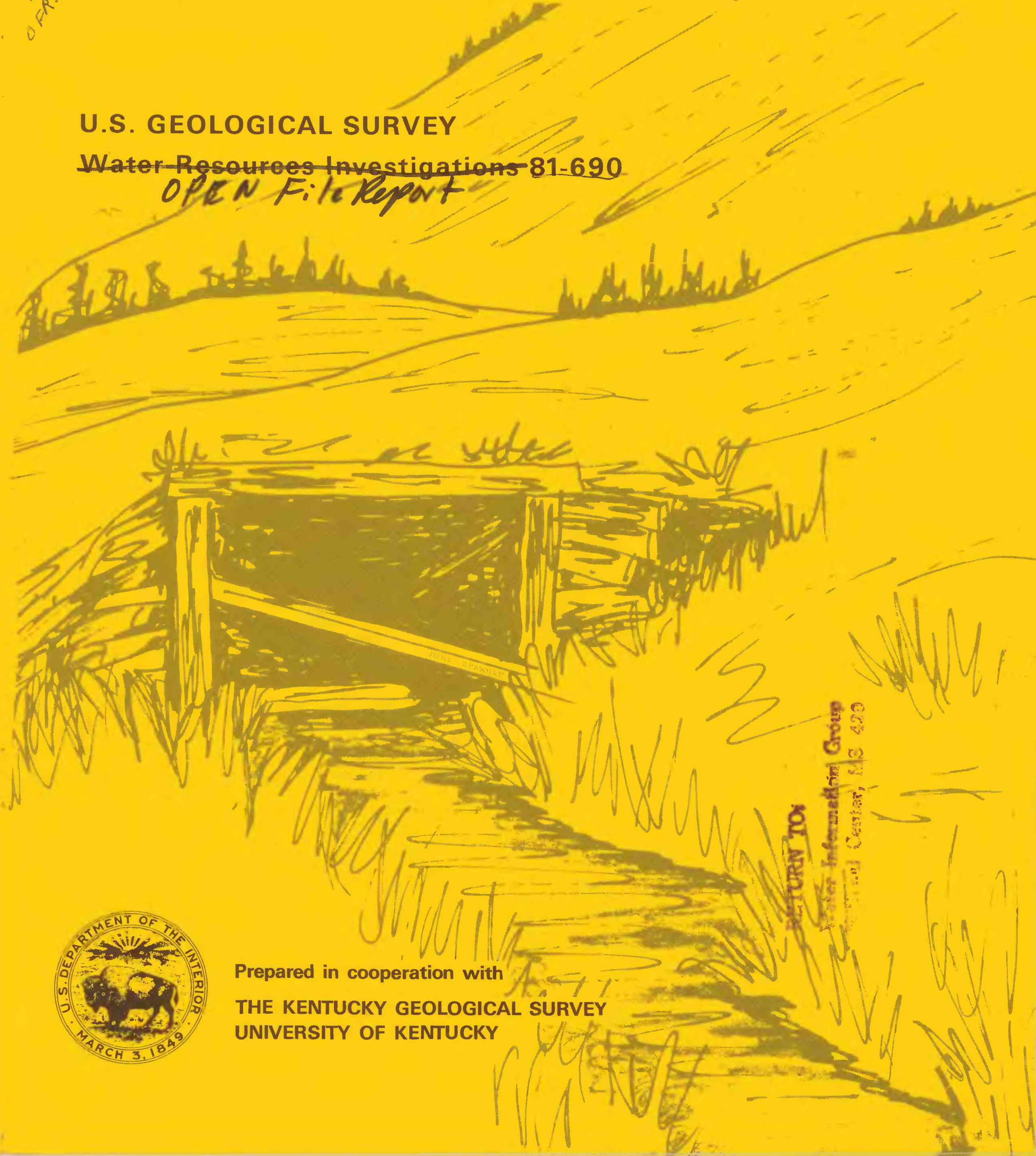
AVAILABILITY AND QUALITY OF WATER FROM UNDERGROUND COAL MINES IN JOHNSON AND MARTIN COUNTIES, KENTUCKY



U.S. GEOLOGICAL SURVEY

~~Water-Resources Investigations~~ 81-690
OPEN File Report

Prepared in cooperation with

THE KENTUCKY GEOLOGICAL SURVEY
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By D. S. Mull, U.S. Geological Survey
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1981

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Doyle G. Frederick, Acting Director

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Louisville, Kentucky 40202

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Conversion of inch-pound units to metric (SI) Units

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

Multiply inch-pound	By	To obtain metric units
inch (in)	25.4	millimeters (mm)
foot (ft)	0.3048	meters (m)
mile	1.609	kilometers (km)
square mile	2.590	square kilometers (km^2)
gallon	3.785	liters (L)
million gallons (Mgal)	3.785×10^{-3}	cubic hectometers (hm^3)
gallon per minute (gal/min)	6.309×10^{-2}	liters per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)

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By D. S. Mull, U.S. Geological Survey,

and

Steven Cordiviola and Dennis W. Risser, Kentucky Geological Survey

ABSTRACT

This report provides water users with detailed information on the location, quantity, and quality of water available from underground coal mines in the Breathitt Formation of Pennsylvanian age in part of eastern Kentucky. The principal coal seams mined are the Van Lear in Johnson County and the Alma in Martin County. Coal mines that contained water were located by field inventory and coal-mine maps.

The principal factors that affect the occurrence of water in coal mines are the size of the recharge area overlying the mine, the intensity and duration of precipitation, and the altitude of the mine relative to that of the nearest perennial stream.

Ten above-drainage mines (that is, mines at higher elevations than that of the nearest perennial stream) are considered potential sources of water. Discharge from these mines ranged from 12 to 1,700 gallons per minute. The highest sustained discharge from a mine ranged from 750 to 1,200 gallons per minute.

The water in coal mines is part of the hydrologic system and varies seasonally with precipitation. Annual discharge from most above-drainage mines ranged from 3 to 10 percent of annual precipitation on the land-surface area above the mine.

Eight below-drainage mines are considered potential sources of water. Two were test-pumped at rates of 560 to 620 gallons per minute for as long as 6 hours. After test pumping the Warfield Mining No. 1 mine during September 1977 and March 1978, the recovery (or recharge) rates were significantly different. In September, the recharge rate was about 1,150 gallons per minute, but in March the recharge rate was 103,500 gallons per minute. This difference reflects the seasonal variations in the amount of water available to the ground-water system. Estimates of water stored in below-drainage mines ranged from 22 to 1,462 million gallons. This storage represents a safety factor sufficient to provide water through periods of limited recharge to the mine.

Most mine water is of the calcium magnesium sulfate type. In general, water from below-drainage mines had lower concentrations of dissolved constituents and higher pH than water from mines above drainage. The hardness of water ranged from soft to very hard and pH ranged from 3.1 to 8.0 units. Dissolved iron ranged from 0.01 to 64 milligrams per liter. Phenol concentrations in water from eight coal mines ranged from 0 to 5 micrograms per liter.

There seems to be a significant difference in the chemical quality of water from above- and below-drainage mines. The concentration of most constituents was lower in water from below-drainage mines than it was from above-drainage mines.

The better quality water from below-drainage mines may reflect (1) lower mineralization resulting from less atmospheric oxygen available to react with pyrite or, (2) the result of sampling only the upper zones of water in below-drainage mines where the water has been diluted by less mineralized surface water or inflow or recharge.

INTRODUCTION

Purpose and Scope

The resurgence of coal mining, increased commercial and industrial activity, coupled with a general growth in population have increased the demands on existing water supplies of many communities in eastern Kentucky. Pursuant to the need for a dependable source of water, some communities, industries, and individuals have turned to coal mines for their water supply.

The purpose of this report is to provide information on the reliability, quality, and quantity of water available from underground coal mines. Johnson and Martin Counties, Kentucky were selected for a pilot project to evaluate coal mines as a source of water because of the abundance of coal mines in different stratigraphic units and topographic positions. This investigation is part of an on-going cooperative study of the water resources of Kentucky by the Kentucky Geological Survey, and the U.S. Geological Survey.

The scope of the report is limited to a discussion of those geologic and hydrologic factors that affect the occurrence and chemical quality of water in underground coal mines in Johnson and Martin Counties, Kentucky. Problems related to coal mining such as sedimentation, erosion and surface-water quality are not within the scope of this report.

Location

Johnson and Martin are adjoining counties located in the northeastern section of Kentucky's Eastern Coal Field (fig. 1). The two-county study area of about 495 squre miles, lies between latitudes 37°40' and 38°00' North and between longitudes 82°20' and 83°00' West. The Tug Fork of the Big Sandy River borders Martin County on the east and also forms the border between Kentucky and West Virginia.

Acknowledgments

The authors acknowledge the assistance of many residents in the study area, who allowed access to private property. Many coal mine owners and operators provided information on water conditions in their mines. Special thanks are extended to Mr. Roy Coleman who provided information on mining and furnished shelter for water-level-recording equipment near Warfield, Ky.

Methods of Investigation

Underground coal mines in the study area were located by field reconnaissance from 1975 through 1977. Initially, attempts were made to visit all mine openings shown on 7-1/2 minute topographic maps. However, these visits indicated that only the relatively large coal mines contained significant quantities of water. A search of mine maps at the Institute for Mining and Mineral Research, Lexington, Kentucky, revealed areas of large-scale mining activity and these areas were plotted on 7-1/2 minute topographic maps. The field reconnaissance then focused on these areas of large-scale mining. This approach shortened field time and eliminated visits to small, dry mines.

Access by addits, shafts, or slope entries to mines that contain water are located by site number on plates 1 and 2. Tables 1 and 2 list the site number, location, mine name, coal seam mined, and the estimated volume of the mine for all mines inventoried in Johnson and Martin Counties. Note from tables 1 and 2 that in several mines, water is accessible through multiple openings each of which is designated by a separate site number.

To estimate the amounts of water available, discharge and water-level measurements were made at each mine opening. Storage and recharge capabilities of the mines were estimated by test pumping selected mines (sites 5 and 58).

The mine entry at site 5 was equipped with a water-stage mercury manometer coupled to an automatic digital recorder to record the recovery of water level after test-pumping and natural variations of water level in the mine. Continuous water-stage recorders and V-notch weirs were installed at entries of two mines (sites 21 and 22) to provide continuous records of mine-water discharge.

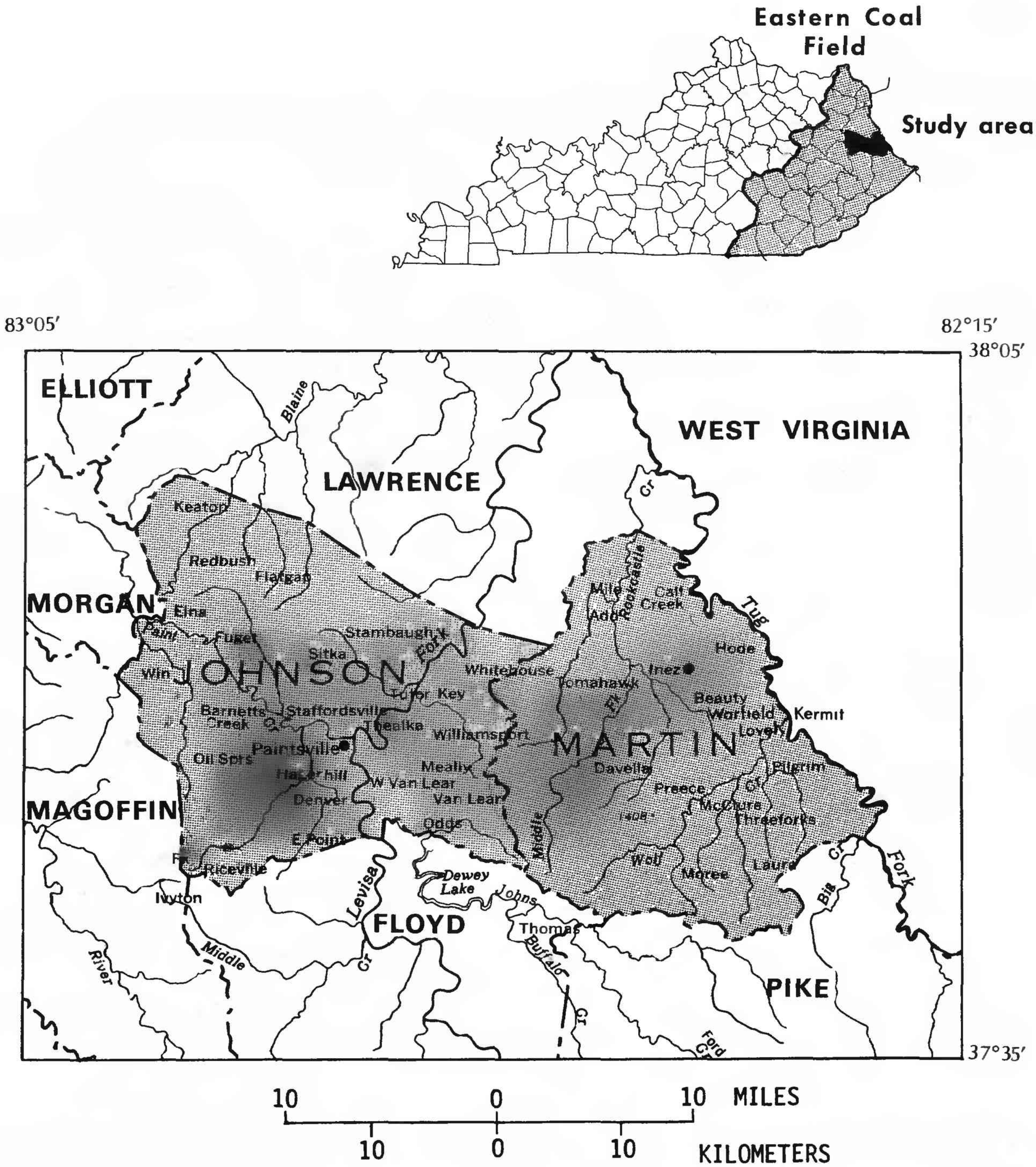

Figure 1. – Location of Johnson and Martin Counties, Eastern Kentucky Coal Field.

Table 1.--Mine-water sampling sites in Martin County

Site number	Latitude longitude	Mine name	Seam mined	Mine volume[a/] (million cubic feet)	Date abandoned
1	375028 822542	Buck Creek Coal Co., Himmler.....	Alma	195[b/]	1951
2	375035 822458	Buck Creek Coal Co., Coleman.....	.....do.......	195[b/]	1930
3	375032 822504	Buck Creek Coal Co., Earlston....	.....do.......	195[b/]	1930
4	375025 822450	Collins Creek Coal Co., Sluss....	.....do.......	195[b/]	1961
5	375047 822518	Warfield Mining Co. No. 1........	.....do.......	5.7	1963
6	374911 822406	Wolf Creek Collieries No. 3......	.....do.......	103	1977
7	374805 822239	.............do................	.....do.......	103	1977
8	374839 822533	Wolf Creek Collieries No. 4......	.....do.......	17	1965
9	374849 822507	Wolf Creek Collieries No. 2......	.....do.......	31	Active
10	374838 822539	Peter Cave Coal Co. No. 1........	.....do.......	85	Active
11	375348 823529	-	Unnamed	-	?
12	375334 823520	-	.....do.......	-	?
13	375334 823529	-	.....do.......	-	?
14	375344 823537	-	.....do.......	-	?
15	375516 823200	-	Broas	-	?
16	374526 823143	Martin County Coal Co. No. 1, Coalburg.	Peach Orchard	22	Active
17	374447 823217	Martin County Coal Co. No. 1, Stockton.	Broas	3.0	1972
18	374446 823210	Martin County Coal Co. No. 1, Coalburg.	Peach Orchard	22	Active
19	374859 823900	-	Peach Orchard	-	?
20	375113 823538	-	.....do.......	-	?
20a	374332 823017	Pontiki Coal Co. No. 1..........	Pond Creek	6.0	Active

a/ Volume of mine available for water storage calculated assuming a 5-foot thickness of coal removed over 50 percent of the areal extent of the mine.
b/ Himmler, Earlston, Coleman, and Sluss mines reportedly all interconnected.

Table 2.--Mine-water sampling sites in Johnson County

Site number	Latitude longitude	Mine name[a]	Seam mined	Mine volume[b] (million cubic feet)	Date abandoned
21	375024 824737	North East Coal Co. No. 1.........	Van Lear	30	1930
22	375035 824734	North East Coal Co. No. 3.........	......do......	146[c]	1951
23	375101 824654	North East Coal Co. No. 4.........	......do......	146	1930
24	375056 824643	.........do.....................	......do......	146	1930
25	375059 824634	.........do.....................	......do......	146	1930
26	375030 824734	North East Coal Co. No. 2.........	......do......	59	1923
27	375043 824613	.........do.....................	......do......	59	1923
28	375029 824600	.........do.....................	......do......	59	1923
29	375038 824605	.........do.....................	......do......	59	1923
30	375027 824605	.........do.....................	......do......	59	1923
31	375025 824614	.........do.....................	......do......	59	1923
32	374944 824634	-	......do......	-	?
33	374951 824633	-	......do......	-	?
34	375052 824543	North East Coal Co. No. 5.........	......do......	34	1951
35	375052 824506	.........do.....................	......do......	34	1951
36	375055 824454	.........do.....................	......do......	34	1951
37	375104 824457	.........do.....................	......do......	34	1951
38	375102 824455	.........do.....................	......do......	34	1951
39	375122 824443	.........do.....................	......do......	34	1951
40	375035 824501	-	......do......	-	?
41	375032 824431	Tutor Key Coal Co. No 1..........	......do......	17	1964
42	375129 824552	Stambaugh Coal Co. No 1 and No. 2	......do......	3.2	1964
43	375130 824539	.........do.....................	......do......	3.2	1964
44	375129 824401	White Ash Coal Co. No 4..........	......do......	.6	Active
45	375133 824401	White Ash Coal Co. No. 3........	......do......	.8	1976
46	375158 824355	White Ash Coal Co. No. 1........	......do......	46	Active
47	375212 824208	Miller's Creek Co-op Inc., Whitehouse mine.	......do......	38	1956
48	375112 824337	Royal Collieries, Offutt mine....	......do......	30(est.)	1938
49	375032 824352	-	......do......	-	?
50	375002 824215	-	......do......	-	?

Table 2.--Mine-water sampling sites in Johnson County--Continued

Site number	Latitude longitude	Mine name[a]	Seam mined	Mine volume[b] (million cubic feet)	Date abandoned
51	375122 824724	Meade & Castle Coal Co. No. 1...	Van Lear	.1	1955
52	375125 824720	-	......do......	-	?
53	375655 824807	-	......do......	-	?
54	375244 824925	Goose Fork Coal Co. No. 1.......	......do......	.9	1971
55	375258 824923	-	......do......	-	?
56	375257 824919	-	......do......	-	?
57	375308 824900	-	......do......	-	?
58	375144 824937	M & P Coal Co. No. 1............	......do......	8.3	1963
59	375138 825007	Hagar Hill Mining Co. No. 1 and No. 2.	.....do.......	9.5	1954
60	375129 825024	...............do..............	.....do.......	9.5	1954
61	375102 825001	-	.....do.......	-	?
62	375054 825002	-	.....do.......	-	?
63	374552 825212	-	.....do.......	-	?
64	374700 824928	-	.....do.......	-	?
65	374753 824546	-	.....do.......	-	?
66	374756 824525	William's Mining Co. No. 1........	.....do.......	3.2	1953
67	374747 824503	-	.....do.......	-	?
68	374751 824444	Fitch Coal Co. No. 3.............	.....do.......	2.6	1955
69	374748 824431	...............do...............	.....do.......	2.6	1955
70	374752 824411	Buffalo Creek Coal Co. No. 1......	.....do.......	.9	1961
71	374638 824609	-	.....do.......	-	?
72	374638 824544	Consolidation Coal Co. 151 - 155..	.....do.......	510	1949
73	374610 824531	Well, does not penetrate mine.....	-	-	?
74	374444 824410	Consolidation Coal Co. 151 - 155..	Van Lear	510	1949
75	374459 824254	...............do...............	.....do.......	510	1949
76	374636 824328	...............do...............	.....do.......	510	1949
77	374943 824814	North East Coal Co. No. 1.........	.....do.......	30	1930
78	374458 824324	North East Coal Co. No. 11[d]......	.....do.......	510	1949

a/ Small truck mines which connect with large mines are listed under the mine name, size, and abandonment date of the major working.
b/ Volume of mine available for water storage calculated assuming a 5-foot thickness of coal removed for 50 percent of the areal extent of the mine.
c/ North East Coal Company's No. 3 and No. 4 mines are connected.
d/ Reportedly connected with Consolidation Coal Company's mines 151-155.

At each site where water could be collected, field measurements of pH, specific conductance, and temperature were made. Field measurements for pH were made with Hach* narrow-range colorimetric kits. Specific electrical conductance was measured with a Beckman* RB-3 meter. Forty-one water samples were collected for more complete chemical analysis from 27 sites. Repeat samples were collected at several sites to define the variation of chemical quality with seasonal changes in discharge. Eight samples were analyzed for phenol concentrations. Standard analytical methods of the U.S. Geological Survey (Brown, Skougstad, and Fishman, 1970) were used for all analyses.

PHYSIOGRAPHY AND GEOLOGY

Johnson and Martin Counties are located in Kentucky's Eastern Coal Field within the Kanawha Section of the Appalachian Plateaus physiographic province. The Kanawha Section is a highly dissected plateau characterized by narrow valleys, irregular steep-sided ridges, and generally rugged terrain (McFarlan, 1943). Maximum relief in the two-county area is 1,056 feet according to McGrain and Currens (1978).

The area is drained by a well integrated, dendritic system of small streams which flow into the Levisa and Tug Forks of the Big Sandy River. The drainage divide between Levisa Fork and Tug Fork is the boundary between Johnson and Martin County. Thus Johnson County is drained by Levisa Fork and Martin County is drained by Tug Fork.

The rocks which crop out in Johnson and Martin Counties are Pennsylvanian in age and consist primarily of coal-bearing rocks of the Breathitt Formation and the underlying Lee Formation. Rocks of the Lee Formation crop out only in the stream valleys of northern Johnson County.

The Breathitt Formation is about 1,800 feet thick, contains all the major coal seams in the study area, and consists of sandstone, siltstone, shale, coal, and underclay. Limestone is relatively rare in the Breathitt Formation. It occurs in shale as nodules and concretions 2-3 feet in diameter and locally forms discontinuous beds or lenses less than 2 feet thick in the Magoffin Member (Outerbridge, 1976).

The Lee Formation is about 300 feet thick and consists mainly of clean orthoquartzite sandstone with thin beds of shale, siltstone, and coal.

The relative position of major coal seams and lithology of rocks which crop out in the area are shown in the generalized stratigraphic column (fig. 2). Detailed stratigraphic columns and lithologic descriptions are given on each 7-1/2 minute geologic quadrangle map listed in the references.

*The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

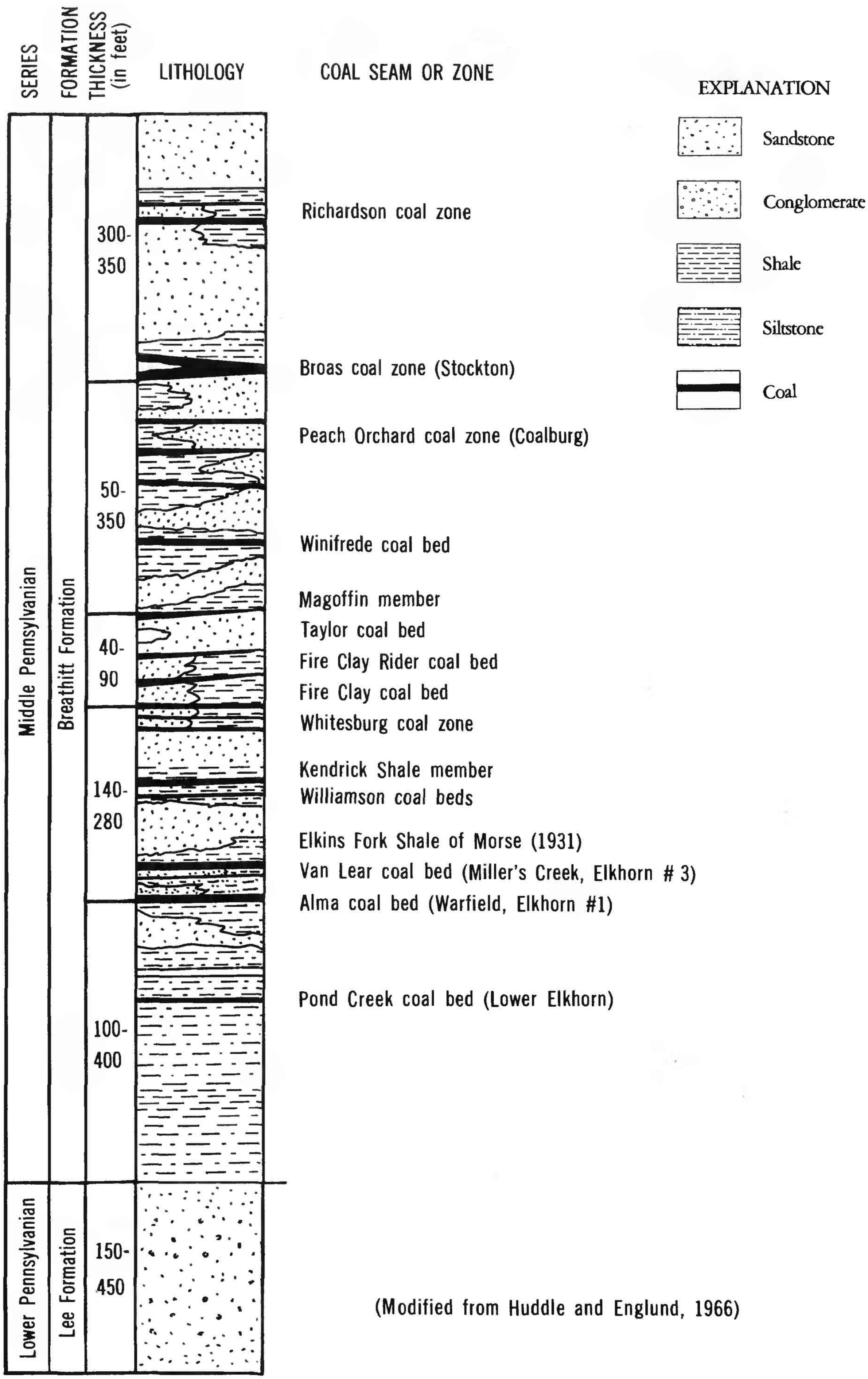

Figure 2. -- Generalized columnar section showing major coal seams in the study area.

Structurally, rocks of the Breathitt Formation are affected by the Irvine-Paint Creek Fault in central Johnson County and the Warfield Fault in eastern Martin County. The Irvine-Paint Creek Fault is a normal fault and downthrown on the south (plate 1). The Warfield Fault also is a normal fault, downthrown on the north, and extends about two miles into the area near Lovely (plate 2). Although the rocks of the area are folded into broad anticlines and synclines, the dip of the rocks is very gently except in the vicinity of the faults where the dip is as much as eight degrees.

The coal seams of major economic importance in the study area are the Van Lear and Alma. The Van Lear seam has been mined extensively in Johnson County near Paintsville and the Alma has been mined primarily in Martin County near Warfield. Coal production was first reported from both counties in 1879. The total production from underground mines through 1975 exceeded 32 million tons for Johnson County and 25 million tons for Martin County (Currens and Smith, 1977).

OCCURRENCE OF WATER IN UNDERGROUND COAL MINES

The occurrence of water in underground coal mines is controlled by many factors. The principal factors are: (1) precipitation, (2) recharge area of the mine, (3) rock fractures (both natural and caused by roof collapse) related to depth to mining horizon, (4) relation of mine openings to dip of the coal seam and (5) position of the mine above or below drainage. The influence of these factors on the occurrence of water in underground mines is discussed below.

Precipitation.--All water in underground mines originates as precipitation which percolates downward to the mined-out areas. Only a small portion of water from a given rainfall percolates directly into an underground mine because some water runs off into streams, some evaporates, and some is used by plants. Precipitation is fairly evenly distributed throughout the year (fig. 3), but high evapotranspiration rates in spring and summer months reduce the volume of water available to percolate into the mines. Most precipitation percolates to the mines from about October to May, when most vegetation is dormant.

Recharge Area.--The recharge area to an underground mine is the land surface above the mine which acts as a catchment and infiltration area for precipitation. During the ground-water recharge season the amount of precipitation which can potentially infiltrate into a mine is largely a function of the size of the mine's recharge area. The recharge area of a mine may be larger than the areal extent of the underground workings, but generally the recharge area is approximately equal to the mine size.

Rock Fractures Related to Depth to Mining Horizon.--The character of the bedrock overburden and the depth to the mined zone below land surface control the quantity of water available to underground mines. In general, rocks of the Eastern Kentucky Coal Field have very low primary permeability,

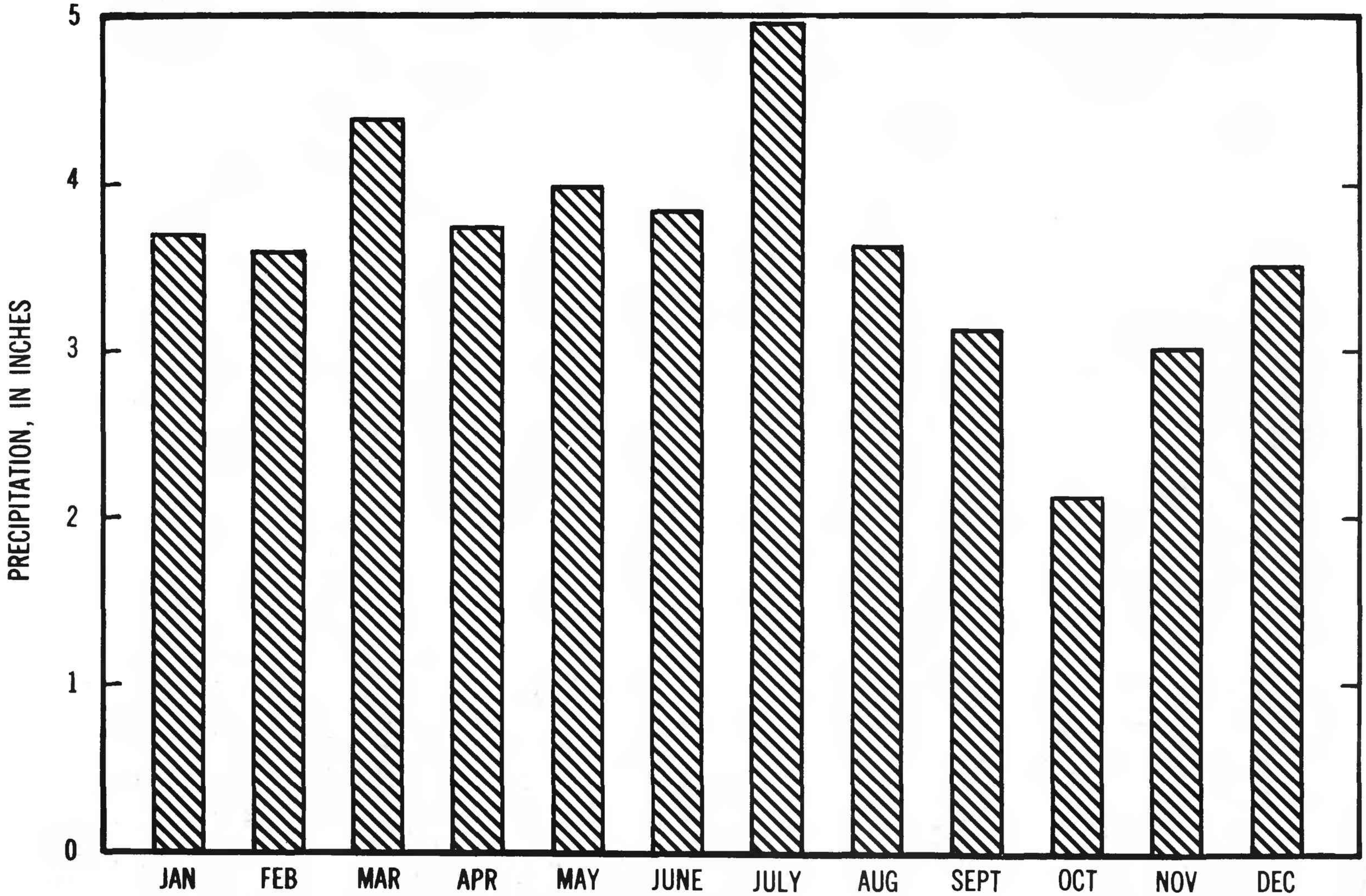

Figure 3. - - Mean monthly precipitation at Paintsville, Kentucky, 1941-1970.

thus most ground-water movement occurs in secondary fractures in the rocks (Price, Mull, and Kilburn, 1962). Secondary permeability is enhanced in rocks overlying coal mines because roof collapse in mined-out areas causes fractures in the overlying rock which may extend to land surface. The extent of roof collapse and resulting fracturing is controlled to a large extent by the type of mining. All underground mines in Johnson and Martin Counties were worked by the room and pillar methods in which coal is removed from rooms on a grid pattern and pillars of coal are left intact to support the roof and prevent land-surface subsidence. Prior to abandonment, pillars are usually removed and the roof is allowed to collapse.

Secondary fractures related to roof collapse are especially significant to vertical flow of water into the mined area and are controlled in part by the depth of the mine below land surface. If roof failure occurs within 150 feet of land surface, the amount of surface subsidence is approximately 50 percent of the thickness of the material removed from the mine (Davis, 1968). However, surface subsidence is only 25 to 30 percent of the thickness when roof failure is approximately 300 feet in depth.

In some mines the roof is supported by backfilling as the mining progresses. This technique reduces the likelihood of roof collapse and also reduces the space available for the storage or movement of water. However, it is likely that the mined areas continue to function as collection galleries because the backfill material is usually more permeable than the undisturbed rock.

Relation of Mine Openings to Dip of Coal Seam.--The relation between the location of the mine openings, and the dip of the coal beds and the occurrence of water in three different types of underground mine entries is shown on figure 4.

Coal mines can be classified as drift, slope, or shaft mines based upon the type of entrance used to access the coal. A drift mine is used where a coal seam crops out on a hillside and the mine is worked directly into the outcrop. Water will discharge naturally or accumulate in the mine depending upon whether the mine was worked up or down the dip of the coal seam (fig. 4, examples 1 and 2). The drift mine is the most common type of coal mine in Johnson and Martin Counties because the hilly topography affords easy access to many coal seams. In cases where a coal seam is relatively close to the land surface, but cannot be reached by a drift mine, an inclined shaft which slopes down to the coal bed is used. This is called a slope mine (fig. 4, examples 4 and 5). When the coal bed lies some distance below the surface, a vertical shaft is used (fig. 4, examples 3 and 6). Although only one shaft mine was found in the study area, water samples were frequently collected from vertical ventilation shafts. Shaft and slope mines are typically used to mine coal below drainage. During active mining, water that accumulates in underground mines is removed by pumping or natural drainage. After abandonment, the water that fills the mine may drain from the mouth depending upon the position of the mine entrance relative to the dip of the coal seam.

EXPLANATION

1. Drift mine - water ponded in mine
2. Drift mine - water flowing from portal
3. Air shaft - no flow
4. Slope mine flooded - no discharge from portal
5. Slope mine flooded - water flowing from portal
6. Air shaft - water flowing

Not to scale

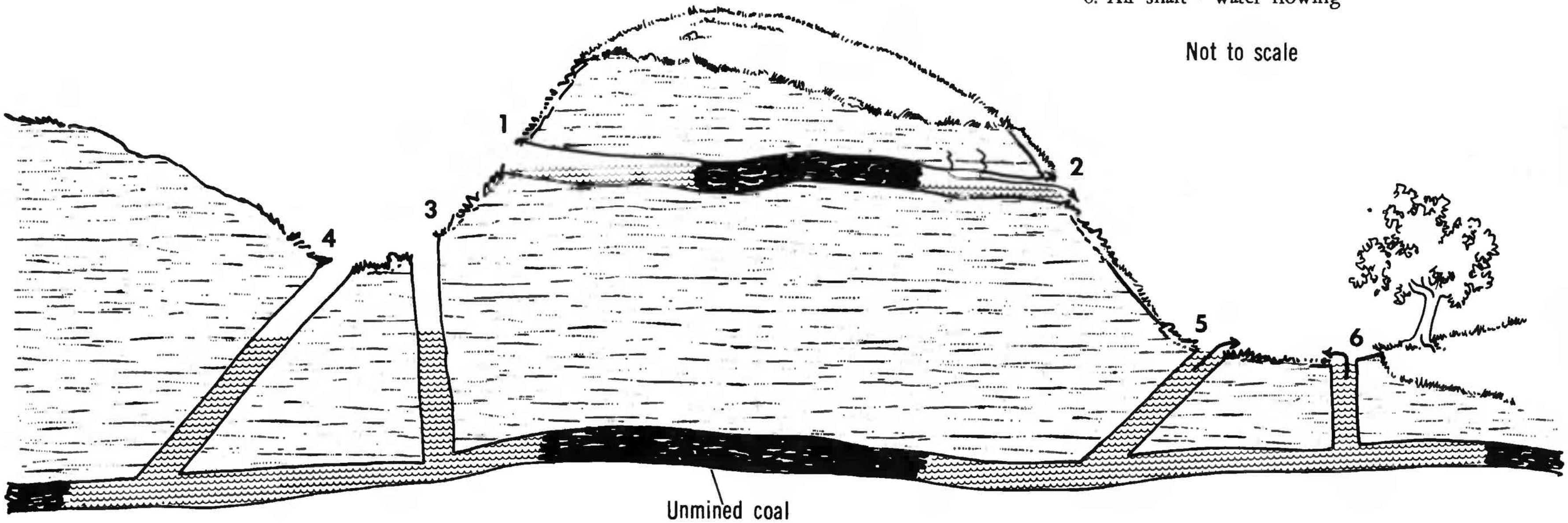

Figure 4.– Occurrence of water in slope mines, drift mines and vertical shafts.

Effect of Mine Location Above or Below Drainage.--The location of mines relative to drainage is of major importance to the occurrence of water in the mines. For this report, mines are classed as below drainage if the mine galleries are at lower elevations than the nearest perennial stream. Mines worked below the level of perennial streams are usually below the regional water table. Thus, mines below drainage receive recharge from the surface and from ground water in the surrounding saturated rocks. The mines below drainage are almost always flooded because water accumulates in the mine. Usually there is no water discharge from the slope or shaft openings (fig. 4, examples 3 and 4). Under certain conditions however, water will flow from a shaft or slope opening provided the hydraulic head is great enough to cause the water in the mine to rise to land surface (fig. 4, examples 5 and 6).

EVALUATING THE WATER-SUPPLY POTENTIAL OF UNDERGROUND COAL MINES

The quality and quantity of water should be evaluated when planning to use a coal mine as a water supply. Although the quality of raw mine water may be undesirable, modern treatment procedures can usually produce water of acceptable quality for almost any use. Because the chemical quality of mine water usually can be improved by treatment, the primary factor is usually the quantity of water which the mine can dependably supply throughout the year.

The two most important hydrologic factors that must be known to evaluate a mine as a potential water supply are the water in storage and recharge rate. The volume of water in the mine is water in storage; the rate which water replenishes storage is the recharge rate. Obviously, a mine having both a large storage volume and rapid recharge rate will provide the most reliable water supply. A large storage volume provides a margin of safety against sudden increases in demand or seasonal fluctuations of recharge rate or both, and a rapid recharge rate will allow water to be replenished to the mine as it is used.

To define the seasonal variation of mine discharge, the discharge from selected mines in Johnson and Martin Counties shown on plates 1 and 2 was measured during the wet and dry season throughout the study period. These measurements are listed by site number and date of observation on tables 3 and 4.

Accurate evaluation of the storage and recharge characteristics of coal mines will vary considerably depending upon whether the mines are located above or below drainage. The water-supply characteristics of above-drainage mines can be determined in part by simply measuring water flowing from mine openings. However, below-drainage mines usually have no natural surface drainage and are more difficult to evaluate. The water-supply potential of below-drainage mines is discussed separately from mines above drainage in a following section.

Table 3.--Field measurements of mine discharge, specific conductance and pH, Martin County

Site	Date	Discharge (gal/min)	Specific conductance (micromhos per cm at 25°C)	pH (units)
1	8-12-75	NF	100	6.4
	6- 9-76	NF	280	6.1
	7-27-76	NF	280	6.2
	8-31-77	NF	83	6.5
	11-10-77	NF	125	6.5
2	9- 3-75	-	1,500	4.8
	4-27-76	76	2,000	5.0
	6- 9-76	89	1,900	4.9
	5-18-77	63	2,800	4.0
	12- 5-77	215	1,600	4.9
	12-21-77	125	1,875	4.7
3	11-21-77	23	1,820	5.8
	12-21-77	34	1,790	5.7
	1-24-78	53	-	-
4	3-10-76	3	900	5.1
5	8-12-75	NF	260	6.9
	6- 9-76	NF	350	4.5
	4-27-77	NF	320	5.0
	9-20-77	NF	925	6.4
	11-10-77	NF	310	6.3
	3- 6-78	NF	510	6.4
	3- 6-78	NF	810	6.3
6	6- 4-75	- a/	7,000	7.4
7	6- 4-75	- a/	3,750	7.1
8	6- 4-75	-	7,000	7.9
9	5-21-75	NF	340	6.6
	7-14-76	NF	390	6.6
	11-10-77	NF	350	6.6
10	6- 4-75	-	2,100	7.7
11	6-18-75	NF	65	5.6
12	6-18-75	NF	245	4.9
13	6-18-75	NF	160	5.8
14	6-18-75	NF	210	6.6
15	6-18-75	NF	305	6.0
16	10- 6-77	90	975	6.9
	11-17-77	150	950	7.1
17	3-10-76	-	1,200	6.6
	7-14-76	-	1,050	6.3
18	3-10-76	-	1,100	6.6
	7-14-76	-	640	6.9
19	7- 9-76	NF	150	6.5
20	-	NF	410	6.5
20A	3-31-78	750 b/	-	7.3

a/ Total pumpage from sites 6 and 7 during mining was estimated at 800,000 gal/d. Mine presently being filled with sludge.
b/ Mine pumped 15-20 minutes daily.
NF No flow.

Table 4.--Field measurements of mine discharge, specific conductance and pH, Johnson County

Site	Date	Discharge (gal/min)	Specific conductance (micromhos per cm at 25°C)	pH (units)	Site	Date	Discharge (gal/min)	Specific conductance (micromhos per cm at 25°C)	pH (units)
21	3-10-76	45	615	7.5	23	4- 9-76	60	685	3.8
	4-27-76	73	800	7.0		4-27-76	44	800	5.0
	6-10-76	40	820	7.4		6-10-76	14	925	4.0
	8-11-76	27	800	7.2		8-11-76	11	930	4.0
	8-31-76	24	900	7.1		8-31-76	2	1,100	4.2
	10-26-76	40	760	7.5		10-26-76	15	750	4.0
	11-10-77	40	805	6.3		11-16-77	NF	965	4.0
	12- 5-77	64	805	6.2	24	4-28-76	3	860	4.4
	12- 7-77	64	750	6.4		4- 9-76	10	770	3.7
	12-20-77	53	805	6.4		11-16-77	16	1,010	4.0
	1-23-78	82	740	6.6		12- 8-77	33	965	3.8
	1-25-78	180	715	6.5		12-20-77	18	1,050	3.8
	1-25-78	200	760	6.5		1-25-76	60	-	-
	1-26-78	1,700	535	6.3	25	4- 9-76	10	360	4.6
	1-27-78	600	495	6.3	26	4-28-76	6	590	5.0
	1-27-78	430	520	6.3		6-10-76	4	650	4.8
22	4-13-76	25	560	5.0		8-31-76	2	850	5.2
	4-28-76	65	660	5.0		11-10-77	3	740	5.2
	6-30-76	50	600	5.7		12-20-77	4	750	4.8
	8-31-76	29	850	5.2	27	4- 9-76	12	1,200	4.3
	10-26-76	31	845	4.5		4-27-76	18	1,700	5.0
	11-10-77	23	910	5.5		8-11-76	17	1,550	4.5
	12- 5-77	37	930	5.6		11-16-77	20	1,550	6.1
	12- 7-77	36	930	5.5		12-20-77	29	1,600	6.1
	12-20-77	47	910	5.5		1- 5-78	27	1,600	6.0
	1-23-78	51	880	5.6					

NF No flow.

Table 4.--Field measurments of mine discharge, specific conductance and pH, Johnson County--Continued

Site	Date	Discharge (gal/min)	Specific conductance (micromhos per cm at 25°C)	pH (units)	Site	Date	Discharge (gal/min)	Specific conductance (micromhos per cm at 25°C)	pH (units)
28	4- 9-76	9	560	3.9	43	3-11-76	3	200	5.3
	6-10-76	-	825	4.0	44	3- 8-78	NF	230	5.7
	11-11-77	10	1,000	6.9	45	3- 8-78	NF	700	7.1
	12-20-77	12	950	6.9	47	9- 1-77	NF	540	6.7
29	4- 9-76	9	1,000	5.0		11-17-77	NF	480	6.8
30	11-11-77	3	890	4.6	49	4- 7-76	10	340	6.0
31	11-11-77	2	1,420	3.2	50	4- 8-76	NF	170	5.5
32	4-13-76	1	510	4.7	51	4- 9-76	<1	360	3.7
33	12- 8-77	NF	540	6.5	52	4- 9-76	3	790	4.0
34	3-11-76	3	875	5.1		6-30-76	NF	1,650	3.5
35	12- 8-77	6	810	4.8		11- 9-77	3	1,490	3.6
36	12- 8-77	1	480	4.2	53	4-13-76	2	230	4.0
37	12- 8-77	2	1,000	4.8	54	3-17-76	NF	530	3.5
38	12- 8-77	5	520	4.5		6-29-76	NF	1,500	3.1
39	4- 5-78	35	980	5.9		11-21-77	NF	495	3.6
40	12- 8-77	4	450	6.7	55	3-11-76	8	5,000	5.1
41	12- 8-77	35	1,180	4.0	56	3-11-76	2	340	5.1
	12-21-77	19	1,385	3.8	57	3-11-76	5	255	4.0
	1- 5-78	17	1,340	3.9	58	6-29-76	-	505	6.5
	1-24-78	40	-	-		9-21-77	10	470	6.5
42	3-11-76	20	750	3.7		11- 9-77	5	450	6.4
	4-27-76	1	850	4.8		12-19-77	20	395	6.2
	9-29-76	10	700	3.7	59	6-29-76	10	570	7.2
	11-14-77	18	770	3.8		11- 9-77	6	740	4.6
	12-19-77	15	740	4.0		12-19-77	9	655	6.9

NF No flow.

Table 4.--Field measurements of mine discharge, specific conductance and pH, Johnson County--Continued

Site	Date	Discharge (gal/min)	Specific conductance (micromhos per cm at 25°C)	pH (units)
60	3-17-76	NF	310	5.5
	6-29-76	NF	318	5.9
	11- 9-77	NF	330	5.5
61	3-17-76	4	850	6.3
62	3-17-76	4	940	5.2
63	3-30-76	60	900	5.0
	4-27-76	3	1,100	4.0
	6- 7-77	NF	-	-
64	3-31-76	NF	2,900	3.1
65	4- 7-76	<1	340	5.4
	12- 7-77	<1	420	5.2
66	4- 7-76	6	520	4.0
	7-15-76	8	760	4.2
	11-11-77	-	785	4.3
	12-21-77	8	730	4.1
67	4- 7-76	NF	800	3.3
	12- 7-77	2	800	3.6
68	4- 7-76	1	440	4.0
	12- 7-77	NF	280	3.8
69	12- 7-77	5	790	3.9
70	4- 8-76	6	1,400	3.4
	4- 8-76	10	1,200	3.8
71	4- 1-76	1	260	5.1
72	4- 1-76	3	360	6.1
73	8-12-76	NF	330	7.0
	11-11-77	NF	270	6.2
	12-21-77	NF	230	6.7
74	6- 8-76	-	2,180	4.1
	5-27-76	-	1,850	7.2
	9- 1-76	750	-	-
	11-11-77	-	1,920	6.9
	12-21-77	-	1,940	7.2
	1- 4-78	1,200	-	-
75	5-27-76	NF	710	6.7
	7-15-76	NF	900	8.0
	11-17-77	NF	530	6.7
76	5-27-76	NF	270	7.2
	8-11-76	NF	400	6.2
	11-11-77	NF	380	7.2
77	3-10-76	10	660	6.3
78	11-11-77	-a/	2,100	6.9

a/ Water is pumped from airshaft to supply 11 houses.
NF No flow.

Mines Above Drainage

Mines are classified in this report as "above drainage" if the mine galleries are at higher elevations than the nearest perennial stream. The quantity of water available from above-drainage mines can best be estimated by measuring the range of discharge from each mine for a period of at least one year. The flow from the mine represents the maximum quantity of water available unless additional water is available from storage within the mine. Because mine-discharge changes seasonally, the amount of water available for use is highly variable. A water supply from above-drainage mines can be made more dependable by sealing the mine openings allowing wet-weather flows to be impounded within the mine for use during low-flow periods.

The seasonal variability of flow from above-drainage mines is illustrated in figure 5. Entrances to two mines, North East Coal Company Mines No. 1 and No. 3 (sites 21 and 22), were equipped with V-notch weirs and water-level recorders to monitor seasonal variability of mine-water discharge. Other entrances discharge water from these mines but were not monitored on a continuous basis. The 1-year period of record from May 15, 1977, through May 15, 1978, shows that discharge from both mine entries was variable, although discharge from the portal of the North East Coal Company Mine No. 3 at site 22 was less variable than discharge from the Mine No. 1 portal at site 21. Discharge from site 21 was in fact the most variable of any mine entry measured in Johnson or Martin County during this investigation. Discharge from this mine entry responded rapidly to precipitation and ranged from 23 to 1,700 gal/min during the period of record. Discharge from the larger North East Coal Company No. 4 Mine at site 22 was less but considerably more uniform, ranging between 23 to 80 gal/min. The difference in response of the two sites can be explained in part by the character of the openings from which the water discharges. The mine entry at site 22 has collapsed, thereby impounding water behind the fallen debris. Water bubbles up as a spring in front of the dam. However, the portal at Number 1 Mine (site 21) is open and water flows freely from it.

The hydrograph in figure 5 shows that base flow from both mines begins to increase in early November. With the exception of the series of storms from August 11-14, the intense summer rains of 1977 did not significantly affect the discharge of either mine. Apparently, the precipitation during August exceeded evapotranspiration demands and recharge to the mines was sufficient to increase discharge. The hydrograph for each mine shows peaks in mid-January and March with lesser peaks in late April of 1978. These peaks show the effect of relatively heavy rainfall preceded by periods of average precipitation in winter months while vegetation was dormant.

The difference in mine discharge during summer and winter months can be quantified by analyzing discharge as a percentage of precipitation falling on the mined-out area. During the recharge months November 1977 to May 1978, precipitation totalled 601 acre-feet on the 275 acre surface area of the North East Coal Company Mine No. 1. Mine discharge measured from the entry at site 21 was 168 acre-feet for the same period. This site is the only

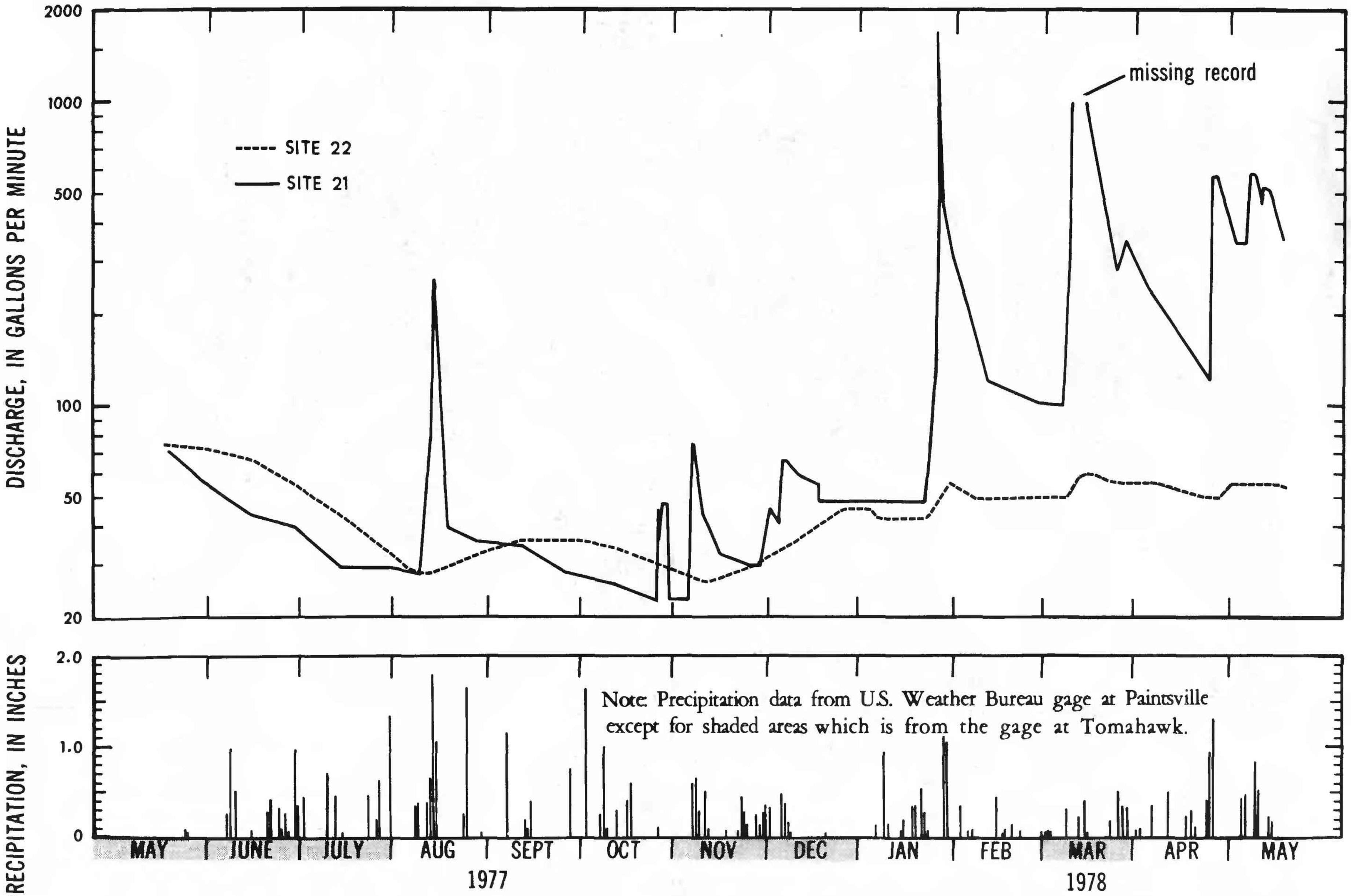

Figure 5. – Hydrograph of discharge from mine entries at sites 21 and 22 and precipitation for the period of record May 15, 1977 through May 15, 1978.

outlet for water from the mine other than the small flow measured at site 74. If only discharge from site 21 is considered, discharge from the North East Coal Company Mine No. 1 was 28 percent of incident precipitation during the recharge season. During the period June-September, 1977, precipitation totaled 517 acre-feet but discharge from the mine at site 22 was only 24 acre-feet which was less than 5 percent of the total precipitation during the period.

The potential of a coal mine to provide large quantities of water throughout the year is dependent to a great extent upon the size of the mine. Obviously a large mine should be able to supply more water than a small mine. Since many of the large mines discharge water through several openings, the range of discharge from an individual mine was estimated by summing the flows for all points of discharge from that mine (table 5). The estimates are subject to potentially large error because the mine-discharge was sampled with varying frequencies and at different times of the year.

The quantitative relation between the amount of water discharging from a mine and the size of mined area is illustrated on figure 6. This graph shows the relation between the total discharge from a particular mine (table 5) and the mined area as calculated from mine maps on file at the Institute for Mining and Mineral Research, Lexington, Kentucky. The highest and lowest totaled discharges from all openings from a particular mine were plotted to show a range of total discharge from each mine (fig. 6). The figure illustrates the strong correlation between mine size and discharge. This relation was expected because large mined areas have large recharge areas. Although this relation was developed only for above-drainage mines, a similar relation probably exists between mine size and recharge rates for mines below drainage. It is the large mines therefore, both above and below drainage, which have the greatest potential as sources for water supply.

The total, annual discharge from selected mines was calculated as a percentage of the total amount of precipitation falling on the surface area of the mine during the year (table 6). The annual discharge of all mines analyzed varied from 3 to 10 percent of annual, incident precipitation with the exception of North East Coal Company Mine No. 1 and Stambaugh Coal Company Mines No. 1 and 2. The variation in discharge as a percent of precipitation is probably controlled by many factors including: duration and intensity of precipitation, depth to mining horizon, degree of fracturing, and degree of hydrologic connection within the mine. If discharge is 3 to 10 percent of incident precipitation for most mines, then the expected range of average discharge from mines of various sizes is shown on figure 7 based on an annual precipitation of 43.6 inches.

Based upon discharge rates measured during the study period, the above-drainage mines with the best water-supply potential in the study area are listed in table 7. The post-mining volume of each mine is listed as an estimate of the maximum potential water-storage capacity. It is likely that only a small percentage of the post-mining volume contains water in above-drainage mines because water is generally free to drain from the mine. Thus

Table 5.--Maximum, minimum, and mean mine discharges calculated as sum of discharge from all entries for selected above-drainage mines

Mine name	Site number of mine entry where water discharges	Minimum discharge measured at site (gal/min)	Maximum discharge measured at site (gal/min)	Mean discharge (gal/min)	Number of discharge measurements
Stambaugh Coal Co. Mines No. 1 and No. 2.	42	1	20	13	5
	43	3	3	3	1
	Total of all sites	4	23	16	6
William's Mining Co. No. 1	66	6	8	7	3
	Total of all sites	6	8	7	3
M & P Coal Co. No. 1	58	5	20	12	3
	Total of all sites	5	20	12	3
Hagar Hill Mining Co. No. 1 and No. 2	59	6	10	8	3
	60	0	0	0	3
	Total of all sites	6	10	8	6
Tutor Key Coal Co. No. 1	41	17	40	28	4
	Total of all sites	17	40	28	4
North East Coal Co. No. 1	21	25	1700	120	Continuous gage
	77	10	10	10	1
	Total of all sites	35	1710	130	–
North East Coal Co. No. 5	34	3	3	3	1
	35	6	6	6	1
	36	1	1	1	1
	37	2	2	2	1
	38	5	5	5	1
	39	35	35	35	1
	Total of all sites	52	52	52	6
North East Coal Co. No. 2	26	2	6	4	5
	27	12	29	21	6
	28	9	12	10	3
	29	9	9	9	1
	30	3	3	3	1
	31	2	2	2	1
	Total of all sites	37	61	49	17
North East Coal Co. No. 3 and No. 4	22	23	74	45	Continuous gage
	23	0	60	21	7
	24	3	60	23	6
	25	10	10	10	1
	Total of all sites	36	195	99	–
Buck Creek Coal Co., Himmler and Earlston Mines and Collins Creek Coal Co. Sluss Mine (connected)	2	76	215	108	4
	3	23	54	37	3
	4	3	3	3	1
	Total of all sites	102	272	148	8
Consolidated Coal Co. No. 151-155	74	750	1200	975	2
	Total of all sites	750	1200	975	2

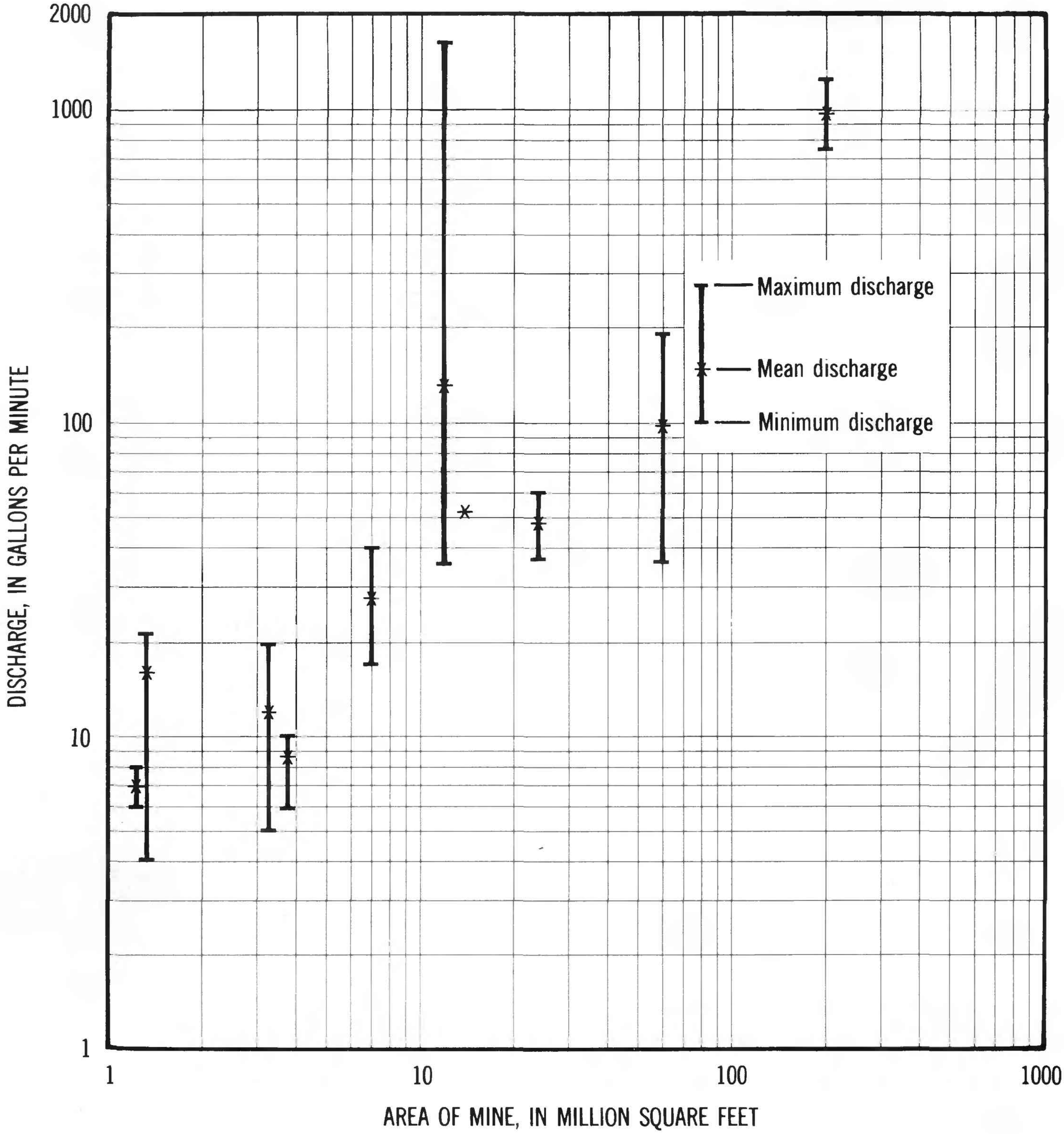

Figure 6.-- Relation of mine size to total discharge measured from above-drainage mines.

Table 6.--Calculation of mine discharge as percent of precipitation on land surface above mine.

Mine name	Average mine discharge from all entries (gal/min)	Average mine discharge from all entries (M ft^3/yr)	Areal extent of mine (M ft^2)	Mean, annual precipitation at Paintsville 1975-77 (ft/yr)	Total incident precipitation on mine per year (M ft^3/yr)	Mine discharge as percent of incident precipitation
Stambaugh Coal Co. Mines No. 1 and No. 2	16	1.12	1.3	3.66	4.8	23
William's Mining Co. No. 1	7	.49	1.3	3.66	4.8	10
M & P Coal Co. No. 1	12	.84	3.3	3.66	12.1	7
Hagar Hill Mining Co. No. 1 and No. 2	8	.56	3.8	3.66	13.9	4
Tutor Key Coal Co. No. 1	28	1.97	6.8	3.66	24.9	8
North East Coal Co. No. 1	130	9.13	12	3.66	43.9	21
North East Coal Co. No. 5	52	3.65	13.6	3.66	49.8	7
North East Coal Co. No. 2	49	3.44	23.6	3.66	86.4	4
North East Coal Co. No. 3 and No. 4	99	6.96	58.4	3.66	213	3
Buck Creek Coal Co., Himmler and Earlston Mines; Collins Creek Coal Co., Sluss Mine	148	10.4	78	3.66	285	4
Consolidated Coal Co. No. 151-155	975	68.5	204	3.66	747	9

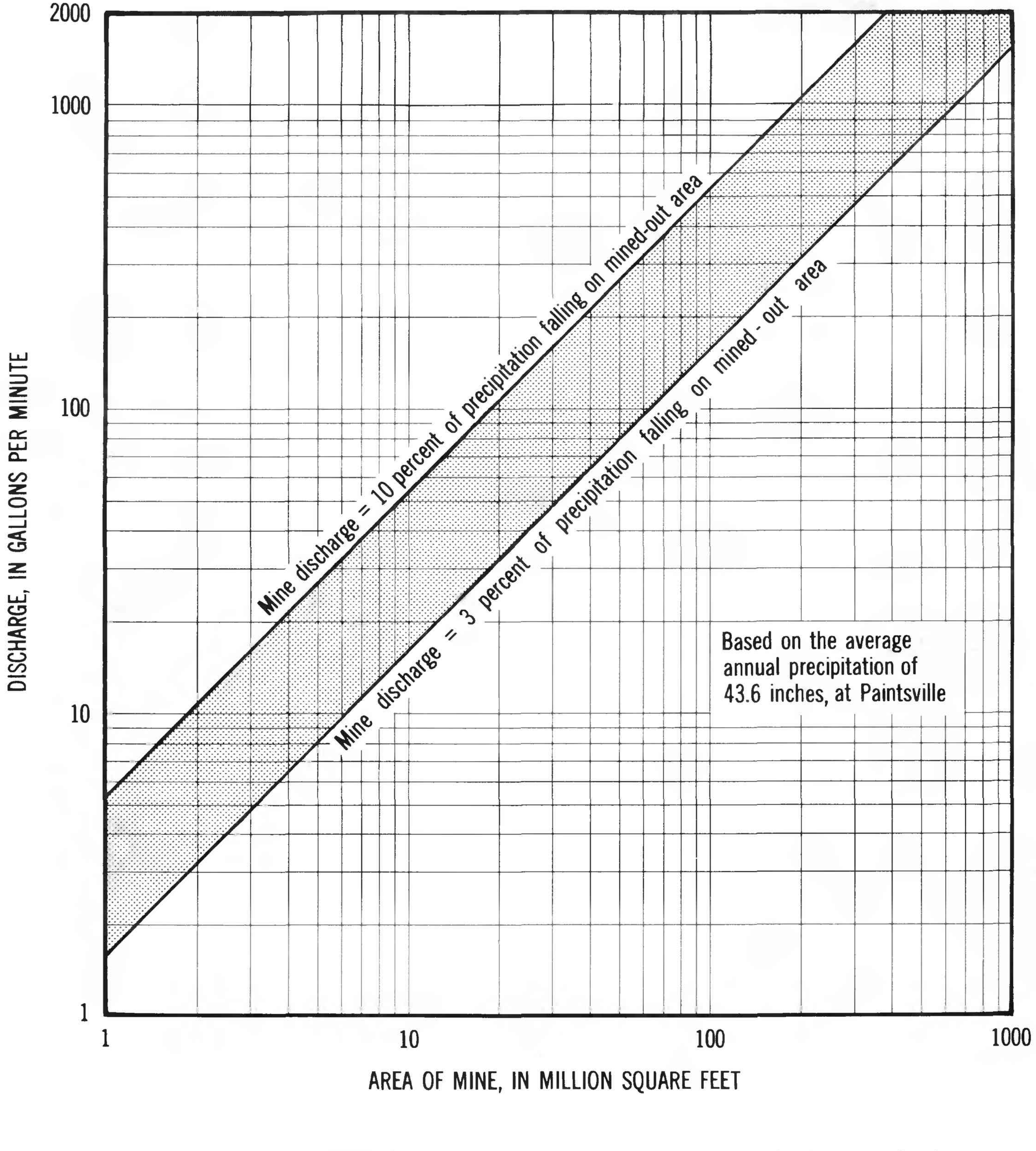

Figure 7. -- Range of average discharge (totaled from all discharge points) for mines above drainage.

Table 7.--Above-drainage mines with best water-supply potential

Site number of mine opening	Name	Estimated storage volume (M ft^3)	Range of discharge from single opening (gal/min)	Coal seam mined	Remarks
2	Buck Creek Coal Co., Coleman Mine	195	63- 215	Alma	Reportedly connected with Himmler, Earlston and Sluss mines. Flows freely from main portal.
3	Buck Creek Coal Co., Coleman Mine	195	17- 40	Alma	Reportedly connected with larger Himmler, Earlston and Sluss mines. Water discharges as spring, not from a mine opening.
6	Martin County Coal Co., Coalburg Mine No. 1	22	90- 150	Peach Orchard	Water pumped from working mine.
21	North East Coal Co., Mine No. 1	30	24-1,700	Van Lear	Water discharges freely from open portal.
22	North East Coal Co., Mine No. 3	146	23- 65	Van Lear	N.E.C.C. Mines 3 and 4 reportedly connected. Discharges through collapsed adit.
24	North East Coal Co., Mine No. 4	146	16- 60	Van Lear	N.E.C.C. Mines 3 and 4 reportedly connected. Discharges from collapsed adit.
27	North East Coal Co., Mine No. 2	59	12- 27	Van Lear	Water discharges through collapsed adit. Water used by local resident for washing.
39	North East Coal Co., Mine No. 5	34	35	Van Lear	Reportedly flows all year.
41	Tutor Key Coal Co., Mine No. 1	17	17- 40	Van Lear	Flows from pipe driven into mine. Used by local resident for nondrinking purposes.
74	Consolidation Coal Co., Mines 151-155	510	750-1,200	Van Lear	Reportedly connected with N.E.C.C. No. 11 which provides water of identical quality for 11 modern homes at sites 76 and 78.

the mine volume is an indication of the storage potential which could be utilized if the mines were sealed and allowed to flood.

All the mines listed in table 7 were discharging more than 10 gal/min from at least one opening when they were field-checked. The range of discharge listed is from a single mine opening identified by site number. Additional entries of the same mine which discharge less than 10 gal/min are summarized on tables 3 and 4. The greatest measured discharge was 1,700 gal/min from the North East Coal Company No. 1 Mine portal at site 21. Discharge from the mine at this site usually ranged from 25 to 200 gal/min. Discharge from the Buck Creek Coal Company, Coleman Mine at site 2 in Martin County exceeded 200 gal/min periodically, but flow was generally less than 100 gal/min. The highest sustained flow was measured at a discharge pipe which reportedly drains the abandoned galleries of the Consolidated Coal Company Mines 151-155 at site 74 in Johnson County. During the study period these mines continuously discharged between 750 and 1,200 gal/min into John's Creek near Van Lear.

Mines Below Drainage

The volume of water in an abandoned below-drainage mine is usually large because all openings are filled with water. Mines below drainage generally do not discharge water from slope or shaft entries. Thus the recharge characteristics and water-supply potential of these mines can best be estimated by test pumping. In addition, valuable information on the water conditions in the mine during mining can be supplied by coal operators and miners. Based on information from miners and limited test pumping, the below-drainage mines with the best water-supply potential in the study area are listed in table 8. The site numbers indicate the principal points of access to water in each mine. The post-mining volume of each mine is listed as an estimate of the maximum water-storage capacity. The estimated storage volume is based on mine maps and the assumption that 50 percent of a 5-foot coal bed was removed from the mine.

A simplified model of the hydrologic system is proposed for below-drainage mines based on results of two pumping tests. After a rainfall, water infiltrates into an abandoned mine mainly through cracks and fractures in the rocks. The mine and fractures in the rock are saturated to the level of the potentiometric surface. When water is pumped from the mine the pressure in the mine is reduced allowing fractures to dewater vertically into the mine. Horizontal permeability of rocks above the coal mine is probably low so lateral ground-water flow to the mine is restricted. In the summer months when most precipitation is used by plants or evaporated, the mine is recharged only very slowly through vertical fractures. During the late fall and spring months, when vegetation is dormant and precipitation quickly replenishes fractures, mine recharge is relatively rapid.

Table 8.--Below-drainage mines with best water-supply potential

Site number of mine opening	Name	Estimated storage volume (M ft³)	Estimated water in storage (M gal)	Coal seam mined	Remarks
1	Buck Creek Coal Co., Himmler Mine	195	1,462	Alma	Connected with Earlston, Sluss, and Coleman Mines. Water from Buck Creek enters mine through roof collapse. Water pumped during mining reportedly very corrosive.
5	Warfield Mining Co., No. 1 Mine	5.7	42.7	Alma	Mine flooded. During mining, dewatering reportedly required pumping at 5,000-10,000 gal/d. Warfield pumped 3,000 gal/d for emergency water supply.
18	Martin County Coal, No. 1 Stockton	3	22.5	Broas	Water reportedly pumped 4 months at 100,000 gal/d during mining. Water levels recovered 2 days after pumping stopped.
46	White Ash Coal Co., No. 1 Mine	46	345	Van Lear	Active mine. Mine is flooding as mining moves updip. Dewatering reportedly requires pumping 6 hours per day from 3 in. line.
47	Millers Creek Co-op, Inc., Whitehouse Mine	38	285	Van Lear	Mine flooded. Water pumped 5 hours at 10 gal/min. No drawdown. Attempted dewatering required pumping 1 month with 8 in. high pressure pump. Water level reportedly lowered 80 ft.
48	Royal Collieries, Offutt Mine	30	225	Van Lear	Mine flooded. Roof collapse and fractures in land surface common.
58	M & P Coal Co., No. 1 Mine	8.3	62.3	Van Lear	Mine flooded. Airshaft discharges about 10 gal/min.

Test Pumping

Two small below-drainage mines were tested with a centrifugal pump capable of pumping 800 gal/min. The pump was positioned at the flooded air shaft of one mine and slope entry of another. The pump could not be lowered into either mine, thus drawdown was limited to the lift capacity of the pump, or about 15 feet below land surface. The water level was observed on staff gages installed at each site. A flow meter on the discharge line measured the discharge rate and recorded the total water pumped from each mine. Water pumped from the mines was discharged into William's Branch during one test and Tug Fork in the other test.

Test pumping illustrates the difficulty of evaluating the dependability of a water supply from a below-drainage mine. Tests conducted in dry summer months may indicate little water-supply potential, but pumping the same mine during the wetter spring months might suggest that greater water supply is possible. The seasonal variation in recharge rates shown by test pumping of below-drainage mines is analogous to the seasonal changes in flow observed from above-drainage mines.

Results of Test Pumping at Site 5

The abandoned Warfield Mining Company Mine No. 1 (site 5) was test-pumped on September 20, 1977, and again on March 6, 1978. The slope entry is about 300 feet west of Tug Fork and is reportedly 56 feet above the Alma (Warfield) coal seam. Coal was removed by conventional room and pillar methods and mine maps indicate that mine pillars were removed in only a few sections. During active mining, the mine was dewatered by pumping at a reported rate of 5,000-10,000 gal/d (gallons per day). After mining ceased in 1963 the mine reportedly flooded overnight following the blasting of a nearby gas well.

The first pumping test was conducted September 20, 1977, at the slope entry of the mine. During the 6-hour test, the pumping rate was 560 gal/min. Water-level drawdown in the slope is shown on the time-drawdown curves on figure 8. Note that at least 34,000 gallons of water had to be pumped to cause 1 foot of drawdown. Removal of water from storage in the slope entry accounted for only about 1,500 gallons per foot of drawdown. Larger storage was being tapped or water was rapidly recharging the mine as pumping continued. The 77-day recovery data shown on figure 9 tends to discount the possibility of rapid recharge because recovery to the mine from September 20 to November 3 amounted to only 1.16 foot or a rate of 1,150 gal/d. Thus, most of the water pumped was from storage in the main body of the mine and from fractures which were dewatered as pumping progressed.

There is a break in the time-drawdown curve for the time when pumping stopped. When pumping resumed, the slope of the drawdown curve was not as steep as during the first part of the test. This suggests that either the inclined shaft is larger at this level or that a larger section of the mine

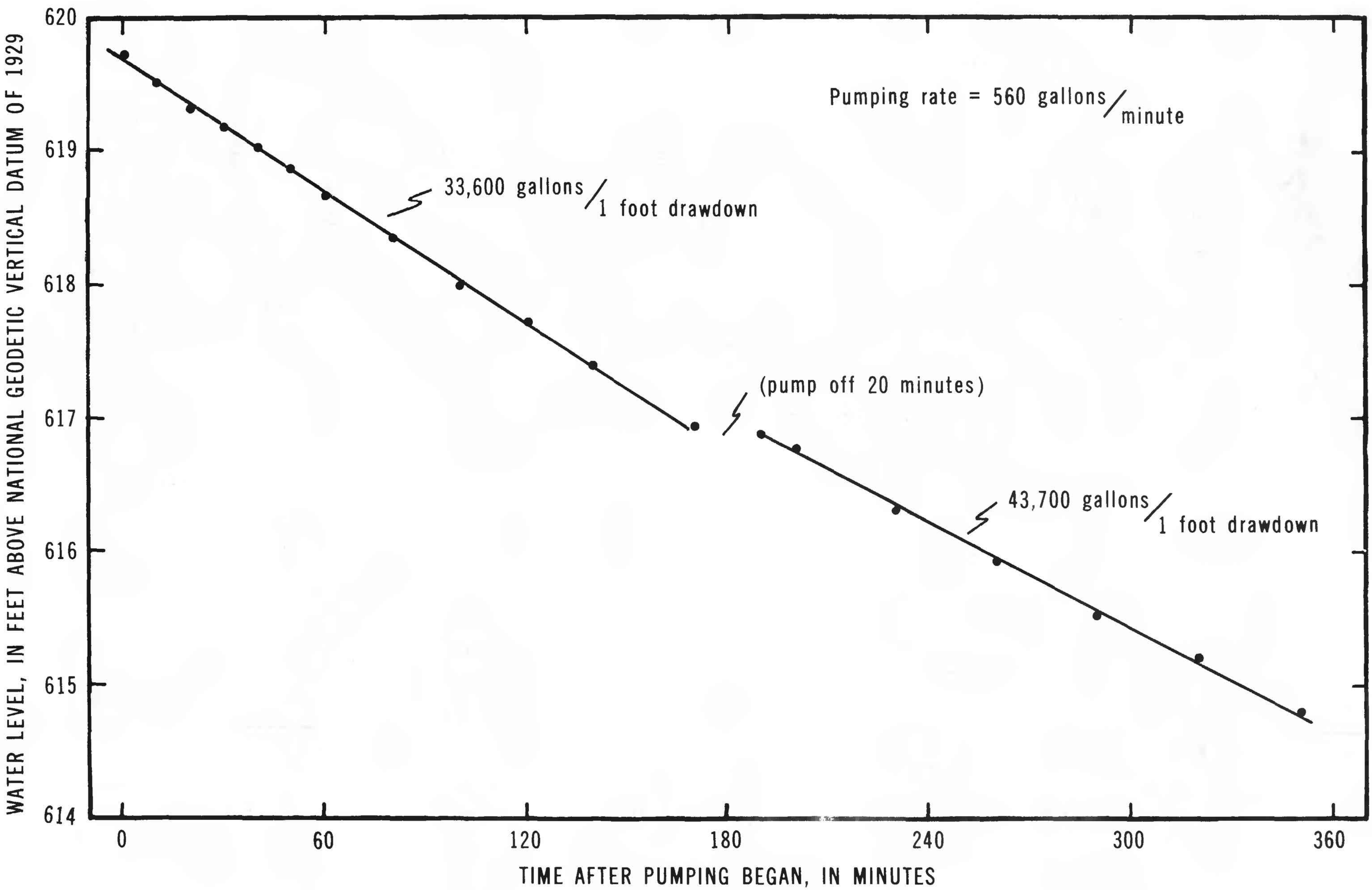

Figure 8 -- Time-drawdown relation, test pumping at site 5, September 20, 1977.

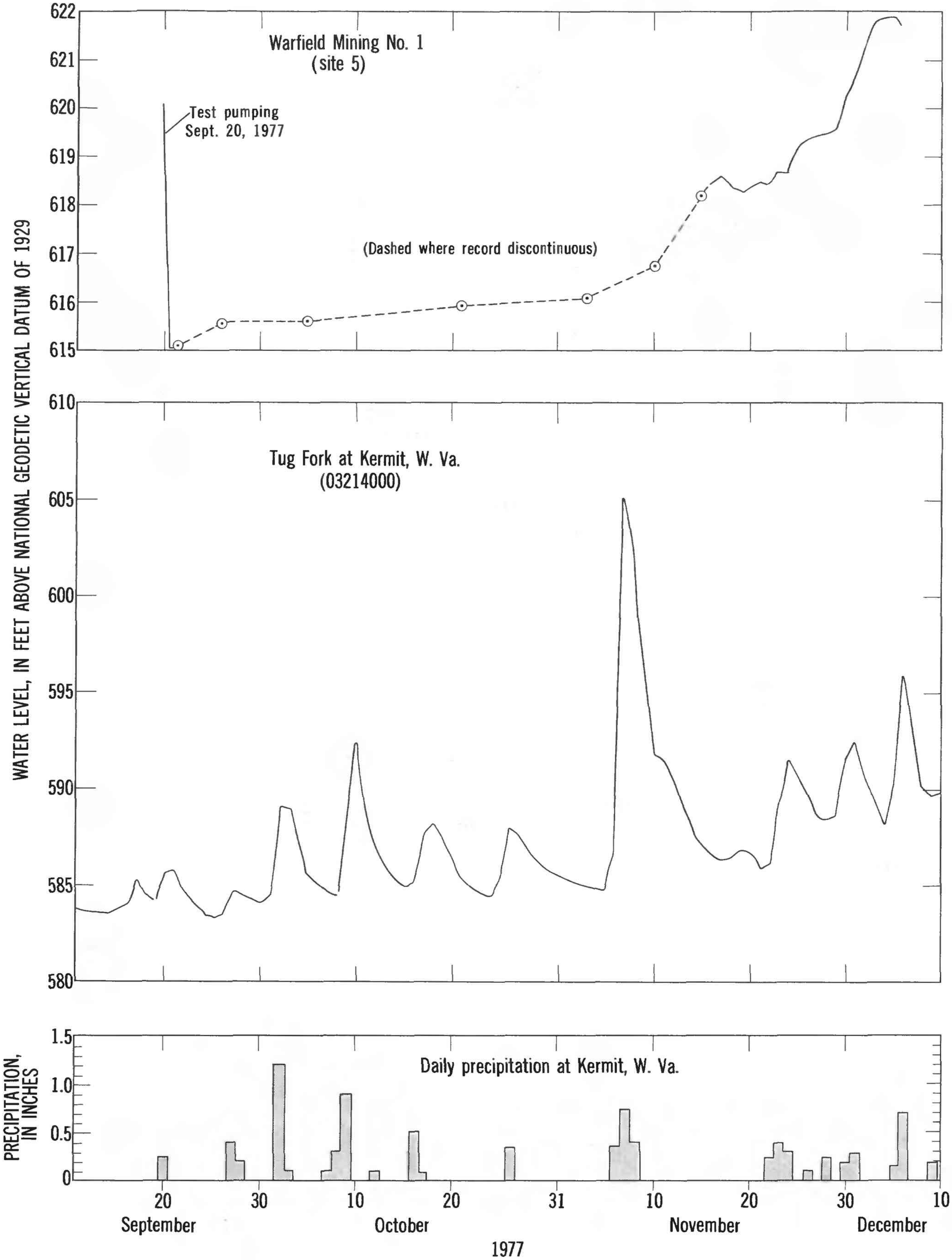

Figure 9.-- Hydrograph of water levels at site 5 after test pumping September 20, 1977, precipitation and stage of the Tug Fork at Kermit, West Virginia.

galleries was being dewatered. Whatever the cause, when the water reached 616.9 feet, more pumpage was required to lower the free water surface in the mine than during the first part of the test and the slope of the time-drawdown curve decreased. It is likely that the slope of the time-drawdown curve would decrease even more during dewatering if the estimated storage volume of 5.7 M ft^3 (million cubic feet) (table 8) is reasonably accurate. This volume would contain about 42.7 Mgal of water. Based on this volume and about 56 feet of available drawdown, a withdrawal rate of 760,000 gallons per foot of drawdown would be required to dewater the mine.

Therefore, the water in storage represents a safety factor sufficient to provide water through periods of limited recharge to the mine. Although the pumping tests indicated that the yield per foot of drawdown was increasing with time, it would take additional pumpage to verify the quantity of water in storage and the shape of the time-drawdown curve. However, the recovery data from this short test does indicate the recharge rates to the mine.

Water-level recovery in the mine was monitored by an automatic water-level recorder. The rate of recovery began to increase around November 3 (fig. 9) and reflects the seasonal ground-water recharge when plants are dormant. The average recovery rate of 1,150 gal/d prior to November 3 was probably due mainly to slow, horizontal movement of water from the regional ground-water body. Direct infiltration of precipitation was probably of minor importance. After November 3, however, the increased recovery rate is probably the result of an increase in recharge from precipitation. For example, during the period November 3-17, the average recovery rate was 6,630 gal/d. If the component from the regional ground-water body (1,150 gal/d) is subtracted, recharge from precipitation amounts to 5,480 gal/d. For the entire mined-out area (2.28×10^6 ft^2) this recharge rate is 0.0039 in/d or 3.6 percent of the 1.5 inches of precipitation during the 14-day period. The recovery period from November 21 - December 5 can be analyzed in a similar manner. Average recovery rate (5,260 gal/d) minus the regional ground-water component (1,150 gal/d) equals a recharge rate of 4,110 gal/d which represents 0.0029 in/d or 1.4 percent of the 2.9 inches of precipitation during the period.

A second pumping test was run at Site 5 on March 6, 1978, to observe recharge to the mine during the wetter spring months. Drawdown and recovery data are shown for this test on figure 10. The water level drawdown in the slope was approximately the same as in the September 20th test. Unlike the previous test, however, the water level recovered rapidly as water from a series of rains, which closely followed the test, recharged the mine. The water level in the mine recovered to pre-pumpage levels in 2 days, which corresponds to an average recovery rate of 103,500 gal/d. If the recovery rate is attributed only to recharge from precipitation moving vertically from the surface, the average recharge rate for the 2 days following the March 6 pumping test was 0.073 in/d. The total recharge of 0.15 inches equals 21 percent of the 0.7 inches of rain falling on March 7 and 8.

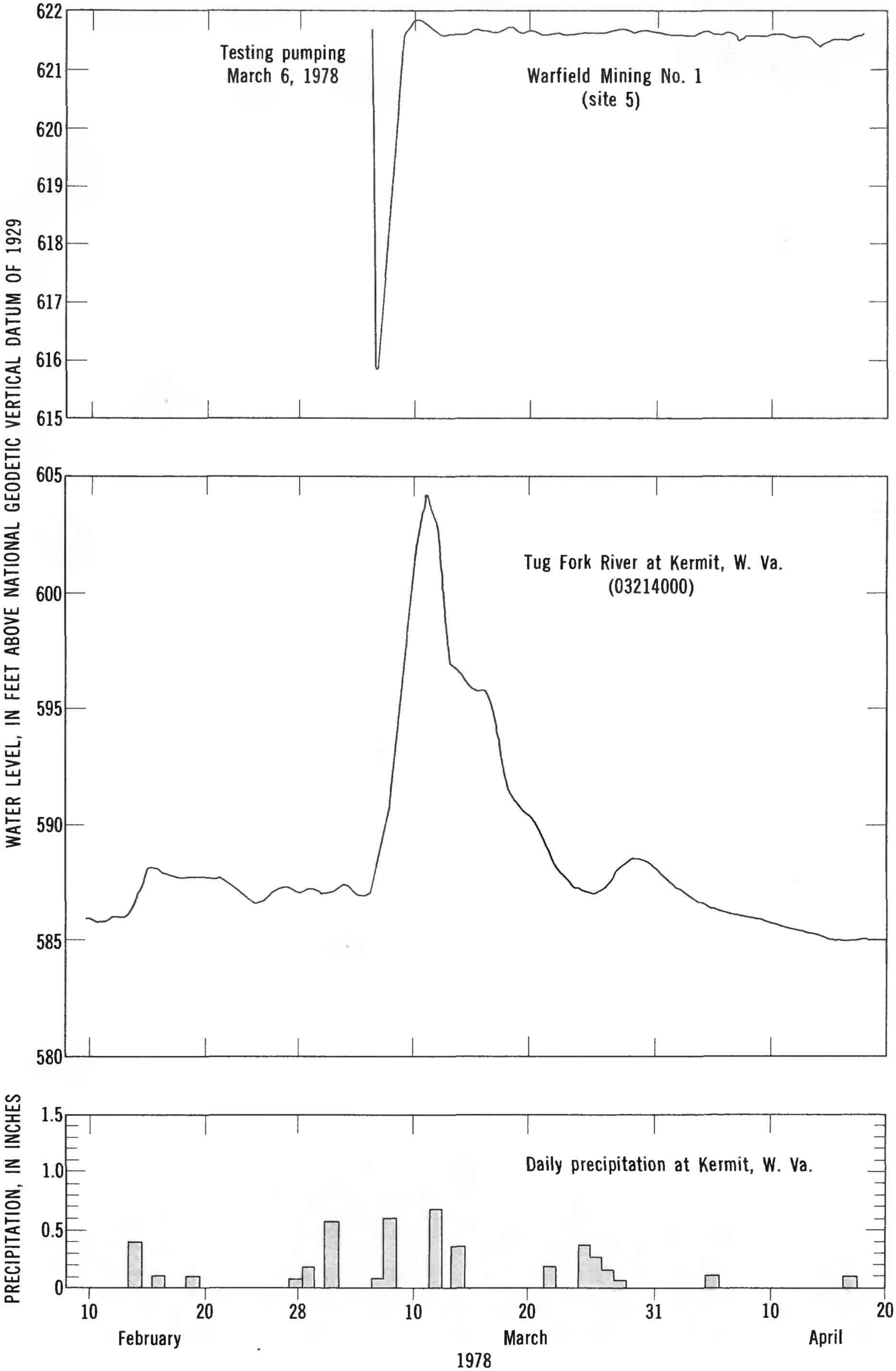

Figure 10.-- Hydrograph of water levels at site 5 after test pumping March 6, 1978, precipitation and stage of the Tug Fork at Kermit, West Virginia.

Results of Test Pumping at Site 58

The M and P Coal Company Mine No. 1 (site 58) was pumped from a flooded air shaft on September 21, 1977. The shaft reportedly extends 18 feet below the surface to the Van Lear coal seam. The mine was abandoned in 1963. At the time of the test, water was flowing from the air shaft at about 10 gal/min and was being used to water livestock. Thus the duration of the pump test was limited so that mine-discharge would be interrupted for only a short time.

Water was pumped at 580 gal/min for the first 30 minutes of the test which lowered the water level in the shaft 0.15 feet. Discharge was increased to 620 gal/min for the remaining 80 minutes which resulted in lowering the water level an additional 0.73 feet. A total of 67,000 gallons was pumped during the test. Water level in the shaft recovered to the pre-pumping level 4 days after pumping stopped. The recovery represents the addition of 67,000 gallons of water to the mine from regional ground-water flow. The average recharge rate to the mine is about 16,750 gal/d which corresponds closely to the natural discharge of approximately 10 gal/min observed prior to the test.

QUALITY OF WATER IN COAL MINES

The chemical quality of ground water is directly related to the type of material through which it flows and the period of time the water is in contact with the material. Water percolating downward from the land surface reacts with soil and rock to dissolve organic and inorganic matter. This percolating water is commonly of a calcium-magnesium bicarbonate composition and is slightly alkaline. As the water seeps into coal mines it comes in contact with coal and associated rocks and minerals. Thus the chemical quality of water in the mines reflects the chemical character of the rock and soil and the changes in water quality caused by chemical reactions within the coal mine.

Oxygen and water react with the pyrite to form iron sulfate and sulfuric acid. The quantities of iron, acids, and sulfate present in mine water are dependent upon the amount and type of pyrite in the coal and overlying rocks, the amount of oxygen available to react with the pyrite, and the length of contact time for the reactions. The chemical quality of the ground water which infiltrates into a coal mine from overlying rocks is, as mentioned; commonly slightly alkaline, and thus has a high capacity to neutralize the acid being produced by pyrite oxidation in the coal mine. Formation of acid-mine water is often prevented naturally in this manner.

General Water Quality from all Mines

Analyses of mine water sampled in Johnson and Martin Counties are listed in tables 9 and 10 and illustrated by Stiff diagrams on plates 1 and 2. The Stiff diagram provides a quick comparison of the chemical character

Table 9.--Chemical analyses of mine water from selected sites in Martin County
(Chemical constituents are in milligrams per liter except where noted)

Site number	Date of collection	Discharge (gal/min)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Dissolved iron (Fe)	Total iron (Fe)	Dissolved manganese (Mn)	Total manganese (Mn)	Bicarbonate (HCO_3)	Acidity (H+)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (Residue at 180° C)	Hardness as $CaCO_3$ Noncarbonate	Hardness as $CaCO_3$ Ca-Mg	Specific conductance (micromhos per cm at 25°C)	Field pH (units)	Field temperature (°C)
1	6- 9-76	NF	13	27	6.6	26	3.5	1.7	3.2	0.50	0.50	80	0	54	18	0.2	184	29	95	305	6.1	12
1*	8-31-77a/	NF	8.7	7.3	2.4	2.3	1.4	.08	.54	.00	.04	17	0	19	1.5	.1	51	14	28	84	6.5	15
2*	6- 9-76	75	17	70	29	310	13	32.	33.	1.1	1.4	13	0	760	170	.2	1,440	280	290	2,080	4.9	13
2	12-21-77	125	22	84	34	300	10	51.	51.	1.6	1.6	0	0	870	16	.2	1,530	350	350	2,180	4.7	10
3*	12-21-77	34	15	76	32	260	10	63.	63.	1.3	1.3	42	0	780	150	.1	1,360	290	320	2,040	5.7	14
5	6- 9-76	NF	9.6	32	13	13	3.3	.26	32.	.41	.60	82	0	92	4.2	.6	222	66	130	338	4.5	13
5*	9-20-77b/	NF	11	110	36	27	8.2	-	16.	.04	1.5	140	0	330	4.1	.2	608	310	420	874	6.4	13
9*	7-14-76	NF	19	40	14	17	2.0	13.	-	.69	-	160	0	55	2.9	.2	236	26	160	375	6.6	11
17*	7-14-76	-	8.2	70	26	31	13	.03	-	.20	-	101	0	260	14	.3	488	200	280	710	6.9	24
18*	7-14-76	-	6.1	99	31	110	16	.57	-	.72	-	360	0	320	13	.3	758	80	370	1,150	6.3	17

a/ Sampled after pumping 9 hours at 10 gal/min.
b/ Sampled after pumping 6-1/2 hours at 560 gal/min.
* Stiff diagram for these analyses shown in Plate 2.
NF No flow.

Table 10.--Chemical analyses of mine water from selected sites in Johnson County
(Chemical constituents are in milligrams per liter except where noted)

Site number	Date of collection	Discharge (gal/min)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Dissolved iron (Fe)	Total iron (Fe)	Dissolved manganese (Mn)	Total manganese (Mn)	Bicarbonate (HCO_3)	Acidity (H+)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (Residue at 180° C)	Hardness as $CaCO_3$ Noncarbonate	Hardness as $CaCO_3$ Ca-Mg	Specific conductance (micromhos per cm at 25°C)	Field pH (units)	Field temperature (°C)
21*	6-10-76	40	15	90	47	28	7.3	0.02	-	0.04	-	48	0	420	2.3	0.3	664	380	420	874	7.4	14
21	12-20-77	49	14	85	43	26	7.6	.04	0.26	.14	0.14	29	0	420	1.9	.2	628	370	390	861	6.4	13
22*	6-30-76	50	15	71	32	45	6.0	.12	5.7	.33	.58	10	0	410	1.8	.3	634	300	310	816	5.7	14
22	12-20-77	47	16	83	38	68	7.7	.11	.32	.36	.36	20	0	480	2.2	.2	749	350	360	1,010	5.5	13
23*	6-10-76	13	22	67	32	55	5.5	1.2	8.0	1.4	1.4	0	1.0	460	1.6	.5	704	300	300	999	4.0	13
24*	12-20-77	18	24	66	36	34	5.0	2.5	2.5	3.2	3.2	0	2.2	460	1.4	.3	677	310	310	1,090	3.8	12
26*	6-10-76	4	9.4	61	40	10	4.4	.34	6.4	.26	.30	0	0	320	2.9	.3	518	320	320	655	4.8	15
26	12-20-77	4	18	68	42	13	5.4	.30	.43	.58	.58	0	0	380	2.8	.2	571	340	340	802	4.8	10
27*	8-11-76	17	11	190	89	120	9.0	.01	.76	.13	.27	42	0	1,000	2.7	.2	1,560	810	840	1,820	4.5	14
27	1- 5-78	27	14	210	92	100	9.2	.02	.17	.51	.51	34	0	1,000	2.3	.2	1,350	880	900	2,140	6.0	14
28*	6-10-76	9	16	88	46	18	5.0	.14	3.4	4.0	5.0	3	0	460	1.0	.6	680	410	410	855	4.0	13
28	12-20-77	12	11	110	53	30	7.4	.02	.47	.26	.44	120	0	440	2.4	.2	759	390	490	1,010	6.9	9
41*	1- 5-78	17	41	140	73	19	6.0	9.7	9.7	4.0	4.0	0	3.0	760	1.4	.3	1,120	650	650	1,750	3.9	13
42*	6-29-76	9	19	50	31	20	7.0	7.0	7.9	2.0	2.0	0	1.7	360	2.0	.4	556	250	250	874	3.7	15
47*	9- 1-77	NF	17	32	11	58	5.8	1.8	1.8	.57	.57	160	0	60	17	.3	312	0	130	550	6.7	13
52*	6-30-76	NF	33	93	56	140	5.5	11.	12.	1.7	1.4	0	1.0	910	2.4	.8	1,380	460	460	1,830	3.5	13
54*	6-29-76	NF	38	100	36	6.6	3.3	64.	69.	2.8	2.8	0	7.1	770	1.8	.8	1,180	400	400	1,750	3.1	16
58	6-29-76	-	11	39	17	37	8.0	.23	24.	.05	.20	99	0	170	2.6	.3	249	86	170	531	6.5	15
58*	9-21-77a/	-	9.8	36	17	29	7.6	.03	.21	.01	.01	75	0	160	1.5	.1	300	98	160	468	6.5	13
58	12-19-77	20	11	32	14	20	6.0	.08	.17	.03	.03	54	0	140	2.1	.1	350	93	140	388	6.2	13
59*	6-29-76	10	11	52	25	36	9.0	.01	2.0	.08	.28	41	0	290	2.1	.3	460	200	230	664	7.2	14
59	12-19-77	9	11	55	24	42	10	.04	.45	.12	.32	55	0	280	2.4	.2	455	190	240	686	6.9	13
60*	6-29-76	NF	19	24	18	7.0	2.7	.01	.11	.56	.60	2	0	140	1.5	.3	216	130	130	328	5.9	14
66*	7-15-76	8	25	69	37	11	7.5	14.	15.	1.3	1.4	0	1.1	380	2.7	.5	584	320	320	880	4.2	21
66	12-21-77	8	23	66	35	11	7.0	5.4	7.3	1.3	1.3	0	1.2	350	1.9	.2	509	310	310	820	4.1	12
73*	8-12-76	NF	8.1	30	6.1	27	15	.69	31.	.04	.08	84	0	64	19	.2	256	31	100	382	7.0	17
73	12-21-77	NF	9.2	20	6.8	10	3.1	.03	36.	.02	.30	21	0	49	11	.0	138	61	78	234	6.7	13
74*	6- 8-76	-	9	57	21	440	12	.03	.70	.18	.18	616	0	320	230	.6	1,380	0	230	2,210	-	14
74	12-21-77	-	9.6	51	18	390	10	.42	.67	.14	.14	620	0	280	220	.4	1,250	0	200	2,120	7.2	14
75*	7-13-76	NF	16	23	7.8	180	4.8	.11	.49	.05	.05	375	0	34	110	.5	558	0	90	970	8.0	17
76*	8-12-76	NF	11	48	15	8.2	4.3	.05	61.	.38	1.3	91	0	110	3.3	.2	262	110	180	400	6.2	15

a/ Sampled after pumping 2 hours at 600 gal/min.
* Stiff diagrams for these analyses shown in Plate 1.
NF No flow.

of mine waters; the shape of the diagram indicates chemical composition while the size of the diagram represents the ionic strength of the principal anions and cations in solution. Dissolved calcium, magnesium, and sulfate are predominant in most of the mine waters in the study area. The calcium-magnesium-sulfate water is the product of pyrite dissolution coupled with the neutralizing action of the calcium and magnesium bicarbonates in the natural ground-water system.

Most of the mine waters are similar chemically; that is, the relative proportions of dissolved constituents are similar between different mines (note the similarity of shapes of Stiff diagrams, plates 1 and 2). The absolute concentrations of dissolved constituents, however, vary significantly between sites (note size variations of Stiff diagrams, plates 1 and 2).

The maximum, minimum, and median values of the dissolved constituents and chemical quality characteristics for all mine waters sampled are listed in table 11. The source and significance of dissolved-mineral constituents are discussed on table 12. Note that concentrations of hardness, sulfate, iron, and manganese found in some mine waters may render the water objectionable for some uses if not treated.

Mine waters having a different chemistry from the calcium magnesium sulfate type were sampled from sites 2, 3, 74, and 75. Water from these mines clearly shows a sodium chloride overprint on the basic calcium magnesium sulfate chemistry. The sodium chloride water is probably from deeper aquifers saturated with brackish water. The brackish fluids may have migrated upward in oil and gas wells which penetrate both the Consolidation Coal Company's mines (sites 74, 75) and the Himmler-Earlston Mines (sites 2, 3).

In addition to the major inorganic elements, samples from selected sites were analyzed for phenols. The maximum allowable concentration of phenols in drinking water is 1 μg/L (microgram per liter). (Kentucky Department of Natural Resources and Environmental Protection, 1977). Results of analyses are listed below:

Site	Phenols μg/L
3	0
5	5
21	1
22	2
24	0
27	0
41	0
58	1

Although phenolic compounds arise from a number of naturally occurring sources and substances, in this case the phenolic compounds are assumed to indicate the level of coal-derived constituents in mine waters. Phenolic

Table 11.--Maximum, minimum, and median values of water characteristics for all samples

Parameter	Median	Maximum	Minimum
Specific conductance (micromhos per cm at 25°C)	859	2,210	84
pH (units)	6.1	8.0	3.1
Temperature °C	13.8	24	9
Calcium	61	210	7.3
Magnesium	25	92	2.4
Sodium	27	440	2.3
Potassium	7.1	16	1.4
Dissolved iron	0.25	64	0.01
Total iron	3.0	69	0.11
Dissolved manganese	0.34	4.0	0.00
Total manganese	0.39	5.0	0.01
Acidity (as H+)	0	7.1	0
Bicarbonate	38	620	0
Sulfate	310	1,000	19
Chloride	2.8	230	1.0
Fluoride	0.25	0.8	0.0
Calcium magnesium hardness (as $CaCO_3$)	225	900	28
Non-carbonate hardness (as $CaCO_3$)	192	880	0
Dissolved solids (residue at 180°C)	608	1,560	51
Silica	13	41	6.1

Concentrations in milligrams per liter unless noted

Table 12.--Source and significance of dissolved mineral constituents and physical properties of natural waters

Constituent or physical property	Source or cause	Significance
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Causes most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Drinking water standards recommend that the chloride content should not exceed 250 mg/L on the basis of taste preferences.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, F. J., 1950, Fluoridation of public water supplies: Journal American Water Works Association, v. 42, pt. 1, p. 1120-1132.)
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/L of soluble iron in surface waters usually indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 mg/L stains laundry and utensils. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. Federal drinking water standards recommend that soluble iron and manganese together should not exceed 0.3 mg/L. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark brown or black stain. Federal drinking water standards recommend that soluble iron and manganese together should not exceed 0.3 mg/L.
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in small amounts from 1 to 50 mg/L. High concentrations, as much as 100 mg/L, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.

Table 12.--Source and significance of dissolved mineral constituents and physical properties of natural waters--Continued

Constituent or physical property	Source or cause	Significance
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium ration may limit the use of water for irrigation.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfide, and other sulfur compounds. Usually present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Transients using water having more than 250 mg/L of sulfate usually experience laxative effects.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	Waters containing more than 1,000 mg/L of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 mg/L are considered soft; 61-120 mg/L, moderately hard; 121-180 mg/L, hard; more than 180 mg/L, very hard.
Hydrogen-ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing ph. However, excessively alkaline waters may also attack metals.
Specific conductance (micromhos per cm at 25°C)	Mineral content of the water.	Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents. Varies with temperature; reported at 25°C. Multiplied by 0.6 approximately equals the dissolved solids.
Temperature		Affects usefulness of water for many purposes. For most users, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground waters from moderate depths usually are nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells the water temperature generally increases on the average about 1°F with each 60-foot increment of depth. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the depth of water but do not reach the extremes of air temperatures.

compounds can cause aesthetic problems in drinking-water supplies because phenol is not removed efficiently by conventional water treatment, and the chlorination process can produce persistent odor-producing compounds.

Comparison of Water Quality from Coal Mines Above and Below Drainage

A significant difference in water chemistry occurs between water in underground mines which are above or below the level of perennial stream drainage. In general, the water from below-drainage mines had lower concentrations of dissolved constituents and higher pH than water from above-drainage mines.

The mean of the dissolved constituents concentration of water from mines above drainage (sites 2, 3, 17, 18, 21, 22, 23, 24, 26, 27, 28, 41, 42, 52, 54, 59, 60, 66, 74) is compared to the mean dissolved constituents concentration of water from mines below drainage (sites 1, 5, 10, 47, 58, 75, 76) on figure 11. Because chemical concentrations appear to differ between the two groups, the significance of these differences was tested statistically using the Kruskal-Wallis analysis-of-variance test (Sokal and Rolf, 1969). The Kruskal-Wallis analysis of variance tests the hypothesis that the two sampled groups come from populations having the same distribution or, as in this case, that there is no difference in water samples from mines above or below drainage. However, the Kruskal-Wallis test indicated that there is a significant differrence in quality of water from mines above or below drainage. The two groups differed significantly at the 99 percent confidence level for bicarbonate, calcium, magnesium, and sulfate. At a slightly lower level of confidence (95 percent), dissolved solids, fluoride, total manganese and dissolved manganese also tested significantly different between groups.

There are at least two possible reasons why mines below drainage yielded water with lower concentrations of dissolved constituents and higher pH than water from mines that are above drainage:

(1) After abandonment, mine galleries below drainage usually flood. The flooding limits the amount of atmospheric oxygen which is available to react with pyrite. The lower rate of pyrite oxidation lessens the amount of sulfate, iron, and acidity in solution.

(2) Below-drainage coal mines were sampled from slope and shaft openings where precipitation and surface runoff could easily enter the mine. The introduction of surface runoff dilutes the ground water in the mine. Thus, the water samples collected from some openings might not be representative of the quality of water deeper within the mine. In addition, the techniques used in sampling the below-drainage mines produced samples from only the upper zones within the shaft or slope. Thus, if waters were layered or zoned with the more highly mineralized water at lower levels, the samples would not reflect the chemical character of the deeper water.

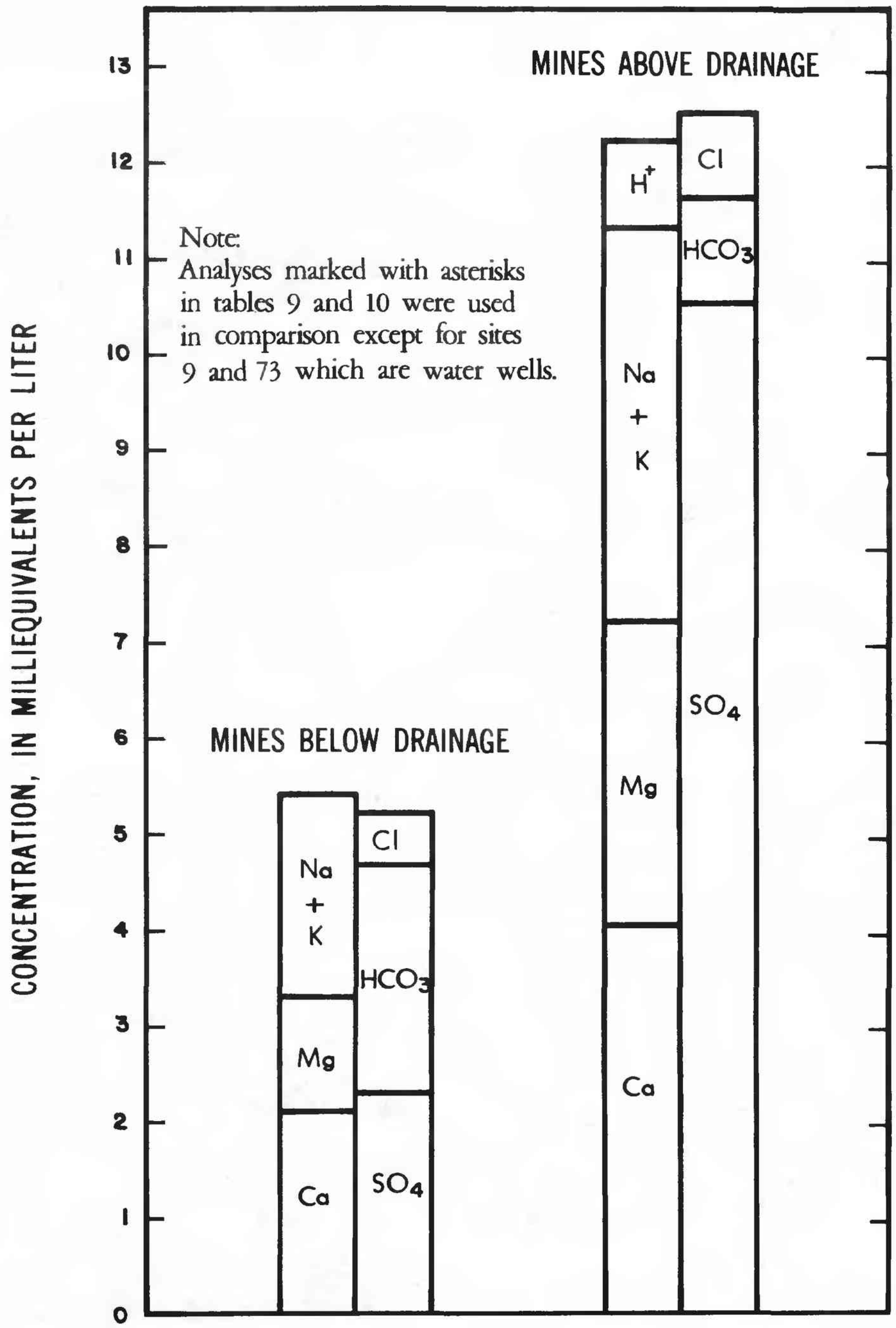

Figure 11. - Comparison of mean dissolved constituents concentration in water from mines above and below drainage.

Variability of Mine-Water Quality

The chemical quality of water from a coal mine does not remain constant, but changes in response to seasonal variations in ground water inflow or to pumping. Changes in chemical quality of water may be monitored by a simple field check of its specific conductance. Specific conductance measures the ability of water to conduct an electric current and is directly related to the quantity and type of ions in solution. Because mine waters in the study area generally have the same types of ions in solution, variations in conductance reflect variations in the quantity of ions, the dissolved solids that are in solution. The relation between dissolved solids and specific conductance in the study area is based on 27 samples of mine water and is illustrated on figure 12. The relation may be expressed analytically as:

$$\text{dissolved solids concentration} = 0.68 \text{ (specific conductance)} + 30.2.$$

The regression of these data has a correlation coefficient of 0.98. Based on this relation, field measurement of the specific conductance can be used to estimate the dissolved solids concentration of mine water of unknown quality.

Effects of Flow Variations on Water Quality

The chemical quality of water from underground mines usually varies with the volume of mine discharge. The rate of flow from a mine usually is related to the rapidity of infiltration of water into the mine. The greater the infiltration rate, the greater the flow. Thus the water that passes through the mine at high flow has less contact time for dissolution of the reactive materials within the mine and also dilutes the water already present. To illustrate the changes in water quality which occur as mine discharge varies, specific conductance was measured at various discharges from the North East Coal Company Mine No. 1 at Thealka (site 21). The relation between 16 specific conductance measurements and discharge for site 21 is shown on figure 13. Note the dilution effects at high flows.

A dramatic short-term change of water quality in both surface and underground mines is referred to as a flushout (Corbett and Agnew, 1968). During the dry summer and early fall months, the ground water that seeps into underground mines typically has a relatively long residence time in the mine. Thus the dissolved solids content is high. During the spring months (or after a hard rain) the inflow of ground water to the mine can flush out a slug of the highly mineralized water. Although the flushout phenomonon was not observed during this study, the possibility that water quality can change quickly in this manner should be considered when evaluating a potential water supply from a coal mine.

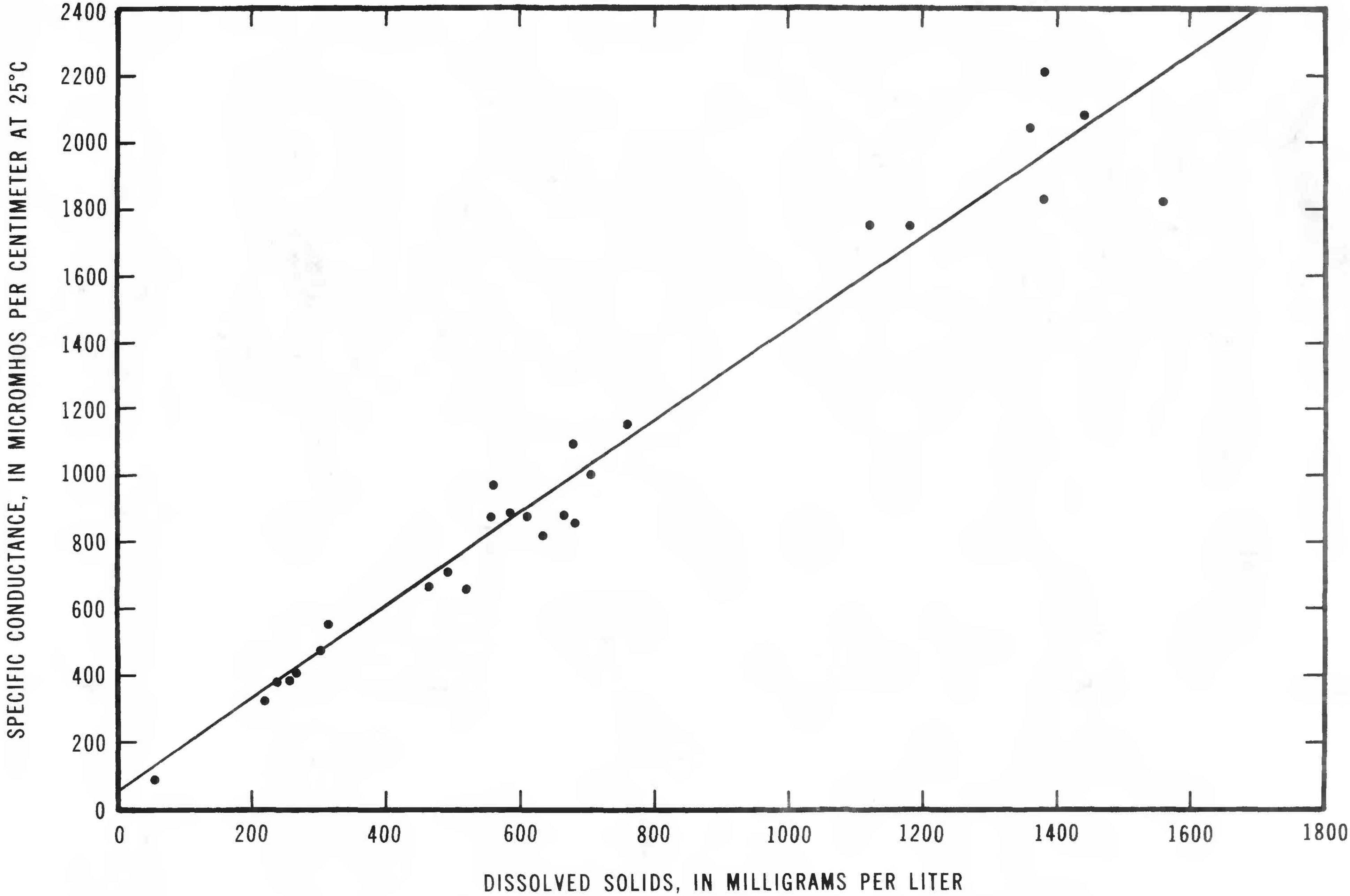

Figure 12. -- Relation between specific conductance and dissolved solids concentration.

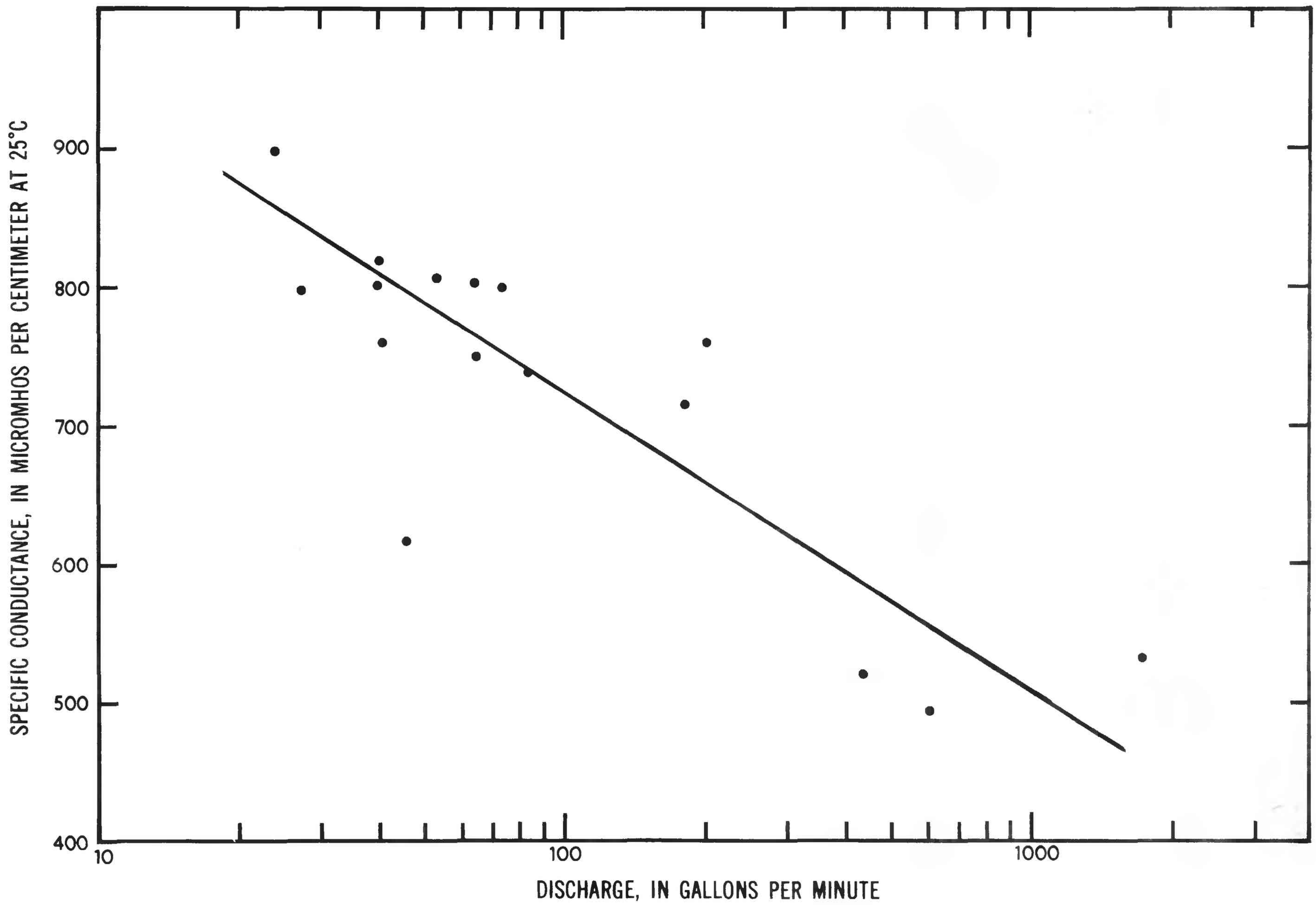

Figure 13. – Relation between specific conductance and discharge at site 21.

Effects of Pumping on Water Quality

Changes in water quality can occur when water is pumped from a mine. Pumping may lower the water level in a mine and expose reactive pyrite to atmospheric oxygen. The byproducts of the oxidized pyrite can in turn degrade the mine water by increasing its acidity and dissolved solids content. Over a long period of pumping, the cyclic wetting and reexposure of pyrite to oxygen could alter the water quality significantly.

Changes in water quality will also be observed as water is drawn from successively deeper sections of a mine. In most below-drainage mines which do not have free drainage, water is probably stratified with respect to water quality. That is, the water that lies in the deeper sections of the mine is more highly mineralized due to its longer residence time in the mine. For example, during pumping the Warfield Mining Company Mine No. 1 (site 5) the pumping of more mineralized water at depth probably caused the changes in water quality shown on figure 14 and listed on table 9.

DEVELOPMENT OF WATER SUPPLY FROM UNDERGROUND MINES

The utilization of water from coal mines depends on a number of factors. Probably the single most important factor is the location of the mine. The cost of constructing a long pipeline may preclude the use of water from mines that are long distances from the point of use.

Water in mines located below drainage can be tapped by drilled wells, but water flowing from above-drainage mines may simply require a pipe from the mouth of the mine.

Wells drilled into below-drainage mines probably offer the safest method of utilizing water from coal mines because sanitary conditions are relatively easy to maintain. In addition below-drainage mines generally yield water of better chemical quality than above-drainage mines that are open to atmospheric oxygen. In mines that are below drainage or in which all openings have been sealed, the limited supply of oxygen tends to lessen the acid and sulfate that is produced when pyritic materials oxidize. The shortage of oxygen may be especially beneficial in the case of wetting and drying of pryitic materials caused by cyclic pumping.

Although a pipe laid into the mouth of a self-draining above-drainage mine may be adequate for a small supply, this method may be inadequate during dry weather. In mines with low flow a dam across the mouth can impound water in the mine and sustain flow during dry weather. Above-drainage mines are usually located high on hillsides, thus water drains by gravity. Obviously, care must be taken to protect the mouth of the mine from contamination.

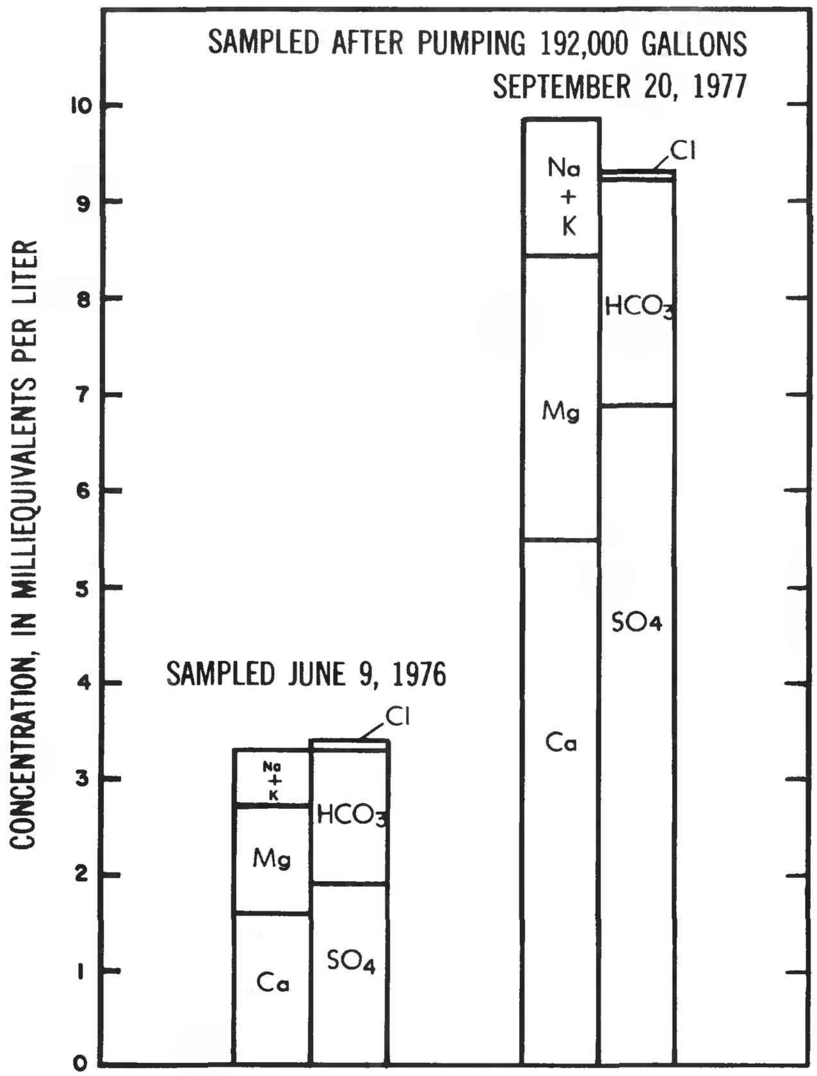

Figure 14, – Chemical quality of water before and after pumping at site 5.

SUMMARY

The water in underground coal mines represents a major ground-water resource in Johnson and Martin Counties. If properly developed, water from these mines could provide dependable supplies for various water needs. The quality and quantity of water available in underground coal mines in the study area may be summarized as follows:

(1) The water-supply capabilities of mines developed above the level of perennial stream drainage can be best estimated by monitoring the seasonal variation of discharge from the mines. Annual discharge from most above-drainage mines ranged between 3-10 percent of precipitation falling on the mine area during the year. Most above-drainage mine openings which were inventoried were dry or discharged less than 10 gal/ min. The highest discharge rate measured from a mine was 1,700 gal/min from site 21. The highest sustained rate of discharge was from site 74 which continually discharged between 750 and 1,200 gal/min. Nine other sites provided a year-round flow greater than 10 gal/min (sites 2, 3, 16, 21, 22, 24, 27, 39, and 41).

(2) Mines with the greatest water-supply potential are large mines which were developed below the level of perennial stream drainage. Large, below-drainage mines have extensive recharge areas and contain large quantities of water trapped in storage below drainage. Five large below-drainage mines are located in the study area (sites 1, 46, 47, 76, 78).

(3) The amount of water available from mines below drainage can best be estimated by test pumping. For this study two below-drainage mines (sites 5 and 58) were tested with a high-capacity pump. Although the mines at sites 5 and 58 have limited potential as high-capacity water supplies due to their slow recharge rates in the summer months (less than 10 gal/min), these mines could be pumped at a somewhat higher rate than the summer recharge rates indicate. The higher rate would need to be based on the volume of water in storage and the rate of replenishment by the higher recharge rates in the winter months. Water-level fluctuations recorded for site 5 revealed a rapid recharge rate to the mine after fall and spring rains. Most mines probably recharge rapidly in this manner as water quickly moves into the mines through fractures in the rock.

Based on the volume of water in storage these mines would be adequate for many small uses or short-term emergency supplies. For example, water from site 5 was used as an emergency supply for the city of Warfield after the flood of April 6, 7, 1977. Water was reportedly pumped 65 minutes per day at 50 gal/min for a period of 3 weeks. Little drawdown was observed in the mine.

(4) Unless treated, the quality of raw mine water will be objectionable for some uses. The mine waters sampled were typically high in calcium, magnesium, and sulfate with pH ranging from 3.1 to 8.0 units. High concentrations of iron and manganese were also present in most mine waters.

(5) Water in below-drainage mines appeared to be less mineralized and less acidic than water from above-drainage mines.

(6) Water from coal mines represents a usable water resource. However, the difficulty of predicting the reliability of the resource may preclude its use in some cases.

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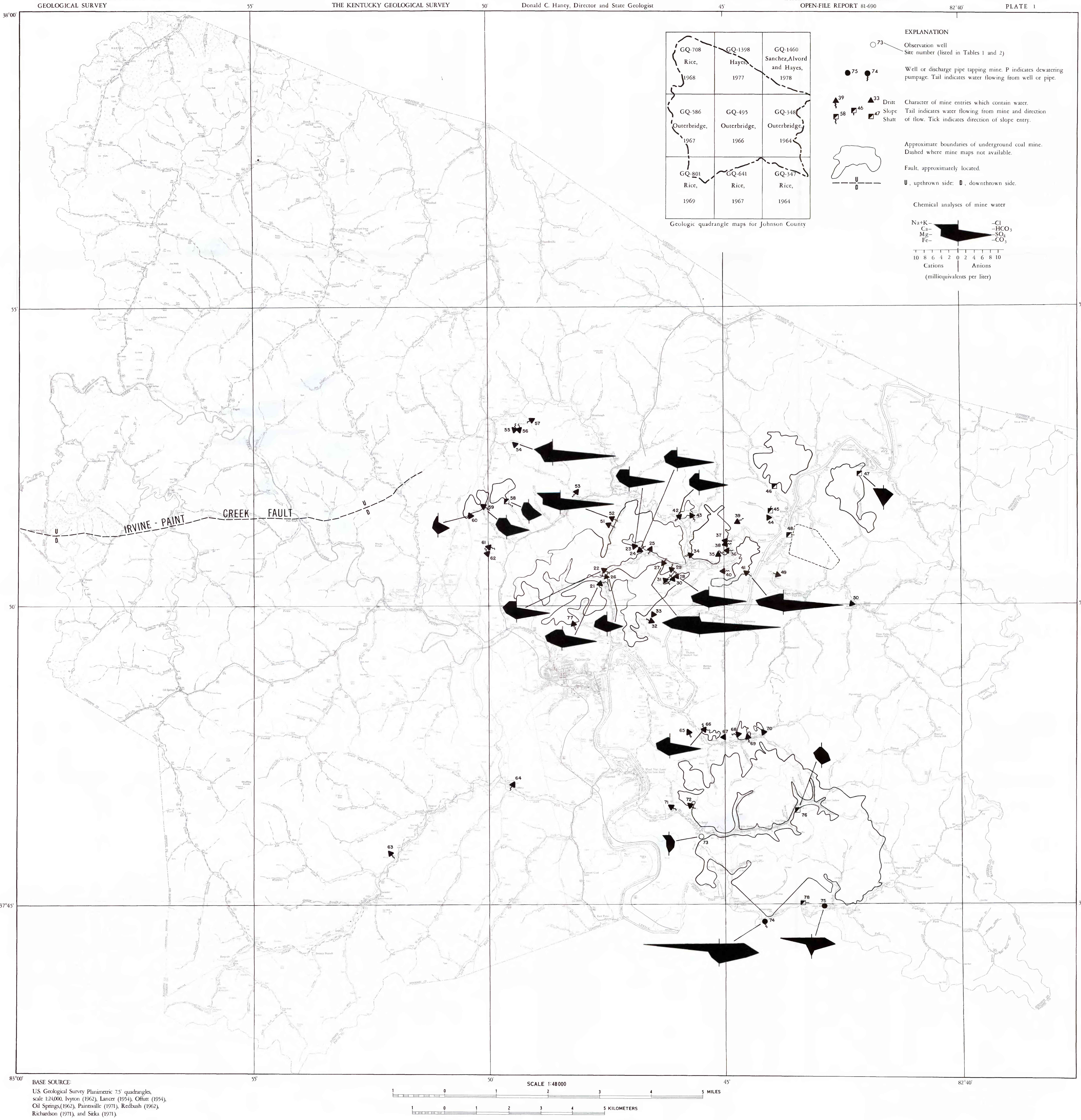

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U.S. Geological Survey Planimetric 7.5' quadrangles, scale 1:24,000, Ivyton (1962), Lancer (1954), Offutt (1954), Oil Springs, (1962), Paintsville (1971), Redbush (1962), Richardson (1971), and Sitka (1971).

Location of coal mines, Irvine-Paint Creek Fault, and chemical character of water from selected mines in Johnson County, Kentucky.

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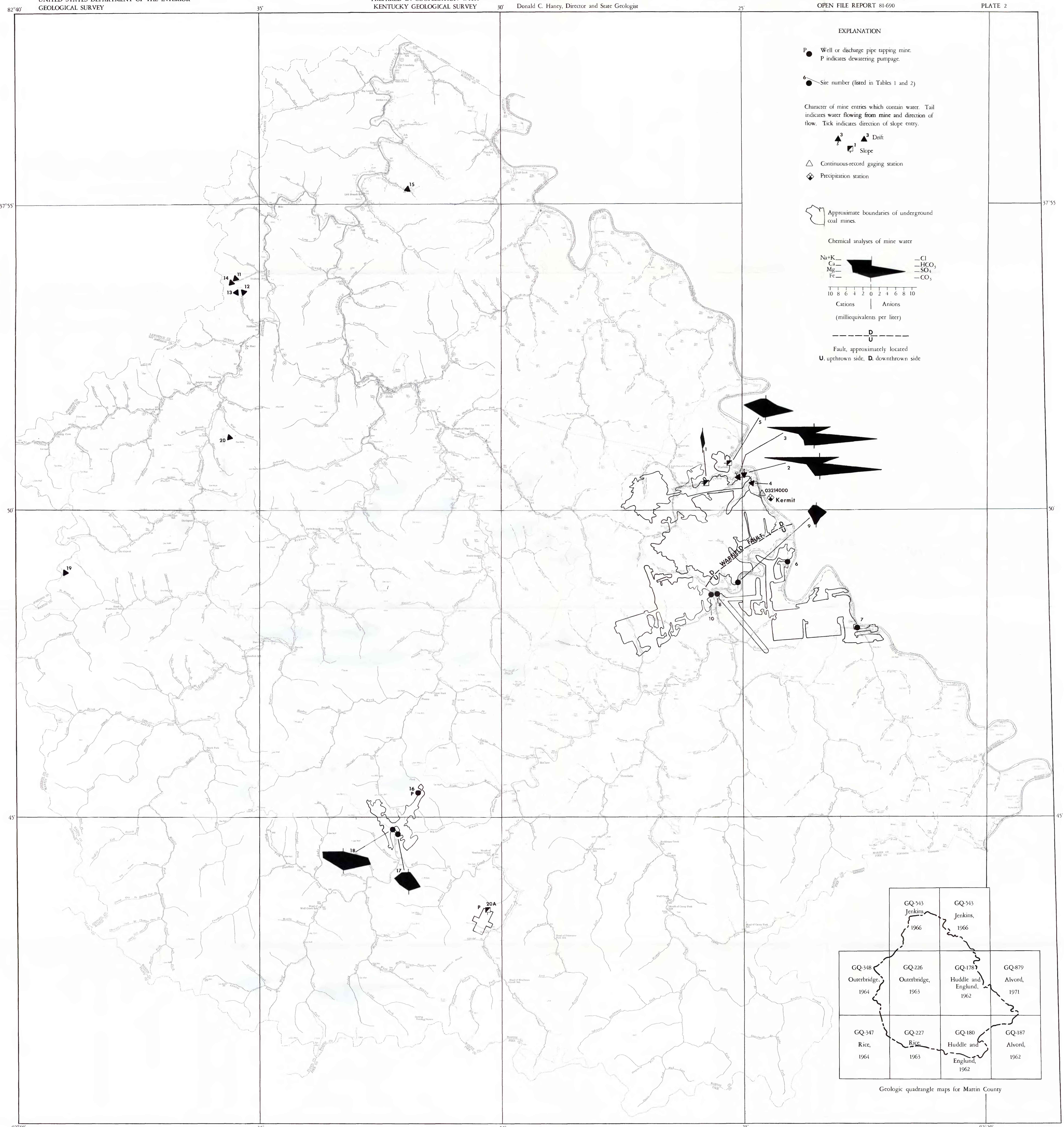
PREPARED IN COOPERATION WITH
KENTUCKY GEOLOGICAL SURVEY

UNIVERSITY OF KENTUCKY
Donald C. Haney, Director and State Geologist

WATER-RESOURCES INVESTIGATION
OPEN FILE REPORT 81-690

PLATE 2



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Location of coal mines, Warfield Fault, and chemical character of water from selected mines in Martin County, Kentucky.