74	1515	.2			1,260		4.0	Almost clear
209	Yellow Creek Unnamed Trib No. 1 at Anco	371518 0830316 00	.073	12-17-74	1520	.3			1,330		2.5	Very dirty
210	Yellow Creek Unnamed Trib No. 2 at Anco	371443 0830333 00	.38	12-17-74	1500	.3			886		4.0	
211	Yellow Creek above Brushy Fork at Anco	371439 0830333 00	1.10	12-17-74	1445	.7			1,110		4.0	Murky gray, smells of sulfur
212	Brushy Fork Yellow Creek at Anco	371439 0830331 00	.41	12-17-74	1435	.3			448		4.5	Almost clear
213	Yellow Creek Unnamed Tributary at Wiscoal	371428 0830338 00	.14	12-17-74	1410	.05			637		5.5	
214	Sugar Branch at Wiscoal	371350 0830330 00	.24	12-17-74	1400	.1			344		5.0	Yellow boy
215	Yellow Creek at Sassafras (03277455)	371315 0830319 00	2.70	12-17-74	1310	1.2	380	32	786	4.8	4.0	Gray sediment
				01-28-75	1740	3.6	280	.7	698		11.0	Black sediment
				02-26-75	1910	1.3	390	28	790	4.9	9.0	Murky, 6 inches visibility yellow boy
				07-10-75	1720	.46			1,020	7.1	29.0	8 inches visibility, small fish
				07-24-75	1730	3.3	170	30	380	6.3	26.0	Zero visibility following cloud burst dark brown
				07-24-75	1740	5.1	280	43	550	6.3	26.0	Still raining, zero visibility, black
216	Stacy Branch at Vicco	371301 0830337 00	2.10	01-28-75	1800	2.5	260	11	576		11.0	Gray sediment
217	Montgomery Creek above Lick Fork near Kodak	371134 0830108 00	1.45	02-24-75	1650	.7			205		11.0	Silty, 2 inches visibility
218	Lick Fork Montgomery Creek near Kodak	371131 0830114 00	.68	02-24-75	1700	.6			86		12.0	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
219	Montgomery Creek Unnamed Tributary near Kodak	371145 0830135 00	0.24	02-24-75	1720	0.12			54		10.0	Clear
220	Montgomery Creek above Right Fork at Kodak	371155 0830145 01	2.63	02-24-75	1730	2.0			161		10.0	Murky, 4 inches visibility
221	Right Fork Montgomery Creek at Kodak	371155 0830145 00	.45	02-24-75	1730	.7			159		10.0	Muddy, 2 inches visibility
222	Kelly Fork Montgomery Creek at Kodak	371217 0830144 00	1.03	02-24-75	1630	.7			264		12.5	Very silty, 1/3 inch visibility
223	Montgomery Creek at mouth	371253 0830341 00	6.01	01-28-75	1815	12	48	1.5	206		10.0	Milky gray
				01-29-75	0950				206		10.0	Murky
				02-11-75	1615				226		7.5	
				02-24-75	1605	5.4	55	2.6	253		12.0	Silty, 2 inches visibility
				08-20-75	1040	.9	91	4.6	430	8.1	22.5	
224	Carr Fork at mouth	371220 0830755 00	85.5	06-11-74	0920				444	8.4	20.5	
				06-13-74	1030		140		439	8.3	20.0	
				01-16-75	1500		84	2.8	271		3.0	
				01-28-75	1015				233		5.5	Muddy
				01-28-75	1850		88	1.8	248		8.0	Muddy
				01-29-75	0930				260		8.5	Muddy
				02-11-75	1400		100	2.7	300		6.0	Muddy
				02-12-75	0925				169		7.0	Muddy, yellow
				02-24-75	1530		100	2.5	318		12.5	Muddy, 2 inches visibility
				02-27-75	1940		110	2.0	335	7.3	8.5	12 inches visibility
				07-09-75	1905		160	5.7	480	7.9	26.0	
				08-20-75	0945		140	5.2	465	8.2	23.0	1 inch visibility
225	Buffalo Branch at Fourseam	371312 0831048 00	1.45	08-21-75	1245	.06	500	35	1,500	7.6	26.0	
226	Buffalo Branch Unnamed Tributary at Fourseam	371314 0831042 00	1.07	08-21-75	1225	.05	370	4.1	820	6.4	24.0	
227	North Fork Kentucky River at Hazard (03277500)	371448 0831055 00	466	06-11-74	0830		110		381	7.7	20.5	
				01-16-75	1530	1/682	71	7.3	271		2.5	Murky
				01-27-75	1800	1/1,880			195		5.0	Muddy
				01-28-75	0950	1/1,490			208		5.5	Muddy
				01-28-75	1925	1/1,260			220		6.5	Muddy
				01-29-75	0830	1/1,110			230		8.0	Muddy
				01-29-75	1900	1/1,070			250		10.0	Muddy
				01-30-75	0830	1/1,050			256		9.0	Muddy
				02-11-75	1315	1/854	82	3.7	285		4.5	Somewhat muddy

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi²)	Date	Time	Estimated discharge unless noted (ft³/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
				02-12-75	0840	1/4,870	58	2.4	202		7.0	Very muddy
				02-13-75	0830	1/3,600			158		5.5	Muddy
				02-24-75	1450	1/630	97	3.4	342		12.5	Murky, 5 inches visibility
				02-25-75	0855	1/600			331		10.0	Muddy, 2 inches visibility
				02-26-75	0905	1/506			323		7.0	Muddy
				02-27-75	0850	1/461			316		7.0	Murky, 4 inches visibility
				02-28-75	0900	1/443	95	2.9	313	7.4	6.5	Murky, 6 inches visibility
				04-03-75	0950	1/2,270	76	2.0	261	7.6	12.0	1/4 inch visibility
				05-01-75	1620	1/794	78	2.8	273	7.7	19.0	Muddy, murky
				05-13-75	1330	1/461	92	2.7	314	8.0	19.0	16 inches visibility
				06-11-75	0945	1/200	120	4.3	440	7.5	20.5	4 inches visibility
				06-12-75	0830	1/172			450		21.0	4 inches visibility
				06-13-75	0900	1/407			403	6.8	21.0	Muddy, 1 inch visibility
				07-07-75	1820	1/124	140	6.5	405	7.3	25.0	Muddy, 1 inch visibility
228	Left Fork Upper Second Creek near Darfork	371610 0830907 00	2.05	05-13-75	1515	1.0	360	.8	850	8.0	19.5	Clear
229	Right Fork Upper Second Creek near Darfork	371610 0830907 01	1.65	05-13-75	1530	1.0	480	10	1,000	8.4	19.5	Muddy, 1 inch visibility
230	Upper Second Creek at Darfork	371632 0831112 00	5.86	01-27-75	1725	8.0	210	14	528		7.5	Almost clear
				05-13-75	1550	4.0	250	15	725	9.2	18.5	Murky, 6 inches visibility
231	Youngs Fork (Head of Lotts Creek) at Elic	371606 0830404 01	2.81	12-17-74	1640	3.0			1,130		1.0	Yellow boy
				02-28-75	1200	2.1	1,200	.5	2,000	3.2	5.5	8 inches visibility
232	Kelly Fork Unnamed Trib Kelly Fork Church	371558 0830309 00	.30	12-17-74	1615	.2			1,030		1.5	Very dirty
233	Kelly Fork Lotts Creek at Elic	371606 0830404 00	2.50	12-17-74	1635	2.0			687		1.5	Yellow boy
				02-28-75	1145	1.5			1,350	3.2	5.0	Clear, yellow boy
				07-24-75	1650	.07	860	14	1,500	3.5	27.0	Yellow boy
234	Lick Branch at Elic	371550 0830439 00	.68	12-17-74	1655	.25			801		2.5	Dirty water
235	Dickson Branch near Elic	371547 0830524 00	.80	12-18-74	1500	.3			746		5.0	Clear
236	Lotts Creek Unnamed Tributary No. 1 near Cordia	371552 0830534 00	.25	12-18-74	1430	.2			899		3.5	Clear
237	Big Fork Lotts Creek near Cordia	371602 0830536 00	1.22	12-17-74	1710	1.0			530		3.0	Dirty water
				02-28-75	1230	.65	280	14	650	7.8	7.0	Gray silt, 5 inches visibility
238	Coles Fork Lotts Creek near Cordia	371611 0830544 00	.32	12-17-74	1720	.3			1,350		2.5	Dirty water
				07-24-75	1620	.02	1,100	13	1,950	7.5	25.5	
239	Lotts Creek Unnamed Tributary No. 2 near Cordia	371607 0830548 00	.033	12-18-74	1410	.002			99		5.0	Clear

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
240	Jacks Branch at Cordia	371648 0830640 00	0.35	12-18-74	1305	0.1	1,000	2.3	1,630	6.6	2.0	Yellow boy
				02-28-75	1315	.17	1,800	5.0	2,710	3.4	7.5	Yellow boy, 3 inches visibility
				07-24-75	1555	.03	1,300	1.2	2,025	7.5	29.5	
241	Clear Fork Lotts Creek at Cordia	371702 0830708 00	1.86	12-18-74	1250	1.0			1,370		3.0	Murky
				07-24-75	1425	.39	1,200	1.5	2,000	7.6	27.0	
242	Lotts Creek Unnamed Tributary near Grigsby	371650 0830729 00	.14	12-18-74	1230	0.1			945		4.5	Clear
243	Elk Fork Lotts Creek near Grigsby	371644 0830728 00	3.15	12-18-74	1220	1.2			876		3.0	Almost clear
				07-24-75	1530	.5	830	.7	1,440	7.3	27.5	
244	Sucks Fork Lotts Creek at Grigsby	371642 0830812 00	.59	12-18-74	1150	.3			186		3.0	Clear
				07-24-75	1330	.01	99	1.1	318	7.5	24.0	Fish and crayfish observed
245	Grigsby Branch at Grigsby	371711 0830815 00	.51	12-18-74	1130	.2			844		2.5	Murky
				07-24-75	1300	.07	720	1.4	1,375	7.3	25.0	
246	Hammonds Branch at Grigsby	371718 0830900 00	.25	12-18-74	1115	.1			836		2.5	Clear
				07-24-75	1210	.03	590	1.4	1,180	7.4	24.0	Yellow boy
247	Lotts Creek above Trace Fork at Darfork	371717 0831044 00	20.1	12-05-74	1130				867		1.0	
				12-17-74	1745				771		3.0	Very dirty water
				12-18-74	1000		400	1.3	816	6.6	1.0	
				01-16-75	1600				791		4.0	
				01-27-75	1705		340	3.6	694		6.5	Muddy
				02-13-75	0915		350	1.1	680		4.5	Yellow, 3 inches visibility
				02-28-75	1030		600	1.2	1,300	3.6	3.5	Yellow, 3 inches visibility
				04-03-75	1040		340	1.4	914	4.7	8.5	Yellow, 1/4 inch visibility
				05-01-75	1705		410	.9	801	4.9	20.0	Muddy, brown, 1/2 inch visibility
				05-13-75	1420				1,040	4.0	18.5	Orange, 6 inches visibility
				06-13-75	1025				1,020	5.8	19.0	Yellowish, 6 inches visibility
				07-09-75	1625	1.7			1,180	7.8	26.0	
				07-24-75	1125	1.0	830	2.2	1,510	7.5	26.5	Silty
248	Trace Fork Unnamed Tributary at Bulan	371811 0830953 00	1.72	12-18-74	1615				412		4.5	Black
249	Trace Fork Lotts Creek Ab Jakes Branch at Bulan	371752 0831006 00	2.63	12-18-74	1600				458		5.0	Black
250	Jakes Branch at Bulan	371751 0831005 00	2.92	12-18-74	1555				886		4.0	Gray

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper- ature (°C)	Remarks
251	Trace Fork Lotts Creek at Darfork	371718 0831045 00	6.40	12-05-74	1125				649		2.0	
				12-17-74	1750				641			
				12-18-74	1020				682	6.7	2.5	
				01-16-75	1600				567		6.0	
				01-27-75	1700				470		8.0	Dark and silty
				02-13-75	0920				444		5.5	Black, 2 inches visibility
				02-28-75	1045	3.3	250	3.3	623	7.0	5.0	Gray, 4 inches visibility
				04-03-75	1050				523	6.6	8.0	Dark, 2 inches visibility
				05-01-75	1710				615	6.6	20.0	Muddy gray, 1/2 inch visibility
				05-13-75	1425				598	7.1	18.5	Black gray, 2 inches visibility
				06-13-75	1015				660		17.5	Gray, 4 inches visibility
				07-09-75	1645	.8	350	6.7	850	7.8	23.5	
252	Big Creek above Browns Fork near Typo	371536 0831455 00	13.5	12-06-74	0920				544		0.0	
253	Browns Fork Big C above Curly Fork at Browns Fork	371454 0831422 00	3.89	12-06-74	0905				653		0.0	Yellowish, muddy
254	Curly Fork Browns Fork at Browns Fork	371455 0831421 00	1.24	12-06-74	0910				361		0.5	Clear
255	First Creek Unnamed Tributary at Harveyton	371849 0831138 00	--	02-25-53	----				688	6.6	11.5	The year 1953 is correct
				01-30-75	1010	.1	310	1.1	800		13.0	Clear
				07-23-75	1615	.1	360	1.1	845	7.6	17.5	
256	First Creek at Clemons	371741 0831401 00	3.54	12-05-74	1300				581		5.5	
				05-13-75	1615	3.3	240	2.7	596	8.8	21.0	Clear
257	First Creek at Typo	371633 0831517 00	5.76	05-13-75	1650	4.0	205	3.2	530	8.7	19.5	Clear
258	Lower Second Creek at Butterfly	371715 0831610 00	3.45	05-13-75	1730	2.0	180	1.8	430	7.9	18.0	Clear
259	Big Willard Creek at Busy	371628 0831722 00	9.11	12-06-74	0955				210		.5	Dirty
260	Little Willard Creek at Busy	371633 0831716 00	1.66	12-06-74	1005				291		1.0	
261	Forked Mouth Creek at Yerkes	371650 0831834 00	3.47	12-06-74	1015				86		1.0	
262	Jake Campbell Branch near Napfor	371837 0831740 00	.95	05-16-75	1255	1.1			301		16.5	2 inches visibility
263	Sam Campbell Branch near Napfor	371859 0831727 00	2.25	05-16-75	1305	2.2	120	1.1	330	7.7	17.0	1 inch visibility
264	Napier Branch at Napfor	371856 0831840 00	1.99	05-16-75	1220	4.2	38	.5	130	7.6	16.0	3 inches visibility, murky
265	Meadow Branch at Napfor	371828 0831915 00	.75	05-16-75	1350	1.0			103		16.0	3 inches visibility
266	Campbell Creek at Krypton	371831 0832019 00	2.49	12-06-74	1040				93		2.5	
				05-16-75	1130	6.0			90	7.6	15.5	4 inches visibility, muddy

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper-ature (°C)	Remarks
267	Lick Branch at Krypton	371854 0832119 00	2.77	05-16-75	1410	4.5			73		16.0	12 inches visibility
268	Oldhouse Branch near Chavies	371953 0832135 00	.61	05-16-75	1415	1.2			226		17.0	2 inches visibility, muddy
269	Eversole Creek at Chavies	372031 0832115 00	1.60	05-16-75	1430	3.3			195		18.0	12 inches visibility
270	Grapevine Creek above Clear Fork at Manuel	372048 0831717 00	4.07	05-16-75	1010	6.0			330		16.0	4 inches visibility, muddy
271	Clear Fork Grapevine Creek at Manuel	372047 0831718 00	.87	05-16-75	1015	1.2			230		15.5	8 inches visibility, murky
272	Grapevine Creek at Chavies	372119 0832104 00	13.9	12-06-74	1105				222		1.5	
				05-16-75	1040		45	1.3	152	7.9	15.0	3 inches visibility, muddy
273	Strong Branch at Barwick	372134 0832220 00	1.88	05-16-75	1515	4.4			106		17.5	4 inches visibility, muddy
274	Millers Branch at Barwick	372138 0832237 00	1.02	05-16-75	1530	1.7			88		17.5	9 inches visibility, murky
275	Bush Branch at Altro	372248 0832312 00	2.39	05-16-75	1600	4.0			99		19.0	8 inches visibility, murky
276	Wolf Creek at Wolf Coal	372354 0832245 00	2.86	04-02-75	1855	3.2	15	1.2	75	7.3	15.0	18 inches visibility
				05-16-75	1620	8.9			81		18.0	12 inches visibility clear
277	Caney Creek above Orchard Branch near Wolf Coal	372359 0832134 01	4.59	05-14-75	1245	4.0	41	1.1	113	8.3	19.0	24 inches visibility, surface mined about 1974
278	Orchard Branch near Wolf Coal	372359 0832134 00	.17	05-14-75	1240	.06			76	7.6	15.5	Murky, 6 inches visibility, much sediment
279	Georges Branch at Whick	372521 0832240 00	2.27	04-02-75	1830	2.6	21	.9	76	7.2	15.0	15 inches visibility
				07-22-75	0955	.05	55	84	213	8.0	23.0	Small fish, raw sewage
280	Fishtrap Branch at Whick	372525 0832228 00	2.51	07-22-75	1050	.01	18	1.6	98	7.5	23.5	
281	North Fork Kentucky River Unnamed Tributary at Little	372611 0832221 00	.016	07-22-75	1140	<.01	6.4	2.3	110	6.4	25.0	
282	John Littles Branch at Little	372627 0832137 00	1.98	07-22-75	1240	.06	15	1.3	213	6.8	23.0	
283	Lick Branch at Copland	372623 0832304 00	1.88	04-02-75	1810	1.4	15	1.1	66	7.4	16.5	12 inches visibility
284	Howards Creek near Copland	372806 0832249 00	2.83	04-02-75	1730	3.1	15	.9	55	6.7	16.5	Murky, 5 inches visibility
285	Big Branch at Haddix	372838 0832135 00	3.29	08-22-75	1020	.03	27	1.2	115	8.1	22.0	
286	Left Fork Troublesome Creek at Hindman	372010 0825855 00	12.6	12-04-74	1630		16	3.6	127	7.4	5.0	
				02-12-75	1430		14	2.8	61		6.0	Muddy, 3 inches visibility
287	Right Fork Troublesome at Brinkley	371855 0825653 01	4.47	12-04-74	1715				126		4.5	
288	Trace Fork Right Fork Troublesome C at Brinkley	371855 0825653 01	1.56	12-04-74	1720				204		4.5	
289	Right Fork Troublesome Creek at Hindman	372004 0825837 00	10.9	12-04-74	1530		28	4.6	173	7.7	5.0	
				02-12-75	1445				88		6.0	Muddy
290	Odgen Branch at Hindman	372012 0830022 00	2.00	12-05-74	0845				254		0.5	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
291	Big Branch near Carrie	371936 0830053 00	5.96	12-05-74	0915				311		0.0	
				02-12-75	1515				187		6.0	Muddy
292	Big Branch Unnamed Tributary near Carrie	371936 0830053 01	.091	02-12-75	1510	0.5	13	1.4	51		6.0	Clear
293	Mill Branch at Carrie	371930 0830203 00	2.66	12-05-74	0940				318		0.5	
294	Walkers Branch at Carrie	371949 0830226 00	1.56	12-05-74	0955				219		0.5	
				02-12-75	1535				177		6.0	Muddy
295	Lick Branch at Carrie	372009 0830231 00	.96	12-05-74	1005				211		1.0	
296	Montgomery Creek at Emmalena	372009 0830347 00	3.95	12-05-74	1020				239		0.0	
				02-12-75	1550				160		6.0	Muddy
297	Troublesome Creek above Clear Creek at Fisty	372004 0830605 00	49.7	12-05-74	1050				196		1.5	
298	Clear Creek above Shop Hollow at Fisty	372002 0830605 00	8.56	12-05-74	1030				363		1.0	
				02-12-75	1605				233		6.0	Muddy
299	Shop Hollow at Fisty	372004 0830604 00	.39	12-05-74	1035				132		1.0	Clear
				02-12-75	1600	1.8	30	1.4	99		6.0	
300	Combs Branch at Dwarf	372014 0830740 00	3.29	12-05-74	1105				410		1.5	
				02-12-75	1625	8.0	120	3.0	331		6.5	Murky, 4 inches visibility
				02-28-75	1400	2.1			610	8.1	8.0	"Soapy," 9 inches visibility
301	Pigeonroost Branch at Ary	372159 0830903 00	2.82	12-05-74	1650				490		2.5	
302	Balls Fork Troublesome Creek at Soft Shell	372357 0825651 00	3.43	06-10-75	1500	2.6	5.3	1.2	54	7.8	17.5	8 inches visibility
303	Wiley Branch at Soft Shell	372357 0825651 01	4.23	06-10-75	1515	1.6	12	2.8	108	7.4	18.5	1 inch visibility
304	Bucks Branch at Soft Shell	372407 0825725 00	.62	06-10-75	1550	.22	11	1.4	55	7.6	17.5	Clear
305	Mill Branch at Yellow Mountain	372417 0825804 00	1.67	06-10-75	1635	.09			48		17.5	24 inches visibility, clear
306	Little Branch at Yellow Mountain	372416 0825805 00	.57	06-10-75	1640	.20			109		17.0	5 inches visibility
307	Terry Branch near Yellow Mountain	372319 0825804 00	2.40	06-10-75	1805	.67	10	1.4	55	7.4	18.0	6 inches visibility
308	Knob Bottom Branch near Vest	372344 0825930 00	.70	06-10-75	1900	.27	8.6	.4	46	7.6	16.5	18 inches visibility
309	Trace Branch at Vest	372344 0830022 00	1.76	06-10-75	1930	.90	120	1.3	341	7.3	18.5	5 inches visibility
310	John S. Combs Branch at Vest	372400 0830054 00	1.35	06-10-75	1945				59		17.5	6 inches visibility
311	Laurel Fork near Vest	372405 0830227 00	2.20	06-10-75	2005	.67	8.5	.7	47	7.7	17.0	1 inch visibility
312	Balls Fork Troublesome Creek near Talcum	372224 0830543 00	31.9	06-10-75	2045				80	7.7	19.0	2 inches visibility
313	Big Branch near Talcum	372223 0830542 00	5.94	06-10-75	2025	3.0	110	1.1	305	7.4	18.5	1 inch visibility
314	Rockhouse Branch at Talcum	372224 0830702 00	.24	06-13-75	1120	.03			875	5.8	19.5	Muddy, 1/4 inch visibility
315	Lick Branch at Ary	372310 0830821 00	3.23	06-10-75	2105	2.1			610		19.0	1/4 inch visibility, muddy
				06-13-75	1150	1.7	220	4.6	615	6.7	21.5	Clear

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper- ature (°C)	Remarks
316	Balls Fork at mouth	372245 0830851 00	45.4	06-12-74	1725		60		233	8.3	21.5	
				12-05-74	1640				149		2.5	
				01-30-75	1115		46	1.4	151		7.5	Muddy
				02-12-75	1650				110		6.0	Muddy
				02-28-75	1420		59	1.8	187	6.7	6.0	9 inches visibility
				05-15-75	1650				160	7.9	18.0	2 inches visibility
				06-10-75	2115		79	2.0	230	7.4	19.0	1 inch visibility
				06-13-75	1210				208	6.6	21.5	Yellowish, 5 inches visibility
				07-09-75	1040		130	4.4	405	8.1	24.5	12 inches visibility
317	Williams Branch at Ary	372307 0830933 00	1.38	05-15-75	1635	1.0			228	7.8	18.0	1 inch visibility, muddy
				06-13-75	1225	.94			350	6.5	24.0	Muddy, 1/4 inch visibility
318	Mac and Nellie Branch near Stacy	372322 0831125 00	1.31	05-15-75	1605	.5			69	7.6	17.5	2 inches visibility, muddy
319	Rowdy Branch at Stacy	372353 0831236 00	1.26	12-05-74	1355				233		5.0	
320	Clemons Fork Buckhorn Creek at Camp Robinson	372719 0830957 00	6.00	05-15-75	1500	4.5			50	7.7	16.0	Clear
321	Lewis Fork Buckhorn Creek at Noble	372717 0831038 00	1.56	05-15-75	1445	1.7			56	7.8	16.0	8 inches visibility, murky
322	Buckhorn Creek above Long Fork at Noble	372649 0831124 00	30.1	12-05-74	1440		11	.5	44	7.1	3.0	
				01-30-75	1215	43	11	.7	43		6.5	Clear
				02-12-75	1730		11	.6	37		6.0	Murky, 5 inches visibility
				02-28-75	1535	45	11	.9	45	7.0	6.5	Clear, clean
				05-15-75	1400	18	9.6	.7	45	7.7	16.0	24 inches visibility
				06-13-75	1335				48	7.1	19.0	Murky, 10 inches visibility
				07-09-75	1315		9.9	1.6	89	8.0	26.0	
323	Long Fork Buckhorn Creek at Noble	372647 0831122 00	8.15	12-05-74	1430				161		3.0	
				01-30-75	1205	8.0			229		6.0	Murky
				02-12-75	1725				177		5.5	Muddy
				02-28-75	1525	5.1	84	1.0	243	6.8	5.5	Clear, clean
				05-15-75	1340	7.0	77	.9	240		15.5	Clear
				06-13-75	1320	5.6			271	6.7	19.5	Murky, 8 inches visibility
				07-09-75	1250	.67	180	1.2	475	7.8	24.0	9 inches visibility, a dam gave way within previous 2 months
324	Bear Branch near Noble (03278000)	372702 0831143 00	2.21	12-05-74	1420				155		3.5	
				01-30-75	1155	1.3			208		6.0	Almost clear
				02-12-75	1720				120		6.0	Muddy
				02-28-75	1500	1.6			220	6.9	7.5	Clear, clean
				05-15-75	1240	2.5	47	.9	226	7.9	15.0	Clear
				06-13-75	1300	5.1			138	6.7	17.5	Murky, 5 inches visibility
				07-09-75	1150	.2	92	1.2	405	8.1	22.5	5 inches visibility, crayfish present

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper-ature (°C)	Remarks
325	Laurel Fork Buckhorn Creek	372627 0831230 00	3.77	12-05-74	1545				40		5.0	
	near Noble			05-15-75	1150	3.3	11	0.5	49	7.6	15.0	Clear
326	Fugate Fork Troublesome Creek at Hardshell	372732 0831424 00	2.95	05-15-75	1100	2.0	59	2.4	245	7.8	15.5	Murky
327	Caney Creek at Hardshell	372730 0831547 00	4.06	05-15-75	1745				162	7.9	17.5	1/2 inch visibility
328	Nix Branch at Hardshell	372753 0831556 00	2.08	05-15-75	1025	.9	77	.6	267	7.8	15.0	Clear
329	Russell Branch	372832 0831610 00	3.37	05-15-75	0955	2.5	45	.6	182	7.7	15.0	Clear
	near Hardshell			05-15-75	1800				222	8.2	16.5	1/4 inch visibility
330	Barge Creek at Clayhole	372750 0831652 00	2.00	05-15-75	1820	4.0			149	7.8	17.5	1/4 inch visibility
331	Riley Branch at Clayhole	372754 0831723 00	1.96	05-15-75	0935	1.3	11	.7	113	7.7	15.5	Clear
				05-15-75	1840	1.7			120	8.1	18.0	1 inch visibility
332	Hays Branch at Lost Creek	372858 0831845 00	1.14	05-15-75	0915	.6			99	7.4	15.5	Clear
333	Troublesome Creek above	372840 0831921 00	202	06-12-74	1615		76		258	8.3	22.0	
	Lost Creek			12-06-74	1200				144		2.0	
				01-16-75	1640		50	1.4	164		2.0	
				01-30-75	1300		58	1.7	186		8.5	Very muddy
				02-12-75	1815		50	1.7	157		6.5	Muddy
				02-13-75	1015		37	1.3	125		5.0	Muddy
				02-24-75	1330		74	1.7	223		11.0	Muddy, 1/2 inch visibility
				02-28-75	1640		69	2.4	221	7.0	7.5	16 inches visibility
				04-02-75	1945		58	1.5	166	7.6	12.0	4 inches visibility
				05-14-75	1025		42	1.3	168	7.7	17.0	6 inches visibility
				06-13-75	1420				220	6.4	21.0	Muddy, 2 inches visibility
				07-08-75	1130		180	15	439	7.3	25.0	Muddy, 1 inch visibility
334	Lost Creek above Harris	372016 0831057 01	.60	12-18-74	1645	.25			269		5.0	Clear
	Branch near Harveyton			05-14-75	1800	.3			375	8.2	19.5	
335	Harris Branch near	372016 0831057 00	.66	12-18-74	1640	.5			794		8.5	Yellow
	Harveyton			05-14-75	1755	.3			774	7.1	20.0	
336	Lost Creek below Harris Branch near Harveyton	372018 0831058 00	1.26	07-23-75	1455	.09			715	7.3	25.0	
337	Laurel Fork Lost Creek	372041 0831123 00	.92	05-14-75	1740	1.5			382	7.3	19.5	Clear
	near Dice			07-23-75	1415	.08	200	1.6	545	7.2	27.0	Fish and crayfish observed
338	Maple Branch near Dice	372052 0831136 00	.24	07-23-75	1355	.11	150	3.9	365	6.8	25.5	
339	Rube Fork Lost Creek near	372113 0831125 00	.39	05-14-75	1715	.20			1,320	5.9	16.5	Clear
	Dice			07-23-75	1315	.04	830	.8	1,450	4.8	20.0	
340	Rock Fork Lost Creek near	372125 0831127 00	.43	05-14-75	1650	.17			1,020	5.0	18.5	Clear
	Dice			07-23-75	1245	.06	740	1.9	1,390	5.0	22.0	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
341	Bowmans Branch near Dice	372134 0831201 00	0.16	07-23-75	1130	0.03	610	2,400	8,000	3.2	23.0	
				03-08-77	1820	.03	230	18	459	4.5		The year 1977 is correct
342	Lewis Collins Branch near Dice	372130 0831220 00	.24	07-23-75	1205	.02	170	17	395	6.7	23.0	
343	Low Gap Branch at Dice	372157 0831313 00	.26	07-23-75	1035	.002	52	7.3	345	7.6	24.0	
344	Lost Creek above Sixteen-mile Creek at Dice	372150 0831339 00	5.81	12-05-74	1330				536		3.0	
				05-14-75	1615	4.5	300	1.6	655	7.4	20.5	Clear
345	Strong Branch near Dice	372056 0831320 00	.60	05-14-75	1900	.3			270	6.6	19.5	2 inches visibility, muddy
346	Brushy Branch at Dice	372131 0831331 00	.29	05-14-75	1845	.09			297	6.3	16.0	Clear
347	Sixteenmile Creek at Dice	372142 0831338 00	4.68	12-05-74	1340				283		2.8	
				05-14-75	1830	5.0	140	1.1	362	7.6	19.5	30 inches visibility
				07-23-75	1105	.44	190	1.9	475	7.8	24.0	
348	Big Branch near Dice	372232 0831410 00	.62	05-14-75	1555	.67			380		22.0	Clear
				07-23-75	1010	.08	260	1.4	585	7.6	23.5	
349	Francis Branch near Ned	372332 0831454 00	.28	07-23-75	0930	<.01	22	4.5	245	6.7	22.5	
350	Lost Creek above Tenmile Creek at Ned	372355 0831610 00	16.8	05-14-75	1520	15	210	1.3	482	7.6	20.0	16 inches visibility, silt on bottom
351	Tenmile Creek above Rockhouse Fork at Engle	372316 0831624 00	2.06	05-14-75	1950	.67			257	7.2	21.6	Clear
				05-16-75	0910	3.3			202		15.5	4 inches visibility, muddy
352	Rockhouse Fork above Hollybush Branch at Engle	372307 0831611 01	1.98	05-16-75	0935	2.9			296		15.5	1 inch visibility, muddy
353	Hollybush Branch at Engle	372307 0831611 00	1.06	05-16-75	0930	2.0			428		16.0	4 inches visibility, muddy
354	Rockhouse Fork Tenmile Creek at Engle	372316 0831623 00	3.16	05-14-75	1945	1.7			456	6.9	20.0	Slightly murky, yellow sediment
				05-16-75	0915	8.3			355		16.0	2 inches visibility, muddy
355	Tenmile Creek at Ned	372355 0831610 01	5.66	05-14-75	1935	5.8	140	2.0	390	7.6	21.5	Clear
356	Cockrell Fork Lost Creek at Ned	372443 0831617 00	3.00	05-14-75	1455	2.2	51	1.0	215	7.7	22.0	Murky, 6 inches visibility silt on bottom, new surface mine
				07-22-75	1830	.08	86	3.4	380	7.6	32.0	
357	Fugate Fork Lost Creek at Ned	372458 0831639 00	.94	05-14-75	1440	.2			307		24.0	Murky, fresh silt on bottom, new surface mine
				07-22-75	1715	.03	120	2.9	430	7.5	32.0	
358	Campbell Branch near Ned	372520 0831736 00	.36	05-14-75	1420	.1			73		20.0	Clear
359	Ganderbill Branch at Watts	372617 0831811 00	.87	05-14-75	1400	.67			115		21.0	Murky, 12 inches visibility, new surface mine
				07-22-75	1620	<.01	26	5.4	240	8.2	34.5	
360	Macintosh Fork Leatherwood Creek at Head	372421 0831956 00	.011	05-14-75	1330	.002	230	2.1	765	7.9	25.5	Clear
361	Leatherwood Creek at Watts	372632 0831844 00	5.70	05-14-75	1200	3.3	19	1.0	113	7.8	15.5	Murky, surface mined about 1972
				07-22-75	1545	.07	28	2.2	250	7.5	29.0	
362	Mill Branch near Lost Creek	372740 0831900 00	1.43	05-14-75	1110	.5	15	.7	74	7.6	14.0	Clear
				07-22-75	1440	.07	25	8.7	210	7.2	27.5	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper-ature (°C)	Remarks
363	Lost Creek at mouth	372840 0831921 00	42.7	12-06-74	1155				280		1.5	
				01-16-75	1645				271		3.3	
				01-30-75	1310				302		7.0	Muddy
				02-12-75	1825				189		6.0	Muddy
				02-13-75	1025				217		4.5	Muddy
				02-24-75	1340				367		11.0	Muddy, 1/2 inch visibility
				02-28-75	1655		130	1.5	350	7.0	7.0	10 inches visibility
				04-02-75	1955		110	1.4	305	7.1	15.5	3 inches visibility
				05-14-75	1040	36	120	1.7	343	7.6	15.5	18 inches visibility
				06-13-75	1425				254	6.6	20.5	5 inches visibility
				07-08-75	1210		130	5.2	405	7.2	24.5	Muddy, 2 inches visibility
				07-22-75	1345		270	21	700	7.2	27.5	
364	Big Branch at Kragon	373029 0832032 00	1.64	05-15-75	1905	5.6			84	7.9	17.5	2 inches visibility
				05-16-75	0840	5.1			74		14.5	12 inches visibility
365	Laurel Fork Quicksand Creek at Decoy	372953 0830534 00	28.7	04-01-75	1415		10	.7	41	7.1	10.0	4 inches visibility
366	Middle Fork Quicksand Creek at Decoy	372954 0830534 00	18.8	04-01-75	1425		11	.7	45	7.0	11.0	6 inches visibility
367	Quicksand Creek above Spring Fork	373358 0830758 00	57.4	04-01-75	1840		12	.9	53	7.5	11.0	Murky, 8 inches visibility
				08-21-75	1935		18	2.9	132	8.0	29.0	2 inches visibility
368	Spring Fork Quicksand Creek at Evanston	373228 0830207 00	7.99	04-01-75	1600		39	.8	137	7.3	14.0	5 inches visibility
369	Little Fork of Spring Fork at Evanston	373228 0830206 00	2.30	04-01-75	1610	5.3			74	7.3	13.5	6 inches visibility
370	Hughes Creek near Evanston	373250 0830359 00	1.79	04-01-75	1645	3.8			38		12.0	Nearly clear
371	Big Lovely Branch near Evanston	373306 0830514 00	2.44	04-01-75	1700	4.8			52		14.0	Murky, 6 inches visibility
372	Hawes Fork of Spring Fork near Lambric	373415 0830550 00	11.2	04-01-75	1730		34	.6	112	7.3	14.5	Murky, 4 inches visibility
373	Peach Orchard Branch at Lambric	373410 0830736 00	.99	04-01-75	1800	.7	13	1.0	74	7.1	13.0	Silty gray, 1/4 inch visibility
374	Spring Fork Quicksand Creek at mouth	373358 0830758 00	35.5	04-01-75	1900		29	.9	107	7.4	13.0	Muddy, 2 inches visibility
				08-21-75	1925		50	5.2	290	7.9	26.0	
375	Holly Branch at Lunah	373322 0831020 00	2.12	04-01-75	1935	2.5			40		11.0	Murky, 6 inches visibility
				08-21-75	1850	.02	19	5.0	150	8.2	27.0	
376	Improvement Branch at Lunah	373330 0831104 00	1.63	04-01-75	1955	3			75		11.0	Murky, 8 inches visibility
377	Big Caney C above Little Caney Creek at Camp Lewis	373508 0831125 00	9.96	04-02-75	1000		31	1.1	117	6.9	7.5	Silty, 4 inches visibility
				08-21-75	1750	.3	50	2.0	220	7.4	29.0	

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
378	Little Caney Creek at Camp Lewis	373509 0831126 00	7.04	04-02-75	0930	8.8	20	1.5	93	7.3	7.5	Clear, 12 inches visibility
				08-21-75	1740	.05	36	2.8	230	7.8	29.0	
379	Calico Branch at Guage	373545 0831155 00	.74	08-21-75	1710	.000	160	1.5	505	7.6	23.5	Sampled from pool, active mine
380	Wolf Creek at Guage	373551 0831220 00	3.41	04-02-75	1030	6.9	36	1.2	156	7.7	8.0	Murky, 6 inches visibility
				08-21-75	1650	.01	31	2.4	290	7.5	24.5	
381	Hunting Creek at Rosseau	373532 0831340 00	11.8	04-02-75	1100		13	.9	60	7.5	7.5	12 inches visibility
				08-21-75	1610	.06	19	2.1	170	8.2	27.0	
382	Meatscaffold Branch at Stevenson	373459 0831603 00	3.09	04-02-75	1130	7.0	12	.6	56	7.5	9.0	Clear, 24 inches visibility
383	Lick Branch near Noctor	373425 0831842 00	1.50	04-02-75	1230	3.0	20	1.1	103	7.0	12.0	Muddy, 1/4 inch visibility
384	Quicksand Creek above Sugarcamp B near Noctor	373426 0831856 00	155	12-06-74	1305				89		2.0	
385	Sugarcamp Branch near Noctor	373426 0831856 01	.63	12-06-74	1310				176		5.5	
				01-30-75	1355	.2			173		7.0	Slightly muddy
				02-13-75	1210	.7	30	1.5	165		5.5	Muddy, 3 inches visibility
				04-02-75	1300	.4	26	1.2	148	7.7	13.5	Murky, 6 inches visibility
386	Bradburn Branch near Noctor	373415 0831915 00	1.14	04-02-75	1340	1.1	14	1.3	57	7.6	16.5	Clear
387	Quicksand Creek above Roark Branch at Noctor	373333 0832012 00	159	12-06-74	1240				90		2.5	
				01-30-75	1335		20	1.1	80		8.0	
				02-13-75	1120		16	.9	60		5.0	Muddy, 2 inches visibility
				02-24-75	1255		21	1.3	96		10.0	Murky, 3 inches visibility
				03-31-75	1400		16	.7	63	7.9	7.0	Silty, 2 inches visibility
				04-02-75	1400		19	1.1	78	7.1	11.0	Silty, 4 inches visibility
				07-08-75	1555		38	2.8	190	7.2	24.0	Muddy, 2 inches visibility
				08-21-75	1515		38	4.7	235	8.0	27.5	
388	Roark Branch at Noctor	373333 0832013 00	.89	12-06-74	1245				96		5.0	
				02-13-75	1115				84		4.0	Clear, 18 inches visibility
				03-31-75	1420	1.2	15	.7	62	7.9	11.5	Murky, 8 inches visibility
				04-02-75	1415		17	1.2	75	7.0	16.5	Murky, 6 inches visibility
				07-08-75	1525	.002	22	3.3	190	6.7	23.0	Clear
				08-21-75	1500	<.01			220	7.6	25.5	
389	Five Mile Branch near Wilstacy	373053 0830806 00	.27	03-31-75	1950	2.7	290	1.5	908	8.2	10.5	Silty, 1 inch visibility
390	Five Mile Branch Unnamed Spr near Wilstacy	373052 0830805 01	--	03-31-75	1945	.001			595	7.2	11.0	Clear, yellow boy
391	Old House Branch near Wilstacy	373106 0830930 00	.40	03-31-75	1930	.33	13	.9	61			Black and oily, zero visibility
392	South Fork Quicksand Creek near Wilstacy	373049 0831014 00	2.89	03-31-75	1825	11	130	1.2	453	8.0	10.0	Silty, 1/4 inch visibility

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi^2)	Date	Time	Estimated discharge unless noted (ft^3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temper- ature (°C)	Remarks
393	Two Mile Fork near Wilstacy	373047 0831016 00	1.42	03-31-75	1810	4.1	68	1.2	357	8.2	10.0	Silty, 2 inches visibility
394	Laurel Branch near Wilstacy	373101 0831045 00	.84	04-01-75	1230	4.2	9.7	.6	34	7.6	10.0	Clear, clean
395	Open Fork near Wilstacy	373102 0831255 00	1.83	04-01-75	1200	3.0	36	.8	143	7.7	8.5	Silty, 1 inch visibility
396	Leatherwood Creek near Wilstacy	373106 0831410 00	2.63	04-01-75	1115	6.7	100	.7	349	8.0	9.5	Murky, 6 inches visibility
397	Jones Branch near Wilstacy	373104 0831420 00	2.03	04-01-75	1125	7.7			102	7.8	9.0	Murky, 6 inches visibility
398	Press Howard Fork at Wilstacy	373205 0831457 00	5.78	04-01-75	1010	18	20	.6	97	8.2	6.5	Murky, 6 inches visibility
399	Goodloe Branch at Wilstacy	373143 0831528 00	.63	04-01-75	0930	2			91	7.6	6.0	Silty, 1 inch visibility
400	Poll Branch at Wilstacy	373158 0831541 00	.76	03-31-75	1730	2.1			59	8.0	10.5	Clear
401	Hargis Branch near Portsmouth	373210 0831723 00	.57	03-31-75	1705	2.4			61		10.0	Clear
402	Bear Branch at Portsmouth	373202 0831834 00	.43	03-31-75	1650				66		10.5	Clear
403	Smith Branch at Portsmouth	373148 0831901 00	3.24	03-31-75	1600	12.1	11	.5	45	7.6	11.0	
404	South Fork Quicksand Creek Unnamed Trib near Quicksand	373150 0831936 00	.18	03-31-75	1530	.6	11	.6	39	7.4	10.0	Clear, 15 inches visibility
405	South Fork Quicksand Creek at Quicksand	373156 0832012 00	39.7	12-06-74	1230				171		2.0	
				02-13-75	1100				152		4.0	Muddy
				03-31-75	1500		37	1.1	173	8.1	7.0	Silty, 1 1/2 inches visibility
				04-01-75	0900				192		7.0	Muddy, 2 1/2 inches visibility
				07-08-75	1625		41	6.6	241	7.1	25.0	
				08-22-75	1135		95	5.6	420	7.6	25.5	
406	Cane Creek above Lindon Fork at Elkatawa	373316 0832503 00	13.5	04-03-75	1330		16	1.8	80	7.4	8.5	Muddy, 3 inches visibility
				08-22-75	1240	.08	20	6.1	245	8.3	28.0	
407	Lindon Fork Cane Creek at Elkatawa	373319 0832506 00	6.01	04-03-75	1320	8	21	2.9	99	7.4	8.5	Clear, 18 inches visibility
408	Frozen Creek above Cope Fork at Sewell	373701 0832324 01	23.5	02-13-75	1345		17	3.1	77		5.5	Murky, 6 inches visibility
409	Cope Fork Frozen Creek at Sewell	373701 0832324 00	13.7	02-13-75	1335		17	1.9	73		5.5	Murky, 6 inches visibility
410	Frozen Creek above Boone Fork	373646 0832453 00	39.0	12-06-74	1445				111		3.0	
				02-13-75	1410				78		5.5	Murky, 6 inches visibility
				08-22-75	1355	.3	14	20	210	8.4	29.0	
411	Boone Fork at mouth	373646 0832453 00	15.4	12-06-74	1450				99		4.0	
				02-13-75	1420		18	2.6	86		5.5	Murky, 4 inches visibility
				08-22-75	1425		23	7.2	201	8.1	31.0	Large fish observed
412	War Creek near Tallega	373647 0832452 00	6.08	04-03-75	1420	10	18	3.0	82	7.5	9.5	18 inches visibility

Table 8.--Data on drainage areas, stream discharge, sulfate, chloride, specific conductance, pH values, and stream temperature (Continued)

Site number	Station name and USGS gaging station number if available	Station number	Area (mi2)	Date	Time	Estimated discharge unless noted (ft3/s)	Sulfate (mg/L)	Chloride (mg/L)	Specific conductance (umhos/cm at 25°C)	pH (units)	Temperature (°C)	Remarks
413	Holly Creek at Bethany	373902 0832833 00	12.8	12-06-74	1515				90		5.0	
				02-13-75	1450	12	16	1.9	78		6.0	Nearly clear, 16 inches visibility
				02-24-75	1210		16	1.6	73		9.0	Murky, 4 inches visibility
				03-31-75	1240		13	1.0	57	8.4	8.0	15 inches visibility
				08-22-75	1510		15	4.3	152	8.0	28.0	
414	North Fork Kentucky River at Airedale	373609 0833831 00	1,295	12-19-74	1500		65	3.0	223		4.0	
				01-16-75	1755		54	4.7	200		1.0	Murky
				01-30-75	1500		56	2.0	193		7.5	
				02-13-75	1600		69	2.9	229		6.0	Muddy, less than 1 inch visibility
				02-28-75	1810		74	2.3	253	7.0	7.0	Muddy, 4 inches visibility
				04-03-75	1530		71	1.7	203	7.6	11.5	Muddy
				05-01-75	1845		60	1.6	214	7.6	18.0	Muddy, 3 inches visibility
				05-16-75	1820		59	2.3	224	7.8	18.5	Muddy, 3 inches visibility and a smelly oil slick
				06-13-75	1720		75	2.4	273	7.2	22.0	Muddy 1/3 inch visibility
				08-22-75	1640		150	8.6	745	8.3	28.0	
415	Walker Creek at mouth	373624 0833848 00	13.8	04-03-75	1620		7.7	26	127	7.6	9.0	18 inches visibility

1/ Discharge measured or determined from rating table.

Table 9.--Water-quality data for samples having a more complete chemical analysis
Part 1.--Miscellaneous water-quality data - Surface water

Site number	Station name (and USGS gaging station number, if available)	Station number	Date	Time	Estimated discharge except as noted (ft^3/s)	Ratio of gross alka-linity to gross acidity	Specific conductance (umhos/cm)	pH Field	pH Lab 4 to 6 weeks after sampling	Water temper-ature (°C)	Color
5	Potters Fork at Neon Junction	371044 0824246 00	07-25-75	1135	2.3	2.98	715	8.1	-	20.0	5
13	North Fork Kentucky River at Whitesburg (03277300)	370703 0824929 00	01-15-75	0910	-	-	488	7.7	-	.5	-
66	North Fork Kentucky River at Blackey (03277340)	370743 0825827 00	09-26-74	1445	31[c]	1.45[d]	574	-	-	18.5	-
72	Razorblade Branch at Deane	371419 0824645 00	02-26-75	1230	1.0	.94	1,750	5.1	3.3	10.0	5
189	Big Branch near Viper	371018 0831029 00	07-10-75	1215	.15	.63	2,575	2.8	2.7	23.0	23
215	Yellow Creek at Sassafras (03277455)	371315 0830319 00	12-17-74	1310	1.2	1.00[d]	786	4.8	4.5	4.0	-
			02-26-75	1910	1.3	-	790	4.9	4.4	9.0	-
			07-10-75	1720	.5	1.08	1,020	7.1	-	29.0	0
227	North Fork Kentucky River at Hazard (03277500)	371448 0831055 00	04-16-74	1745	710[c]	-	-	-	-	14.0	-
			06-04-74	1500	1,040[c]	-	-	-	-	18.5	-
			07-16-74	1030	75[c]	-	-	-	-	24.5	-
			10-03-74	1610	-	-	-	-	-	14.0	-
			01-16-75	1530	-	-	271	7.4	-	2.5	-
			03-20-75	1700	-	-	-	-	-	10.0	-
			04-29-75	1500	-	-	-	-	-	18.5	-
			06-17-75	1500	-	-	-	-	-	25.5	-
231	Youngs Fork (Head of Lotts Creek) at Elic	371606 0830404 01	02-28-75	1200	2.1	-	2,000	3.2	2.8	5.5	-
240	Jacks Branch at Cordia	371648 0830640 00	12-18-74	1305	.1	1.00	1,630	6.6	-	2.0	-
			02-28-75	1315	.2	-	2,710	3.4	2.8	7.5	-
247	Lotts Creek above Trace Fork at Darfork	371717 0831051 00	12-18-74	1000	-	1.02[d]	811	6.6	6.8	1.0	-
			07-09-75	1625	4.0	1.04	1,180	7.8	-	26.0	0
286	Left Fork Troublesome Creek at Hindman	372010 0825855 00	12-04-74	1630	-	2.35[d]	127	7.4	-	5.0	-
289	Right Fork Troublesome Creek at Hindman	372004 0825837 00	12-04-74	1530	-	1.98[d]	173	7.7	-	5.0	-
322	Buckhorn Creek above Long Fork at Noble	372649 0831124 00	12-05-74	1440	-	1.70	44	-	7.1	3.0	4
341	Bowmans Branch near Dice	372134 0831201 00	07-23-75	1130	.03	-	8,080	3.2	-	23.0	-
414	North Fork Kentucky River at Airedale	373609 0833831 00	12-19-74	1500		1.50	223	7.2	-	4.0	-
			01-16-75	1755	-	1.46	200	7.1	-	1.0	-

See footnotes at end of Part 1 of table.

Table 9.--Water-quality data for samples having a more complete chemical analysis--Continued
Part 1.--Miscellaneous water-quality data - Surface water

Concentration in milligrams per liter

Site number	Dissolved silica	Dissolved calcium	Dissolved magnesium	Dissolved sodium	Dissolved potassium	Bicarbonate	Carbonate	Dissolved sulfate	Dissolved chloride	Dissolved fluoride	Bromide	Dissolved nitrate plus nitrite as N	Dissolved phosphorus	Dissolved solids	Total hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Total acidity as $CaCO_3$	Gross acidity as $CaCO_3$	Gross alkalinity as $CaCO_3$
5	9.7	61	33	54	7.3	317	0	130	7.3	0.5	0.9	0.97	0.16	461[a]	290	28	0[b]	135	403
13	-	-	-	-	-	130	0	130	5.4	-	-	-	-	-	-	-	-	135	-
66	-	-	-	-	-	148	0	160	7.2	-	-	.00	.02[e]	392[f]	220	94	-	167	242[d]
72	20	200	72	130	16	0	0	1,100	15	.2	-	-	-	1,600[a]	800	800	94	1,150	1,080
189	49	170	120	5.1	1.8	0	0	1,400	1.8	2.7	.1	.03	.07	1,920[a]	920	920	695	1,460	922
215	-	-	-	-	-	0	0	380	3.2	-	-	.42	-	-	-	-	40	396	396[d]
	-	-	-	-	-	-	-	390	2.8	-	-	-	-	-	-	-	145	406	-
	18	140	39	29	5.2	32	0	510	4.5	.2	-	.20	.01	765[a]	510	480	0[b]	531	572
227	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	53	0	71	7.3	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
231	-	-	-	-	-	-	-	1,200	.5	-	-	-	-	-	-	-	477	1,250	-
240	-	230	110	6.7	4.8	4	0	1,000	2.3	-	-	.10	-	-	1,000	1,000	50[b]	1,042	1,044
	-	-	-	-	-	-	-	1,800	5.0	-	-	-	-	-	-	-	500	1,875	-
247	-	-	-	-	-	12	0	400	1.3	-	-	.20	-	-	-	-	15[b]	417	426[d]
	13	160	66	8.6	6.0	30	0	640	2.6	.3	.0	.68	.01	914[a]	670	650	0[b]	667	691
286	-	-	-	-	-	27	0	16	3.6	-	-	-	-	-	-	-	39	17	39[d]
289	-	-	-	-	-	35	0	28	4.6	-	-	-	-	-	-	-	-	29	58[d]
322	7.6	4.7	1.8	.4	1.0	12	0	11	.5	.3	-	.03	-	33[a]	19	9	-	11.5	19.6
341	-	-	-	1,000	-	-	-	610	2,400	.4	11	-	-	-	-	-	-	636	-
414	-	21	8.9	7.0	1.8	41	0	65	3.0	-	-	.24	-	-	89	55	5[b]	67.8	101.4
	-	-	-	-	-	32	0	54	4.7	-	-	-	-	-	-	-	-	56	82

See footnotes at end of Part 1 of table.

Table 9.--Water-quality data for samples having a more complete chemical analysis--Continued

Part 1.--Miscellaneous water-quality data - Surface water

Concentration in micrograms per liter

Site number	Dissolved aluminum	Total arsenic	Dissolved arsenic	Dissolved boron	Total cadmium	Dissolved cadmium	Total chromium	Dissolved chromium	Total cobalt	Dissolved cobalt	Total copper	Dissolved copper
5	330	-	-	90	-	0	-	0	-	0	-	1
13	-	-	-	-	-	-	-	-	-	-	-	-
66	-	-	-	-	-	-	-	-	-	-	-	-
72	880	-	-	-	-	-	-	-	-	-	-	-
189	46,000	-	-	10	-	5	-	4	-	400	-	100
215	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	
227	-	76	0	-	1	0	0	0	0	0	9	2
	-	0	0	-	4	4	0	0	3	-	15	3
	-	0	0	-	1	1	0	1	4	0	4	3
	-	0	-	-	1	0	10	0	2	2	5	3
	-	-	-	-	-	-	-	-	-	-	-	-
	-	3	0	-	0	0	10	0	2	1	100	3
	-	4	1	-	8	1	10	0	13	0	48	4
	-	0	0	-	0	0	10	1	0	0	6	3
231	-	-	-	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
247	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	10	-	0	-	0	-	25	-	3
286	-	-	-	-	-	-	-	-	-	-	-	-
289	-	-	-	-	-	-	-	-	-	-	-	-
322	-	-	-	-	-	-	-	-	-	-	-	-
341	-	-	-	-	-	-	-	-	-	-	-	-
414	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-

Table 9.--Water-quality data for samples having a more complete chemical analysis--Continued
Part 1.--Miscellaneous water-quality data - Surface water

Concentration in micrograms per liter

Site number	Dissolved iron	Total lead	Dissolved lead	Dissolved manganese	Total mercury	Dissolved mercury	Dissolved nickel	Dissolved selenium	Dissolved silver	Dissolved vanadium	Total zinc	Dissolved zinc
5	790	-	5	170	-	-	0	5	0	0	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
66	-	-	-	-	-	-	-	-	-	-	-	-
72	37,000	-	-	7,100	-	-	-	-	-	-	-	-
189	82,000	-	37	22,000	-	-	1,300	1	0	67	-	-
215	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
	130	-	-	3,400	-	-	-	-	-	-	-	
227	-	14	0	-	0.1	0.1	-	-	-	-	40	4
	-	3	-	-	.9	1.1	-	-	-	-	60	10
	-	16	3	-	.2	.1	-	-	-	-	30	3
	-	4	2	-	.1	-	-	-	-	-	8	8
	-	-	-	-	-		-	-	-	-	-	-
	-	1,000	0	-	.2	.2	-	-	-	-	80	40
	-	120	4	-	.2	.0	-	-	-	-	80	0
	-	7	6	-	.0	-	-	-	-	-	20	5
231	-	-	-	-	-	-	-	-	-	-	-	-
240	18,000	-	-	1,900	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
247	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	4	2,800	-	-	48	2	0	1.1	-	-
286	-	-	-	-	-	-	-	-	-	-	-	-
289	-	-	-	-	-	-	-	-	-	-	-	-
322	20	-	-	-	-	-	-	-	-	-	-	-
341	-	-	-	-	-	-	-	-	-	-	-	-
414	30	-	-	75	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-

a Calculated as sum of dissolved solids.
b Acidity analysis is normally not performed when the sample pH value exceeds 4.6.
c Discharge measured or determined from rating table.
d Partly estimated.
e Total phosphorus.
f Residue on evaporation at 180°C.

Table 9.--Water-quality data for samples having a more complete chemical analysis
Part 2.--Miscellaneous water-quality data - Ground water

Number	Site description	Altitude (ft)	Depth (ft)	Station number	Date	Discharge (gal/min)	Ratio of gross alkalinity to gross acidity	Specific conductance (umhos/cm)	pH	Water temperature (°C)	Color
1	James Griffith well (on Line Fork opposite Long Branch)	1,000	123	370625 0830133 01	04-30-75 06-12-75	- -	- 157	4,080 4,040	7.9 -	- -	- -
2	Spring from blue gem coal (on North Fork Kentucky River one mile east of Ulvah)	1,080	-	370752 0830206 00	11-10-54	1	1.45	187	6.8	9.0	-
3	Mine drainage from No. 3 Elkhorn coal zone, McRoberts (on Tom Biggs Branch)[a]	1,530	-	371236 0823950 00	08-05-53	165	2.73	1,470	7.7	14.5	1
4	A well tapping a deep mine near McRoberts (on She Fork)[a]		-	371311 0824115 00	08-05-53	240	-	788	7.2	17	-
5	Mine drainage from Fire Clay coal bed, Wiscoal (on Yellow Ceek)	1,120	-	371430 0830338 00	02-24-53	-	1.75	1,850	6.4	10.5	2
6	Mine drainage from Hindman coal bed, Blue Diamond (on First Creek)	1,350	-	371832 0831232 00	02-25-53	-	2.17	619	7.5	11.5	0
7	Mine drainage from Hazard No. 7 coal, site 255 (on First Creek)[b]	1,230	-	371849 0831138 00	02-25-53 01-30-75 07-23-75	- 50[c] 50[c]	2.04 - 1.22	688 880 845	6.6 - 7.6	11.5 13.0 17.5	0 - 0
8	Spring, Emmalena (on Troublesome Creek)	990	-	372017 0830416 00	12-02-54	-	1.51	110	6.6	8.0	-

See footnotes at end of table.

Table 9.--Water-quality data for samples having a more complete chemical analysis--Continued
Part 2.--Miscellaneous water-quality data - Ground water

Concentration in milligrams per liter

Number	Dis-solved silica	Dis-solved cal-cium	Dis-solved mag-nesium	Dis-solved sodium	Dis-solved potas-sium	Bi-car-bo-nate	Car-bo-nate	Dis-solved sul-fate	Dis-solved chlo-ride	Dis-solved fluo-ride	Bro-mide	Dis-solved nitrate plus nitrite as N	Dis-solved phos-phorus	Dis-solved solids	Total hard-ness as $CaCO_3$	Non-car-bo-nate hard-ness as $CaCO_3$	Total acidity as $CaCO_3$	Gross acid-ity as $CaCO_3$	Gross alka-linity as $CaCO_3$
1	-	-	-	-	-	-	-	3.6	1,200	-	-	-	-	-	-	-	-	-	-
	-	22	5.3	850	5.5	318	0	2.3	1,100	1.2	-	-	-	-	77	0	-	2.4	378
2	-	-	-	-	-	31	0	54	2.0	.1	-	0.45	-	-	68	43	-	56	82
3	8.9	82	33	236	9.3	620	0	297	14	.1	-	.29	-	952[d]	340	0	-	309	845
4	10	64	28	70	7.3	284	0	181	5.1	.0	-	.65	-	511[d]	316	42	-	-	-
5	7.9	80	39	308	9.8	559	0	563	9.2	.3	-	.79	-	1,284[d]	362	0	-	587	1,026
6	7.1	70	39	8.7	7.2	219	0	157	5.5	.2	-	.23	-	410[d]	336	156	-	164	354
7	6.2	78	28	28	10	248	0	178	3.1	.1	-	.34	-	468[d]	312	107	-	185	378
	-	-	-	-	-	-	-	310	1.1	-	-	-	-	-	-	-	-	323	-
	5.8	88	37	33	14	97	0	360	1.1	.5	0.5	.29	0.0	588[e]	370	290	0	375	458
8	-	-	-	-	-	18	0	28	3.8	.4	-	.05	-	-	44	29	-	29	44

See footnotes at end of table.

Table 9.--Water-quality data for samples having a more complete analysis--Continued
Part 2.--Miscellaneous water-quality data - Ground water

Concentration in micrograms per liter

Number	Dis-solved aluminum	Dis-solved boron	Dis-solved cadmium	Dis-solved chromium	Dis-solved cobalt	Dis-solved copper	Total iron	Dis-solved iron	Dis-solved lead	Total manganese	Dis-solved manganese	Dis-solved nickel	Dis-solved selenium	Dis-solved silver	Dis-solved vanadium
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	120	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	220	-	-	-	<10	-	-	-	-
4	-	-	-	-	-	-	2,800	-	-	-	<10	-	-	-	-
5	-	-	-	-	-	-	7,500	10	-	890	0	-	-	-	-
6	-	-	-	-	-	-	450	-	-	370	-	-	-	-	-
7	-	-	-	-	-	-	2,200	-	-	180	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	100	0	0	0	0	-	10	0	-	180	13	15	0	0
8	-	-	-	-	-	-	1,000	-	-	-	-	-	-	-	-

[a] Part of public water supply for Jenkins and McRoberts.
[b] Once used as a public water supply for Harveyton.
[c] Estimated.
[d] Residue on evaporation at 180°C.
[e] Calculated.