THE EFFECTS OF COAL MINING ON THE HYDROLOGIC ENVIRONMENT OF SELECTED STREAM BASINS IN SOUTHERN WEST VIRGINIA

By J. W. Borchers, T. A. Ehlke, M. V. Mathes, Jr., and S. C. Downs

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

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
inch per hour (in/h)	25.4 2.54	millimeter per hour (mm/h) centimeter per hour (cm/h)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	4,047	square meter (m^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381 3,785	cubic meter per second (m^3/s) cubic meter per day (m^3/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
pound, avoirdupois (lb)	453.6	gram (g)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per square mile (ton/mi^2)	0.03753	metric tonne per square kilometer (metric $tonne/km^2$)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute per foot of drawdown [(gal/min)/ft]	0.2070	liter per second per meter of drawdown [(L/S)/m]

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

The effects of surface and deep coal mining on the hydrology of small stream basins in southern West Virginia were determined by comparing data collected in two unmined basins with that collected in two actively-mined basins and one basin containing only abandoned mines.

Ground-water flow in unmined areas is primarily controlled by fractures in the nearly flat-lying sedimentary rocks. Most fractures in the study area probably formed as a result of erosional stress relief. The effects of mining on the flow of ground water depend on the hydraulic connection of mines to the fracture system. Deep-mine interiors were surprisingly dry, except in places where mines intersected stress-relief fractures, i.e., beneath valleys or at hillside-mine entries. Aquifer diffusivity values calculated from base-runoff recession curves ranged from 36,000 to 47,000 square feet per day for the unmined basins. Because deep-mine discharges comprised a significant percentage of streamflow (14 and 34 percent of the streamflow in the two mined basins during a low streamflow period), base-runoff recession curves were not used to estimate aquifer diffusivity in mined basins.

Peak stream discharges from mined basins were smaller than those from unmined areas, and mined basins had both lower high flows and higher low flows than the unmined basins. The data do not support the sometimes voiced theory that strip mining causes increased stream runoff.

Water samples were collected from 171 sites, including domestic wells, streams, and mine drains. Mine-discharge water contributed a large percentage of the dissolved chemical load in outflow from mined basins. For example, during a low-flow sampling period, mine discharge contributed nearly 60 percent of the dissolved-calcium load in the stream in the two mined basins, and 41 percent of sulfate in one actively mined basin, and 30 percent in the other. The concentrations of calcium, magnesium, potassium, sodium, sulfate, and bicarbonate in surface waters draining the mined basins were two to four times greater than that in surface waters draining predominantly unmined basins. The mean specific conductance and mean dissolved solids concentration of surface water in the mined basins were considerably higher than those in the unmined basins, as was the yield of dissolved solids leaving the mined basins.

The pH of surface water in the mined basins was higher than in the unmined, probably due to the large quantities (758 tons in one mined basin and 3,332 tons in the other during the study) of limestone dust used to coat mine interiors. Dissolved iron concentrations were similar for surface water in mined and unmined basins; but dissolved manganese concentrations were much higher in the mined basins. The manganous ion probably forms stable complexes with bicarbonate and sulfate ions in mine drainage.

Sulfate, sodium, and bicarbonate concentrations, sodium-calcium ratio, and specific conductance were considerably higher in water from wells located within one-half mile of underground and surface mines than in wells further away. Sodium-bicarbonate type water in local ground water and in some mine discharges probably is the result of ion-exchange processes.

Streams draining the mined basins had the greatest suspended-sediment load and high suspended-sediment yields. Generally, the greatest numbers of genera of benthic invertebrates were found in the unmined basins.

1.0 INTRODUCTION

1.1 Purpose and Scope

EFFECTS OF COAL MINING ON HYDROLOGIC ENVIRONMENT WERE STUDIED BY COMPARING SELECTED MINED AND UNMINED BASINS

This study was undertaken to help answer questions about the effects of coal mining on streamflow characteristics, stream-water quality, ground-water flow and availability, ground-water quality, concentration, loading and types of suspended sediment in streams, and biological life in streams. Three mined basins and two unmined control basins in southern West Virginia were selected for study.

This report defines the effects of coal mining on the hydrologic environment of small stream basins in southern West Virginia. It answers some of the questions that have been raised by coal companies, regulatory agencies, environmental groups, researchers, and the public. The report compares hydrologic data collected in unmined basins to data collected in deep-mined and surface-mined basins. The data include the measurement and description of precipitation, streamflow, ground-water levels, suspended sediment, stream and ground-water quality, and benthic invertebrate life in streams.

The study area, which lies within the Appalachian Plateaus physiographic province, consists of five small basins near the headwaters of the Guyandotte River in east-central Wyoming County and southwestern Raleigh County. (See figs. 1.1-1 and 1.1-2.) Geologically, the study area is in the relatively flat-lying and undeformed sandstone, shale, and coal beds of the Pottsville Group of the Pennsylvanian System. (See fig. 1.1-2.) The bituminous coal mined in this area is high-grade metallurgical coal, typically containing low sulfur, high B.T.U., low volatile organics, low ash, and high fixed carbon (Barlow, 1974). The basins are similar in drainage area, geology, topography, and climate.

The type and location of mining in basins determine the effects of the mining on the hydrologic environment. Surface mining includes contour-strip mining, mountaintop removal, and auger mining. Deep mining includes above- and below-drainage drift mining and shaft mining. For the convenience of the reader unfamiliar with mining terminology, descriptions of types of mining procedures are given in the glossary, at the end of this report.

The authors appreciate the assistance and cooperation received from mine engineers and foremen of Ranger Fuel Corporation, Amigo Smokeless Coal Company, Itmann Coal Company, Consolidated Coal Company, Westmoreland Coal Company, G. and A. Coal Company, Underground Energy Corporation, Extractors, Incorporated, Westigan, Incorporated, Maben Mining Company, and Sioux Coal Company, Incorporated. The authors also appreciate the assistance and cooperation of the West Virginia Geological and Economic Survey and the West Virginia Department of Mines for providing information on deep-mine and surface-mine locations.
This report is a product of a cooperative investigation by the U.S. Geological Survey and the West Virginia Geological and Economic Survey. Many of the conclusions have transfer value to other basins throughout southern West Virginia.

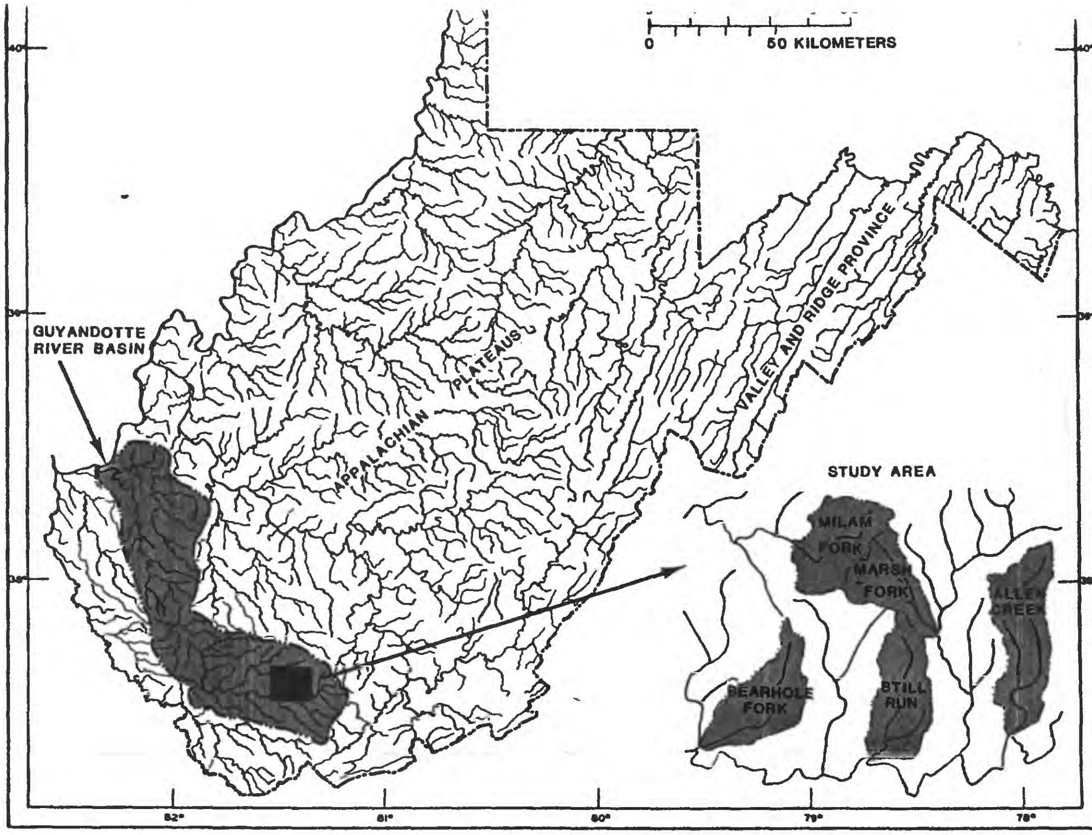


Figure 1.1-1.--Location of study area, physiographic provinces, and drainage features in West Virginia.

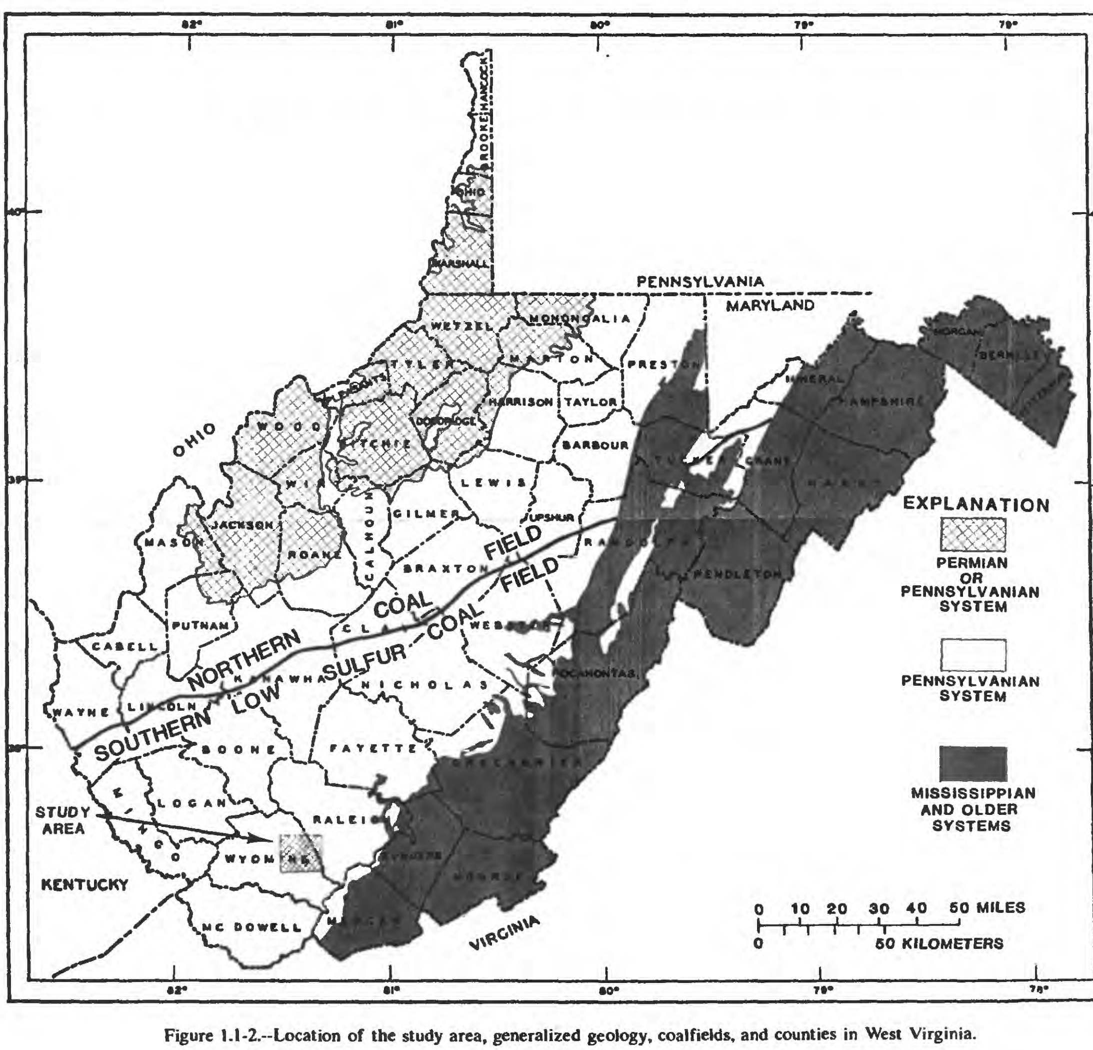


Figure 1.1-2.--Location of the study area, generalized geology, coalfields, and counties in West Virginia.

2.0 DESCRIPTION OF STUDY AREA

2.1 Geology

STUDY AREA CONTAINS UNDEFORMED SANDSTONE, SHALE, AND COAL BEDS OF PENNSYLVANIAN AGE

The study area contains outcropping shale, sandstone, and coal beds of the Pottsville Group, including the Kanawha, New River, and Pocahontas Formations. The rocks dip gently to the northwest and contain only minor anticlines and synclines.

Surficial geology is shown in figure 2.1-1. The rocks are about 300 million years old, Early Pennsylvanian in age. Three formations, similar lithologically, crop out in this area. The lithology of each is described briefly in the explanation of figure 2.1-1.

The regional dip of the strata, about 100 ft/mi to the northwest, is interrupted by small anticlines and synclines shown on figure 2.1-1. These are only minor flexures and are asymmetric about their axes, dipping more steeply on their southeastern limbs than on their northwestern limbs. They roughly parallel the trend of the Appalachian Mountain System and are about 30 mi northwest of the heavily folded and thrust-faulted Valley and Ridge physiographic province. (See fig. 1.1-1.)

The formations shown on the geologic map thicken toward the south. For that reason, the stratigraphic column, shown in figure 2.2-1, illustrates only the relative thickness of the formations. Relative stratigraphic positions of the major coals within each formation are also shown.

The information on the geologic map, the stratigraphic column, and the stratigraphic descriptions were taken from several maps and reports published by the West Virginia Geological and Economic Survey. They are:

- Krebs, C. E., 1916, Raleigh County and the western portions of Mercer and Summers Counties, 778 p.
- Hennen, R. V., 1915, Wyoming and McDowell Counties, 783 p.
- Lotz, C. W., 1970, Probable original mineable extent of the bituminous coal seams in West Virginia, 1 map.

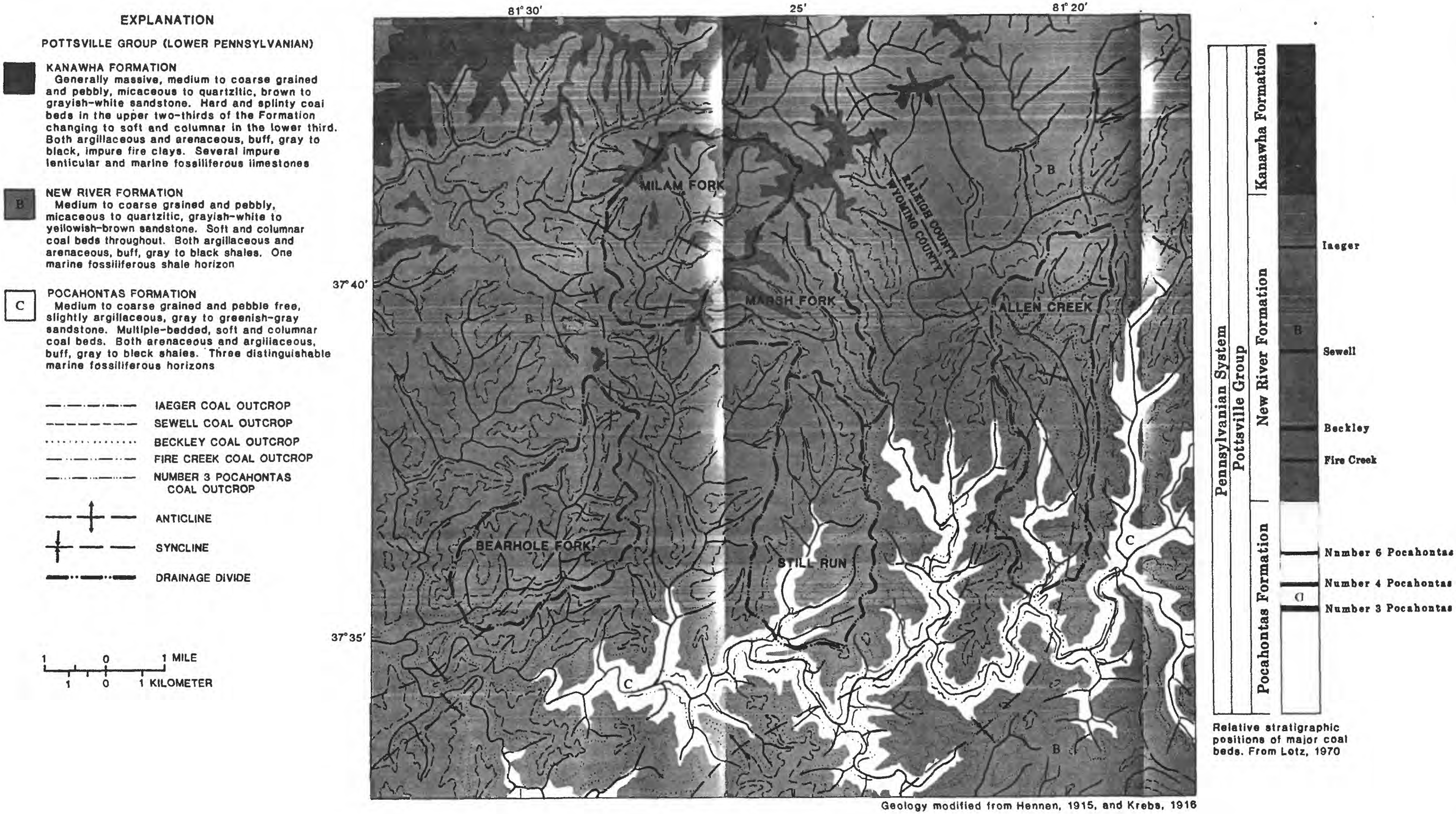


Figure 2.1-1.--Geology of the study area.

2.2 Basin Characteristics

STUDY BASINS HAVE SIMILAR NATURAL BASIN CHARACTERISTICS AND DISSIMILAR LAND-USE CHARACTERISTICS

Natural characteristics of the study basins are similar, whereas, some land-use characteristics are dissimilar, mainly because of the differences in type and amount of coal mining.

The six natural basin characteristics and the land-use characteristic "forest area," listed in table 2.2-1, show less variation among basins than the two land-use characteristics associated with mining. The natural basin characteristics have not been significantly affected by land-use practices. Drainage area, stream length, main channel slope, mean basin altitude, mean basin slope, and main channel azimuth have changed little during recent time and are similar for the five basins. The percentages of forest areas are similar for the basins, although Allen Creek has a smaller percentage of forest area than the remaining basins. Surface mining is responsible for most of the timber removal in Allen Creek basin, although some logging has occurred in Allen Creek, Still Run, and Marsh Fork basins.

The degree to which the basins are affected by the land-use characteristics associated with mining (table 2.2-1) varies considerably. Marsh Fork basin is unaffected by either surface or deep mining, while, in contrast, Allen Creek basin has over half of its area underlain by deep mines and one-fifth of its area covered by surface mines. The remaining basins have intermediate percentages of land that are affected by mining.

Among the natural basin characteristics, basin area ranged from 4.85 to 8.43 mi^2--mean 6.66 mi^2. Length of the main stream channels from stream gage to drainage divide ranged from 4.3 to 8.3 mi--mean 5.8 mi. Main channel slope ranged from 54 to 135 ft/mi--mean 96 ft/mi. Mean basin altitude, in feet above sea level, ranged from 1,940 to 2,230 ft--mean 2,070 ft. Because of similar mean basin altitudes, similar amounts and types of orographically-induced precipitation should occur in each basin. Mean basin slopes ranged from 1,160 to 1,570 ft/mi--mean 1,440 ft/mi. Finally, azimuths of the main channels ranged from 157 to 240--mean 196.

Among the land-use characteristics, forest areas, expressed as percentages of drainage area, ranged from 72 to 93 percent--mean 86 percent. Areas disturbed by surface mining ranged from 0 to 20 percent of the drainage area--mean 5 percent. Surface-mined areas include strip benches, high walls, and spoil piles. Areas underlain by deep mines ranged from 0 to 51 percent of the drainage area--mean 25 percent. Thus, there is considerable variation in the amount and type of coal mining present in the study basins.

The natural basin characteristics were measured and defined as described in the U.S. Geological Survey's basin characteristics computer program (Slaughter and Saxowsky, 1974). Forest, surface-mined, and deep-mined areas were planimetered from land-use and mining data plotted on topographic sheets.

Table 2.2-1.--Basin characteristics

Basin characteristics	Allen Creek	Still Run	Milam Fork	Marsh Fork	Bearhole Fork
Natural characteristics:					
Drainage area, in square miles.	8.43	7.12	6.64	4.85	6.27
Stream length, as main channel length in miles from gage to divide.	8.3	5.6	5.1	4.3	5.5
Main channel slope, in feet per mile.	54	135	62	119	109
Mean basin altitude, in feet above sea level.	2,050	2,010	2,140	2,230	1,940
Mean basin slope, in feet per mile.	1,560	1,400	1,570	1,520	1,160
Main channel azimuth, in degrees from north.	184	188	240	157	211
Land-use characteristics:					
Forest area, as percentage of drainage area.	72	89	84	93	91
Surface-mined area, as percentage of drainage area.	20	5	1	0	0
Deep-mined area, as percentage of drainage area.	51	32	37	0	6
Mining indicator, percent surface mined, percent deep mined.	20,51	5,32	1,37	0,0	0,6

2.3 Precipitation

PRECIPITATION CHARACTERISTICS OF FIVE BASINS ARE SIMILAR

The five study basins have similar monthly distribution of precipitation and similar total annual precipitation.

Monthly distribution of precipitation is similar for the five study basins (fig. 2.3-1). The fall of 1978 was the driest season in each basin, and the winter of 1978-79 and the summer of 1979 were the wettest seasons. Precipitation in the study area was below average with 39 inches in 1978 and above average with 53 inches in 1979. Long-term normal (1931-60) precipitation for the study area is about 44 in/yr.

Precipitation for the period of record and for the individual years 1978 and 1979 is listed in table 2.3-1. Data were obtained from precipitation collectors located at or near the stream-gaging stations in the five basins. The basin precipitation totals are similar both for annual precipitation and for total precipitation during the study period. Precipitation for Allen Creek, which had the greatest departure from the mean, was lower than the average basin precipitation by 11 to 15 percent. Because the precipitation collected at Allen Creek was consistently 10 to 15 percent less than precipitation in the other basins, the gage location or collection methodology might be a factor in explaining this precipitation difference.

Daily precipitation totals were similar for the basins in the fall, winter, and spring months. During these periods of the year, storms are usually associated with low pressure systems that affect weather over thousands of square miles. These large storm systems produce precipitation of fairly uniform intensity and amount over southern West Virginia. During summer, though, small thunderstorms caused by thermal convection can cause uneven distribution of precipitation intensities and amounts. These thunderstorms may miss or only partially affect some of the study basins. The precipitation totals for individual storms may vary from basin to basin, but the differences do not show up in monthly or annual precipitation totals.

Table 2.3-1.--Annual precipitation

Basin	Total precipitation, in inches		
	11/77-12/79	1978	1979
Allen Creek---	86	34	47
Bearhole Fork-	102	40	55
Marsh Fork----	102	40	54
Milam Fork----	106	42	56
Still Run-----	98	39	52

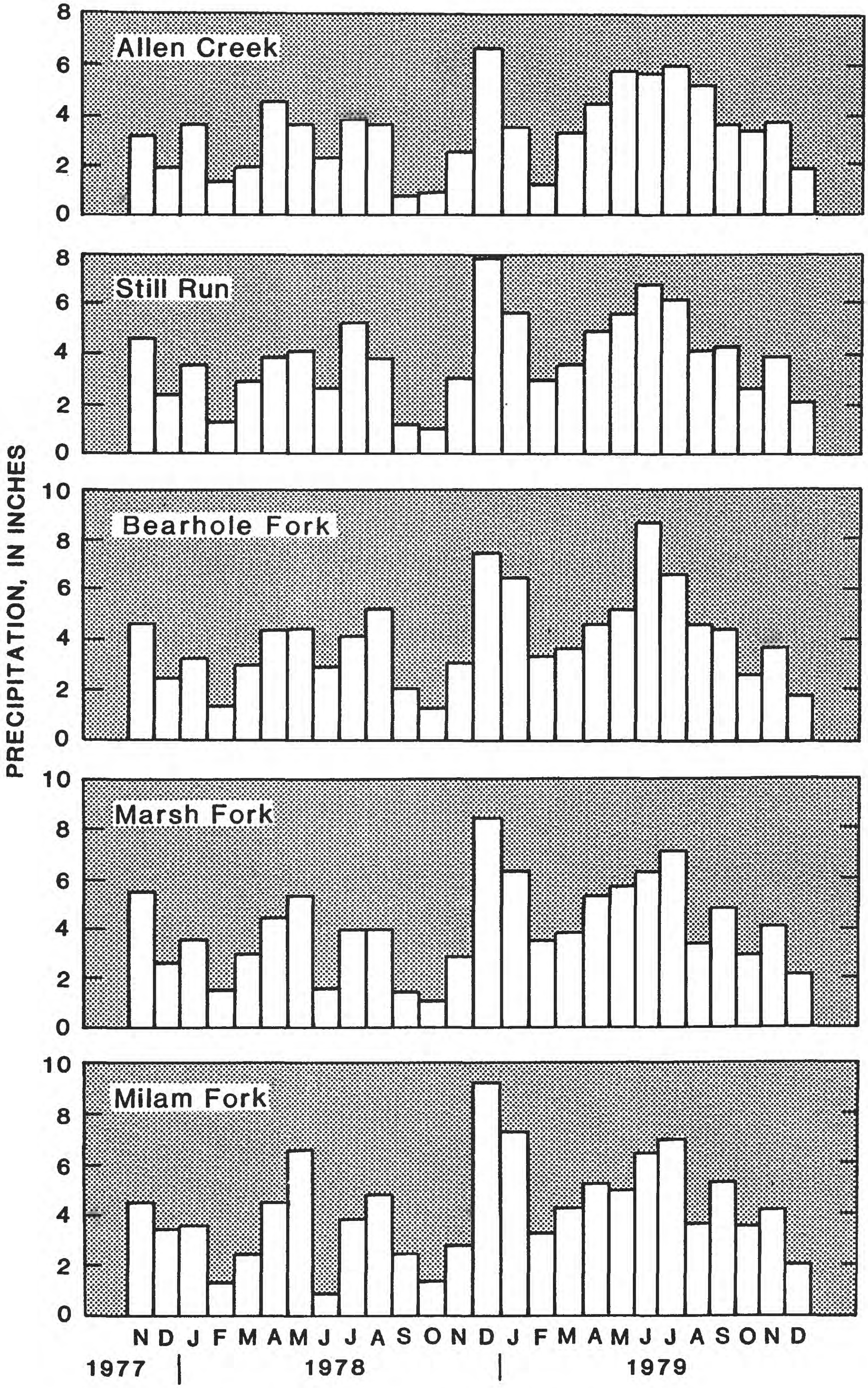


Figure 2.3-1.--Monthly precipitation for basins in the study area.

2.4 Location of and Coal Production from Deep Mines

FIVE DEEP-MINED COAL SEAMS WITHIN STUDY BASINS

Deep coal mines, either drift mines above and (or) below drainage or shaft mines below drainage, exist in five different coal seams in the project area. Allen Creek and Still Run are the most actively mined basins. Mining ceased in Milam Fork basin in 1960. Marsh Fork is unmined, and Bearhole Fork is predominantly unmined.

The maps in figure 2.4-1 show the extent of deep mining within each mined coal seam in the study basins, and table 2.4-1 indicates the percentage of the drainage area of each basin that is deep mined in each coal seam. Figure 2.4-2 illustrates, in cross section, multiply deep-mined areas, and table 2.4-2 shows, among other things, the percentage of each basin that is multiply deep-mined. The five study area maps of figure 2.4-1 show shallowest to deepest seams from left to right across the page. Mines in the stratigraphically youngest seam, the Sewell, are shallowest, followed in order of depth by the Beckley, Number 6 Pocahontas, Number 4 Pocahontas, and the oldest and deepest seam, the Number 3 Pocahontas.

The youngest coal seam, the Sewell, is deep mined about 150 ft below the streams in 5.4 percent of the Milam Fork basin. The Beckley Seam is deep mined above drainage in 23.2 percent and 3.5 percent of the drainage area of Allen Creek and Still Run, respectively. It is shaft mined about 500 ft below drainage in 31.8 percent of Milam Fork's drainage area. The Number 6 Pocahontas Seam is deep mined above drainage in 2.7 percent of Allen Creek's drainage area and 10.4 percent of Still Run's drainage area. The Number 4 Pocahontas Seam is deep mined mostly above drainage in 25.6 percent of the drainage area of Allen Creek. The oldest coal, the Number 3 Pocahontas Seam, is deep mined below drainage in 5.6 percent of the Bearhole Fork basin, and is deep mined above and below drainage in 26.6 percent of the Allen Creek basin and 25.7 percent of the Still Run basin.

Table 2.4-2 shows the percentage of each basin that is mined by deep mines in one or more coal seams and the percentage of the drainage area of each stream basin that is mined as in zone 1, 2, or 3 as shown in figure 2.4-2. Figure 2.4-2, a generalized cross section, defines the zones and shows the relative stratigraphic position of the major coal seams in the study area. Allen Creek basin has the largest mined area (table 2.4-2), followed by Milam Fork, and Still Run. Allen Creek contains active and abandoned deep mines, and Still Run contains mostly active deep mines. All deep mining activity ceased in Milam Fork in 1960. Bearhole Fork and Marsh Fork, for the most part, are treated as unmined basins in this report.

Coal production was average to above-average in Still Run and average to below-average in Allen Creek during the study (fig. 2.4-3). Monthly coal production in Allen Creek and Still Run during the study is shown in figure 2.4-4.

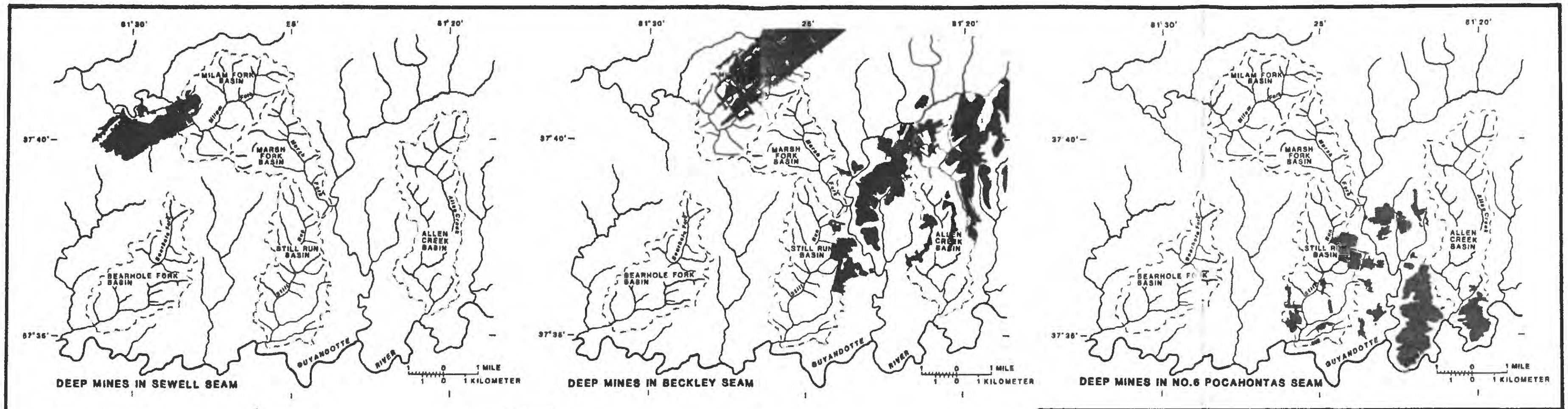
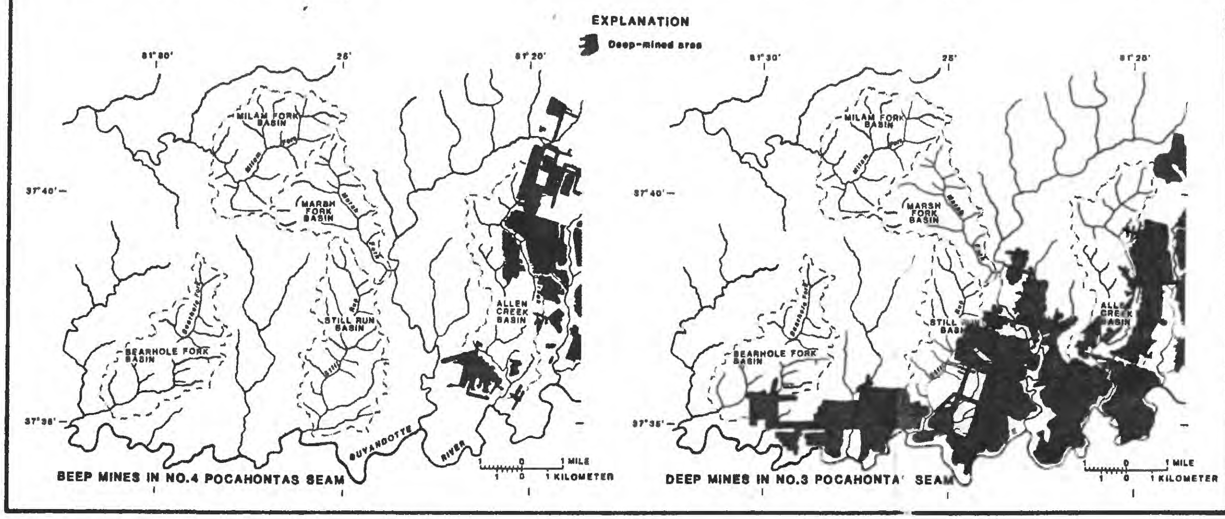



Figure 2.4-1.--Location of deep mines in major coal seams in the study area.

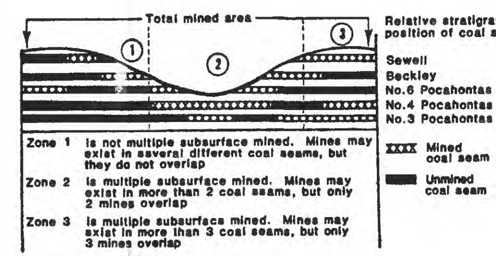


Figure .4-2.--Typical multiple subsurface mined areas.

Table 2.4-1.--Percentage of basins deep mined in each coal seam

Stream basin	Sewell	Beckley	Pocahontas		
			No. 6	No. 4	No. 3
Allen Creek----	0.0	23.2	2.7	25.6	26.6
Still Run------	.0	3.5	10.4	.0	25.7
Milam Fork-----	5.4	31.8	.0	.0	.0
Bearhole Fork--	.0	.0	.0	.0	5.6
Marsh Fork-----	.0	.0	.0	.0	.0

Table 2.4-2.--Percentage of basins undermined

Basin	Percentage of basins with mines as in			Total mined area (percent)
	Zone 1	Zone 2	Zone 3	
Allen Creek---	33.0	14.8	3.6	51.5
Still Run-----	24.3	6.6	.8	31.7
Milam Fork----	37.3	.0	.0	37.3
Bearhole Fork-	5.6	.0	.0	5.6
Marsh Fork----	.0	.0	.0	.0

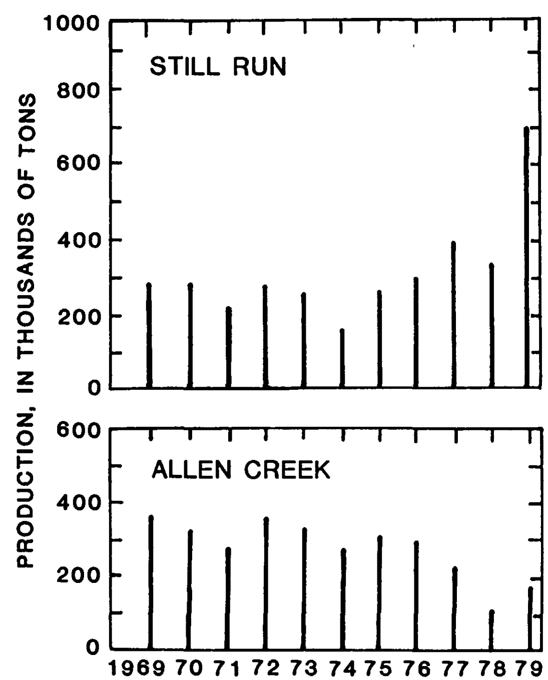


Figure 2.4-3.--Annual coal production from deep mines in Allen Creek and Still Run basins, 1969-79.

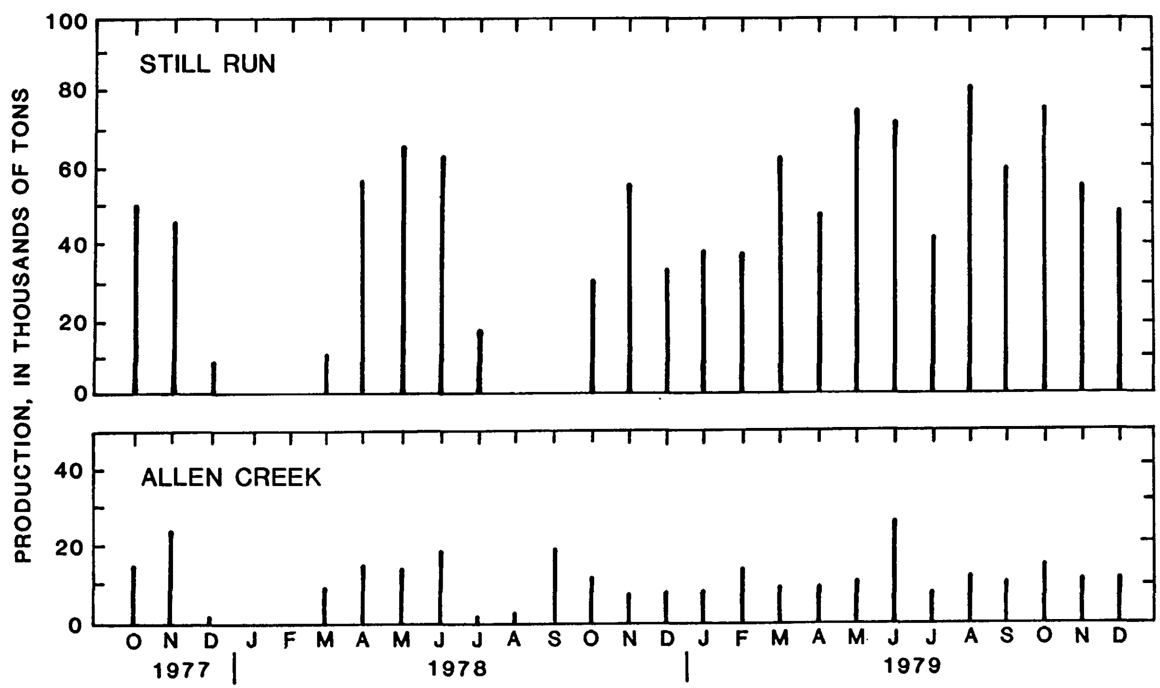


Figure 2.4-4.--Monthly coal production from deep mines in Allen Creek and Still Run basins, October 1977 to December 1979.

2.5 Location of and Coal Production From Surface Mines

SURFACE DISTURBANCE BY SURFACE MINING RANGES FROM 0.0 TO 20.4 PERCENT OF DRAINAGE AREA OF STUDY BASINS

Surface mining within the basins varies in intensity and age of activity. Allen Creek had 20.4 percent of its drainage area disturbed by surface mining prior to and during the study period. About 5.2 percent of the drainage area of Still Run was disturbed by surface mining prior to the study period. Milam Fork was surface mined in about 1.4 percent of its drainage area late in the study period.

The areas disturbed by surface mining in the study basins are shown in figure 2.5-1. The percentage of drainage area disturbed is summarized in table 2.5-1. Yearly and monthly coal production from surface mines in the study basins are shown in figures 2.5-2 and 2.5-3.

Allen Creek, the basin with the greatest amount of deep mining, is also the basin with the greatest amount of surface disturbance due to strip mining. It is also the basin with the greatest total coal production from surface mines.

Still Run basin had 5.2 percent of its surface disturbed by strip mining in 1974-76. No surface mining in the basin occurred during the study.

In January 1979, clearing of trees and brush near the headwaters of Milam Fork began in preparation for strip mining. In April 1979, surface mining began and continued until the end of this study in December 1979. All surface-mine coal production in Milam Fork was from this single mine near the headwaters. Because this strip mine was not entirely within the Milam Fork basin, the coal production shown in figures 2.5-2 and 2.5-3 includes production from the same mine but outside the basin.

Table 2.5-1.--Percentage of basins surface mined

Stream basin	Percentage of basin disturbed by surface mining
Allen Creek---	20.4
Still Run-----	5.2
Milam Fork----	1.4
Bearhole Fork-	.0
Marsh Fork----	.0

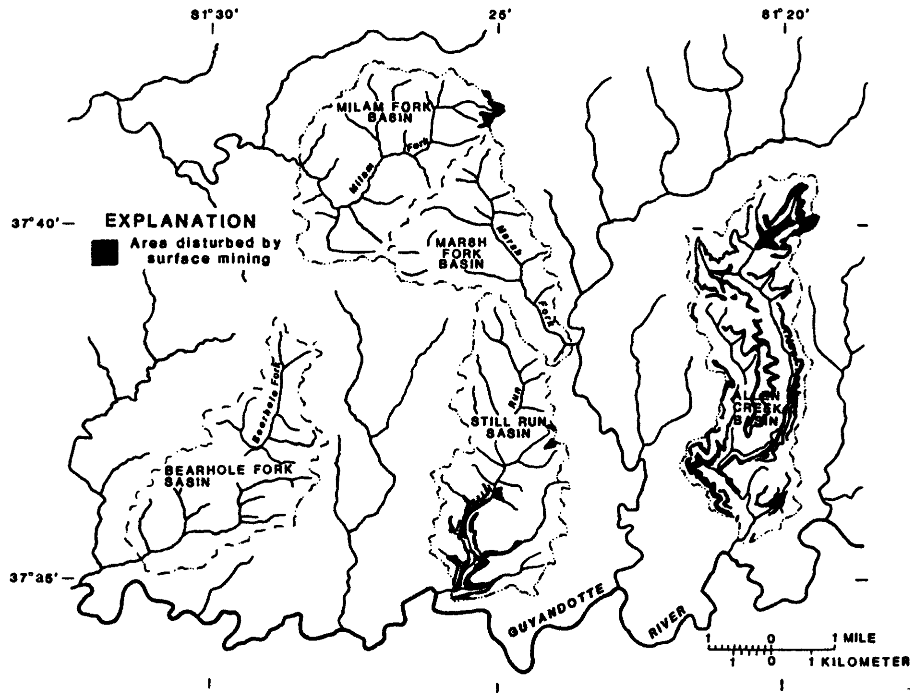


Figure 2.5-1.--Area disturbed by surface mining in study basins.

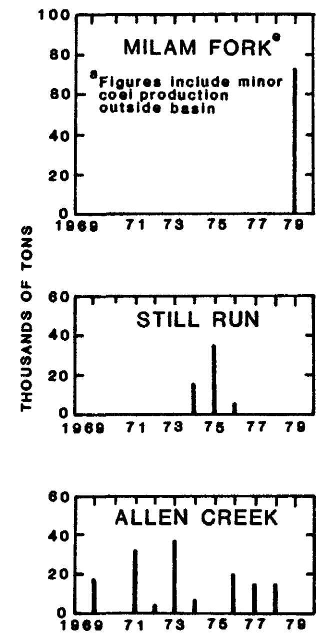


Figure 2.5-2.--Annual coal production from surface mines in Milam Fork, Still Run, and Allen Creek, 1969-79.

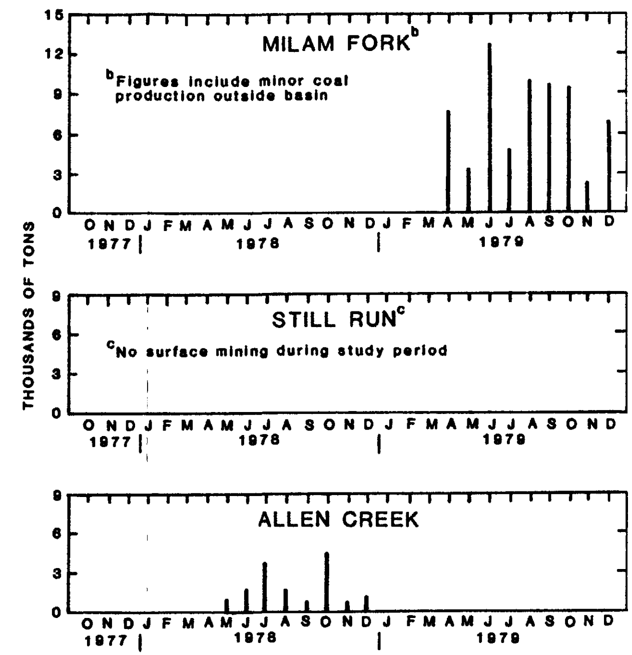


Figure 2.5-3.--Monthly coal production from surface mines in Milam Fork, Still Run, and Allen Creek, October 1977 to December 1979.

3.0 DATA-COLLECTION NETWORK

3.1 Data Network Description

HYDROLOGIC DATA AVAILABLE AT OVER 160 SITES

Streamflow, ground-water level, precipitation, and water-quality data were collected during 1976-79 at over 160 sites in the study area.

The data-collection network consisted of streamflow, ground-water level and precipitation measuring stations, and periodic and synoptic sampling sites to describe surface and ground-water quality. Data were collected for the period 1976-79 and were published by U.S. Geological Survey, 1979.

Continuous streamflow data were collected at gages located near the outlets of Allen Creek, Bearhole Fork, Marsh Fork, Milam Fork, and Still Run basins. The locations are shown in figure 3.1-1. Additional information for all sites is given in appendix 1.

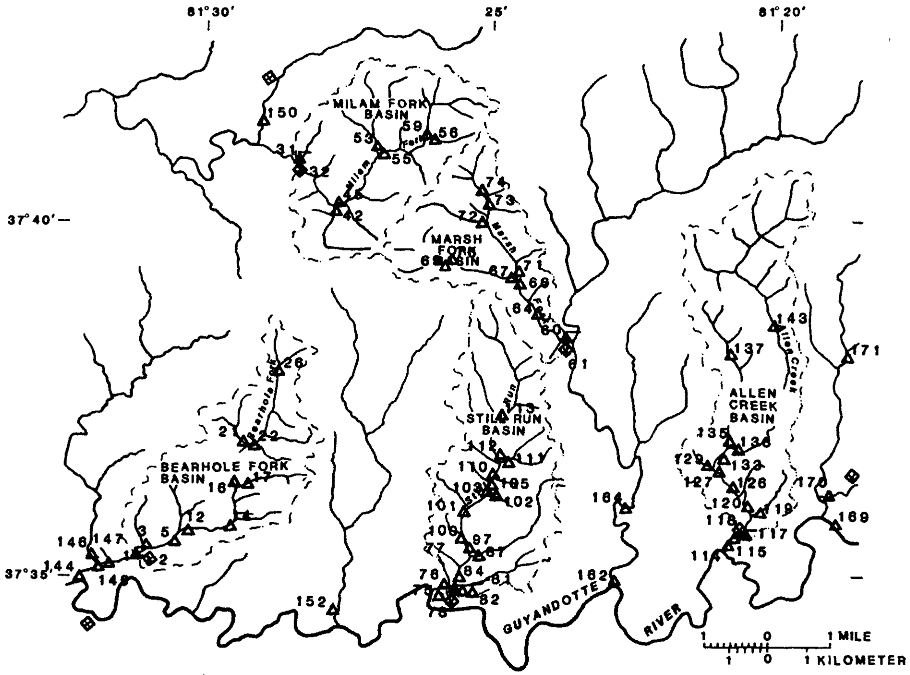
Ground-water-level data were collected at seven observation wells located in Allen Creek, Marsh Fork, Milam Fork, and Still Run and Black Fork basins (fig. 3.1-2). Additionally, water-level records were collected at two abandoned vertical mine shafts in Milam Fork basin. Some water-level data were collected also at private wells in the study area.

Precipitation data were collected at sites 2, 32, 61, 78, and 118 during the study. Rainfall data collected by National Weather Service observers at sites shown in figure 3.1-1 were used to augment the data collected for this study.

Water-quality data were collected monthly at sites 1, 31, 60, 77, and 117 and less frequently at 62 synoptic sites shown in figure 3.1-1 and appendix 1. Monthly water-quality data collection consisted of on-site measurement of streamflow, pH, specific conductance, water temperature, dissolved oxygen, and alkalinity. Laboratory analysis was performed for dissolved major constituent concentrations (calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and fluoride) and selected dissolved and total recoverable trace-element concentrations (iron, manganese, aluminum, arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc). Suspended-sediment, dissolved solids, nutrient, and microbiological concentrations were determined periodically. Standard U.S. Geological Survey methods were used throughout (Skougstad and others, 1978, and Greeson and others, 1977). Daily suspended-sediment samples were collected by observers at sites 1, 31, 60, 77, and 117. Benthic invertebrates were collected at selected sites in the study area.

Synoptic surface-water sites were selected to investigate water-quality differences within each study basin and between study basins. They were sampled for the same water-quality characteristics as the other surface-water sites, except that suspended-sediment, nutrient, microbiological, and benthic invertebrate data were not collected.

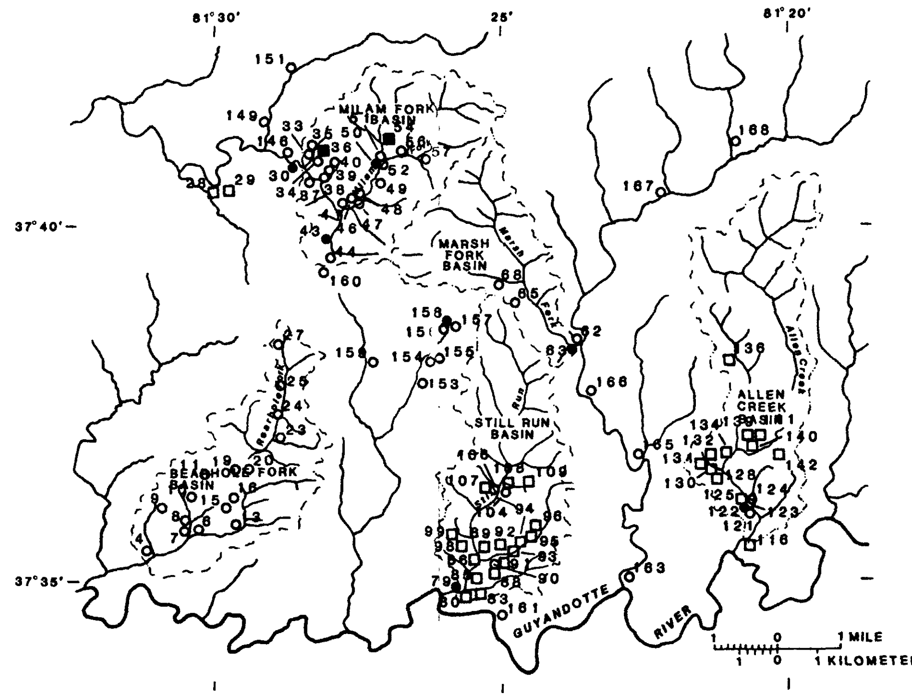
Water-quality samples were collected at 99 ground-water synoptic sites, including private wells, mine-discharge points, flooded mineshafts, and deep-mine interiors. All wells tapped either the Pocahontas or New River Formations of the Pottsville Group (fig. 3.1-2 and appendix 1).



EXPLANATION

- △[5] Surface-water (synoptic) site and number
- ▲[77] Surface-water (continuous record) site and number
- ◈[76] Precipitation site (continuous record) and number
- ◈ Non-recording precipitation site (National Weather Service)
- ◣[1] Sediment-measurement site and number
- —·—·— Basin boundary

Figure 3.1-1.--Location of surface-water and precipitation data-collection sites.



EXPLANATION

- ○[4] Domestic well and number
- ●[50] Well with water-level recorder and number
- □[28] Mine discharge and number
- ■[36] Mine shaft with water-level recorder and number
- —·—·— Basin boundary

Figure 3.1-2.--Location of ground-water data-collection sites.

4.0 GROUND WATER

4.1 Stress-Relief Fractures

STRESS-RELIEF FRACTURES CONTROL LOCAL FLOW AND OCCURRENCE OF GROUND WATER

Fractures form in the rocks of valley bottoms and valley walls in response to a relief of stress, when weighty overlying rocks are removed by stream down-cutting and erosion. These fractures, in the otherwise mostly impermeable sandstones and shales, store and transmit ground water.

In much of the Appalachian Plateaus, the primary permeability of rock is negligible. Most ground water flows through and is stored in secondary-permeability features, such as joints, faults, coal cleats, fractures associated with anticlines and lineaments, solution openings, and subsidence fractures caused by underground mine collapse. For example, a fractured coal bed overlying a nearly impermeable underclay may be a perched aquifer capable of supplying a significant quantity of water to domestic wells. A recent study in the Black Fork Valley at Twin Falls State Park by Wyrick and Borchers (1981) showed that stress-relief fractures were the dominant controls on the flow and occurrence of ground water in the area. The Black Fork Valley is centrally located among the five study basins, and is unmined. While several types of secondary-permeability features may be present, hydrologic data collected in the study basins support the theory that stress-relief fractures are the dominant controls on the flow and occurrence of ground water.

After an uplift, stress-relief fracturing may occur on a regional scale in response to a relief of compressional stress as erosion removes thousands of feet of overlying rocks. Valley stress-relief fracturing, which occurs on a more local scale in the Appalachian Plateaus, was described by Harry Ferguson during foundation investigations at U.S. Army Corps of Engineers' lock and dam sites (Ferguson, 1967, 1974). Figure 4.1-1 is a generalized block diagram of a valley in the Appalachian Plateaus. The main features of valley stress-relief fracturing in this illustration are taken from Ferguson (1974). Valley-wall and valley-floor stress-relief fractures form in response to the erosion of strata in the valleys.

Where material is eroded from a valley, its walls are subjected to unequal horizontal stress. That stress results in vertical tension fractures and horizontal bedding-plane fractures. Strata in the valley walls sag toward the valley center, fracture subvertically, and eventually slip downslope along subhorizontal bedding-plane fractures. The vertical fractures are oriented generally parallel to the strike of the valley, or they may strike at an angle reflecting a tangential stress from tributary valleys. The vertical fractures that develop in one rock type generally stop at the bedding-plane contact with a rock of different competence. They become less numerous inward from the rock outcrop and do not occur beyond the "destressed" zone in the valley walls. This "destressed" zone contains highly weathered fractures that generally disappear between 35 and 100 ft inward from the valley wall outcrop.

Vertical-compressional stress on rocks of a valley floor is relieved where heavy overlying rock is eroded. The weight of the rocks in the hills flanking the valley walls causes the midvalley strata either to bow upward, separating along bedding planes and cracking vertically, to respond by compressional shear fracture and minor thrust failure, or both. These midvalley deformations do not generally occur deeper than 50 ft below the top of midvalley bedrock. The horizontal and vertical fracture systems are interconnected and, thus, become conduits for the movement of ground water.

Fractures in the otherwise impermeable valley wall rocks allow rainfall to infiltrate and migrate toward the central valley fractures which are the most transmissive part of the "aquifer." The local aquifer can be described as a system of fractured rock in valley bottoms and sides. Because the rock beneath the hills flanking the valleys is not commonly fractured and has negligible primary permeability, this rock acts as a barrier to the flow of ground water and separates the shallow ground-water flow system of one valley from that of adjacent valleys. Consequently, each valley has its own local aquifer, and tributary valley aquifers are connected hydraulically to main valley aquifers by stress-relief fractures.

The amount of ground water contained in a valley's stress-relief-formed aquifer depends upon the volume of the open fractures which store the water. The ease with which water moves through the aquifer depends upon the connections among these stress-relief fractures. Thus, both the aquifer storage characteristics and transmissivity are dependent upon the factors which determine the size and distribution of the stress-relief fractures for central valley rocks. These factors as described by Ferguson (1967, 1974) are:

- The lithology and competency of the rocks composing the valley walls and valley floor.

- The dimensions of the valley--width, height.

Because similar rocks crop out in all the study basins, as described in section 2.1, and because physical characteristics (dimensions) of the basins are similar, as described in section 2.2, similar stress-relief fractures should develop with about the same distribution in all the basins. Therefore, hydrologic properties of the bedrock should be similar in all the basins. However, minor lithologic differences in the rocks at or near the surface may cause local variations in the distribution and character of the stress-relief fractures. More importantly, compositional differences in alluvial and colluvial material within the basins allow differing hydrologic conditions to exist both within a basin and from basin to basin. It is, of course, necessary to define these natural variations before describing the effect of coal mining on the ground-water system.

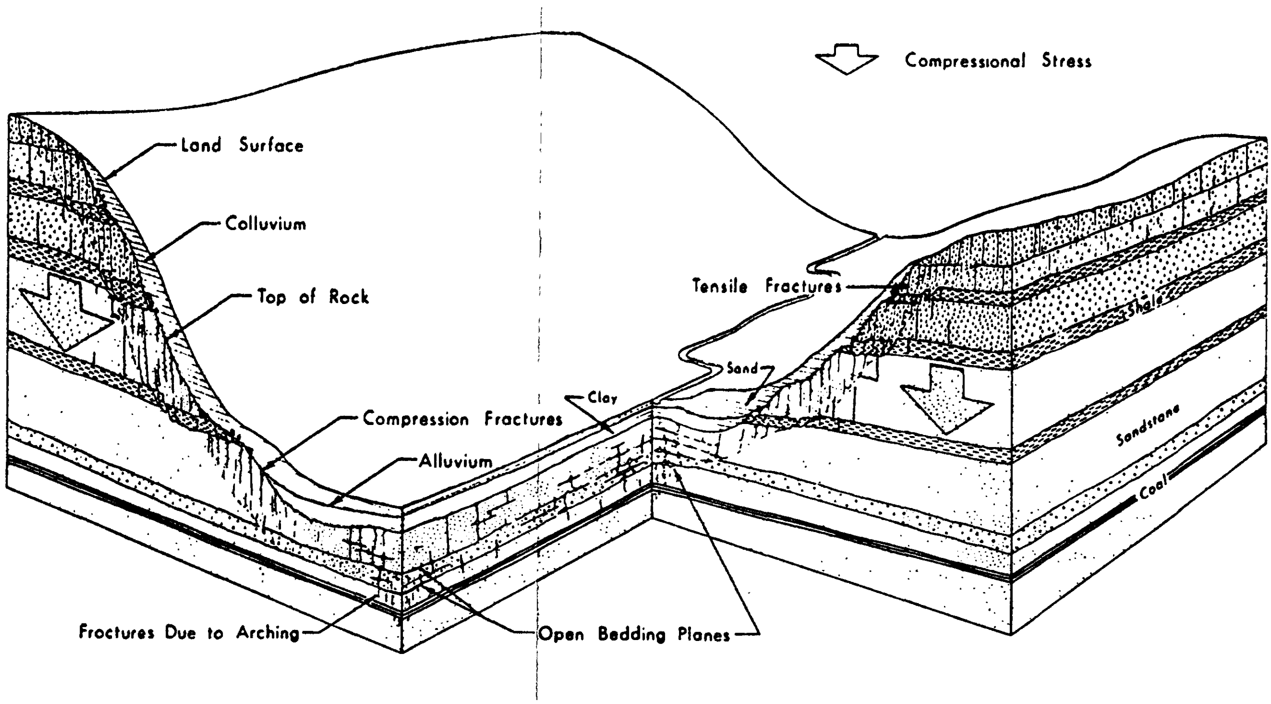


Figure 4.1-1.--Principal features of stress-relief fracturing in an Appalachian valley (after Ferguson, 1974).

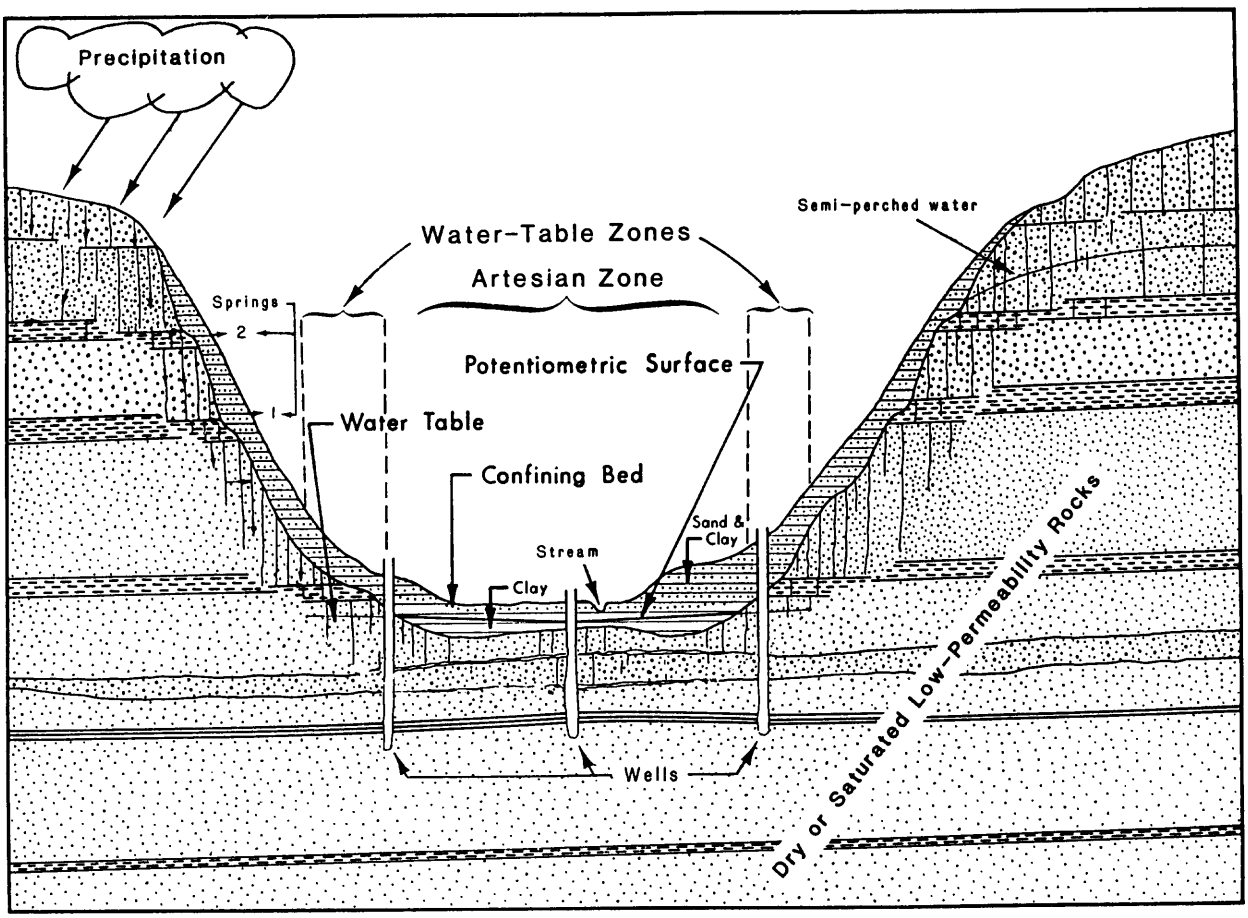


Figure 4.2-1.--The hydrologic effects of stress-relief fracturing in an Appalachian valley.

midvalley bedding-plane separations. Points of inflow to the wells are indicated by dashed lines on the graphs in figure 4.2-2. Sites 157, 158, 156, and 153 are not within the study basins, but were drilled at Twin Falls State Park and tested as a part of another study to help define the flow and occurrence of ground water in the the Appalachian Plateaus physiographic province (Wyrick and Borchers, 1981). The ground-water conditions at the park are typical of conditions in the unmined sections of the study basins.

Figure 4.2-1 also shows, in a generalized fashion, the ground-water conditions near the head of the main valley at Twin Falls State Park. A thick alluvial clay overlays the midvalley bedrock. This clay hydraulically separates the midvalley stress-relief fractures from surface streams and creates artesian ground-water conditions in the fractures at the center of the valley. Wells tapping midvalley fractures have the same water-level elevations as wells located in the water-table zones. These thick alluvial clays are often deposited in midvalley areas where channel slopes are relatively flat. They cause artesian ground-water conditions at Twin Falls State Park and in the Milam Fork basin as shown by the cross-hatched areas on figure 4.2-2.

Where these clays are absent or discontinuous, surface and ground waters may interact. These interactions may be difficult to quantify as illustrated by figure 4.2-3, which shows a map and cross section near the mouth of the unmined Marsh Fork basin. Discharge measurements were made on April 3, 1980, at sites 600 ft upstream and 400 ft downstream of the observation well at site 63. The stream discharge at the upstream site was 9.5 ft^3/s, while the stream discharge 1,000 ft downstream was 9.8 ft^3/s. The difference in flow between the two sites, 0.3 ft^3/s, is within the standard 5 percent discharge measurement error. However, these measurements were made very carefully and were repeated and confirmed. The measurements show that Marsh Fork was not losing water but was gaining in this reach. This is surprising because the ground-water level in the observation well, only 40 ft from the stream, was 40.0 ft below stream level during the time the discharge measurements were made. Possible explanations for this unexpected situation are:

- Marsh Fork was gaining perched water from saturated and unsaturated alluvial and colluvial materials and is hydraulically separated from the stress-relief fractured bedrock.

- Marsh Fork was gaining more semi-perched water from alluvial materials than it was losing to the fractured rock aquifer beneath the stream.

Since no information was available to determine the amount of water contributed from alluvial materials to the stream, it is not possible to state which of the above situations exists at this site. What can be concluded is that Marsh Fork is gaining a small amount of water in this reach, and that a potential exists for leakage from the stream to the ground-water body.

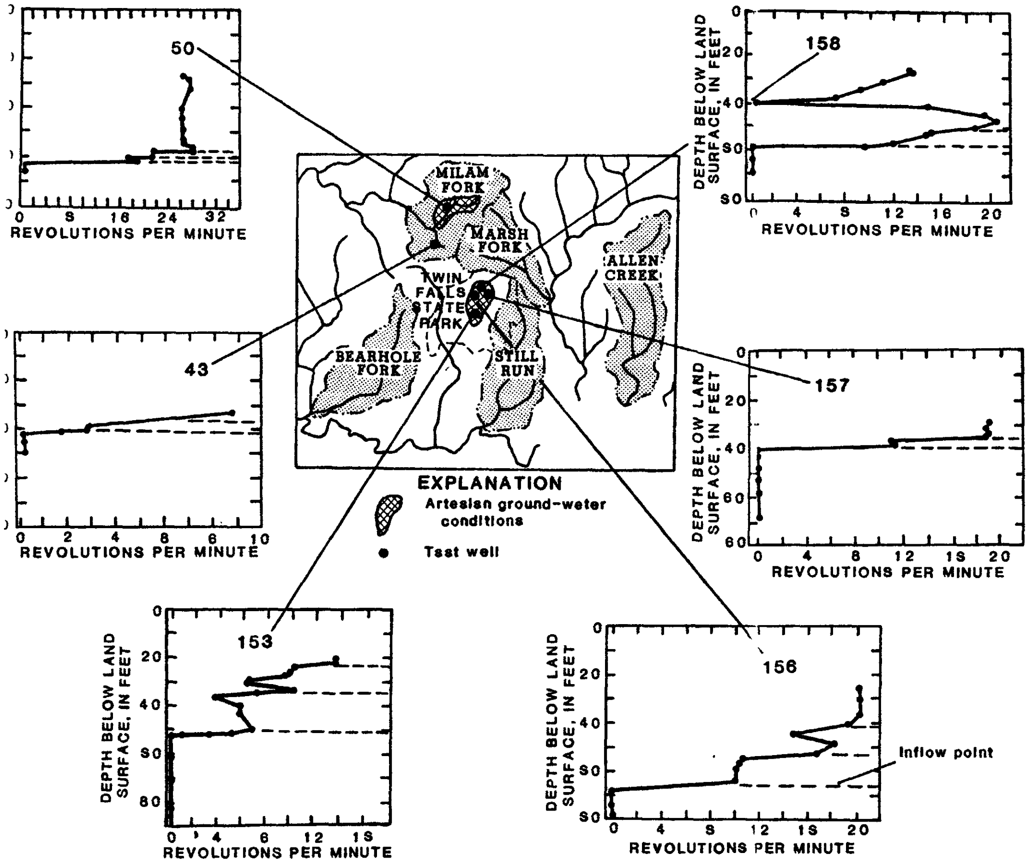


Figure 4.2-2.--Ground-water inflow points in selected wells.

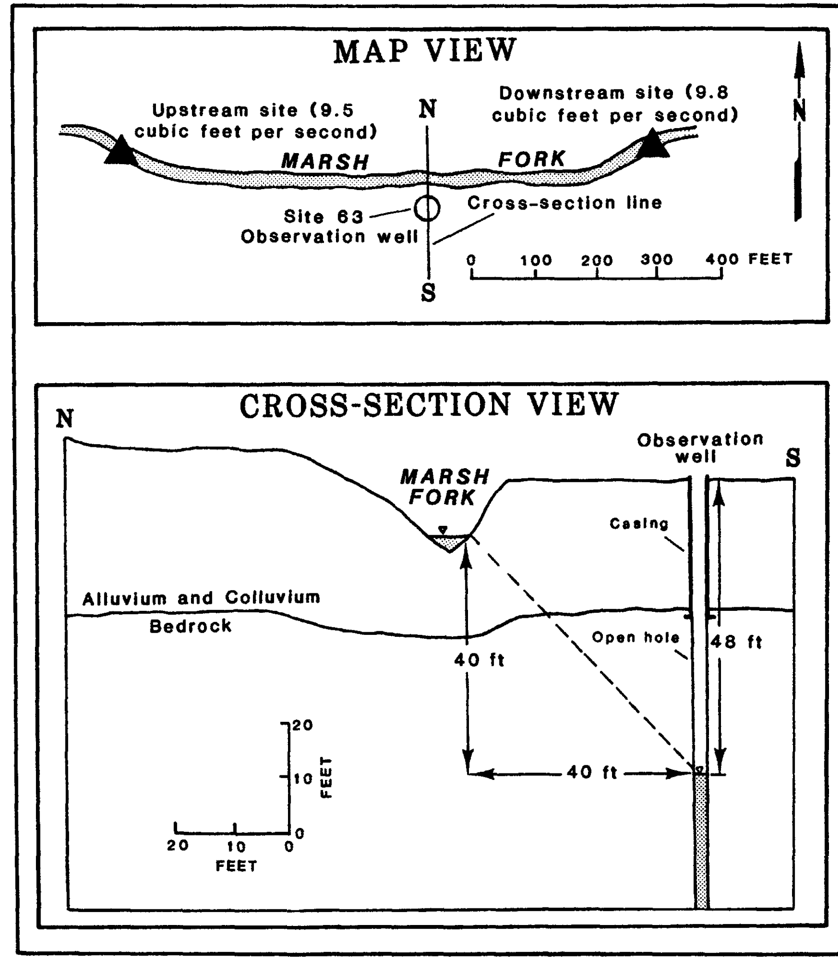


Figure 4.2-3.--Ground-water and surface-water relationships near the mouth of Marsh Fork.

4.3 Base-Runoff Recession Curves

GROUND-WATER DISCHARGE FROM MINES COMPLICATES ANALYSIS OF BASE-RUNOFF RECESSION CURVES

Base-runoff recession curves for the mined basins have gentler slopes than those for the unmined basins. The base-runoff recession curve for the Guyandotte River near Baileysville, W. Va., is similar to those for the mined study basins. Estimates of aquifer diffusivity for the unmined basins range from 47,000 ft^2/d at Marsh Fork to 36,000 ft^2/d at Bearhole Fork.

The slope of a stream's base-runoff recession curve is often used to estimate the diffusivity of the aquifer discharging ground water to that stream. Figure 4.3-1 illustrates the composition of a base-runoff recession curve for Marsh Fork. Daily-mean stream discharge, after a rain storm, is plotted relative to the number of days since the peak streamflow caused by that storm. Daily streamflow is plotted following several storms in this manner with stream discharge plotted on the logarithmic scale, and the number of days since the peak streamflow on the arithmetic scale. The curve will approach a straight line when streamflow is primarily ground-water discharge. The slope of the straight line can be used to estimate a value of aquifer diffusivity (transmissivity/storage).

Unit-base-runoff recession curves were used so that all streams could be plotted using a common base. Unit-base-runoff curves for the five study basins and the Guyandotte River near Baileysville, which is located near the study area (fig. 1.1-1), are shown in figure 4.3-2. The slopes of the curves from unmined basins (Marsh Fork and Bearhole Fork) are steeper than the slopes of the curves from mined basins (Allen Creek and Still Run). The slope of the curve for the Guyandotte River near Baileysville, W. Va., the headwaters of which are heavily mined, is nearly the same as the slope of the curves from the mined basins.

Estimates of aquifer diffusivity were calculated from the unit-base-runoff recession curves for the unmined basins, according to the method desribed by Rorabaugh and Simons (1966), and Trainer and Watkins (1975). Diffusivity of aquifer materials in Marsh Fork is estimated to be 47,000 ft^2/d and in Bearhole Fork 36,000 ft^2/d. However, this method of analysis and most other quantitative techniques contain basic assumptions that allow the use of simple mathematics in the solution of a problem. These assumptions, which include the presence of uniform, homogeneous, and isotropic aquifers hydraulically connected to streams that are everywhere equidistant from basin divides, are usually not valid in the Appalachian Plateaus. Section 4.2, which described ground-water and surface-water relationships near the mouth of Marsh Fork, illustrates a common problem encountered when standard quantitative techniques are applied to hydrologic terrains where these basic assumptions are not satisfied.

When streamflow data are used for quantitative analysis, as in the base-runoff recession curves in figure 4.3-1, the aquifer diffusivity derived from such analysis may reflect properties of all the materials that contribute water to the stream and not necessarily the saturated fractured-rock aquifer that supplies water to most domestic wells in the basin.

The differences in base-runoff recession curves probably reflect the effects of mining, since the basins have similar natural and land-use characteristics, except for mining. The effects of mining on streamflow include alteration of the natural water-transmitting and storage characteristics of near-surface soil and rock and pumping of minewater into streams. These effects are discussed in detail in sections 5.0 and 6.1.

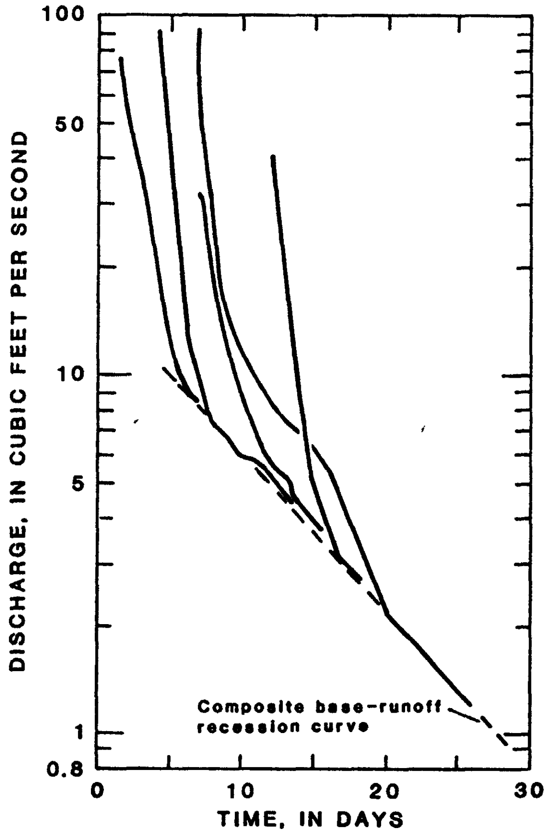


Figure 4.3-1.--Recession hydrographs for Marsh Fork and composite base-runoff recession curve.

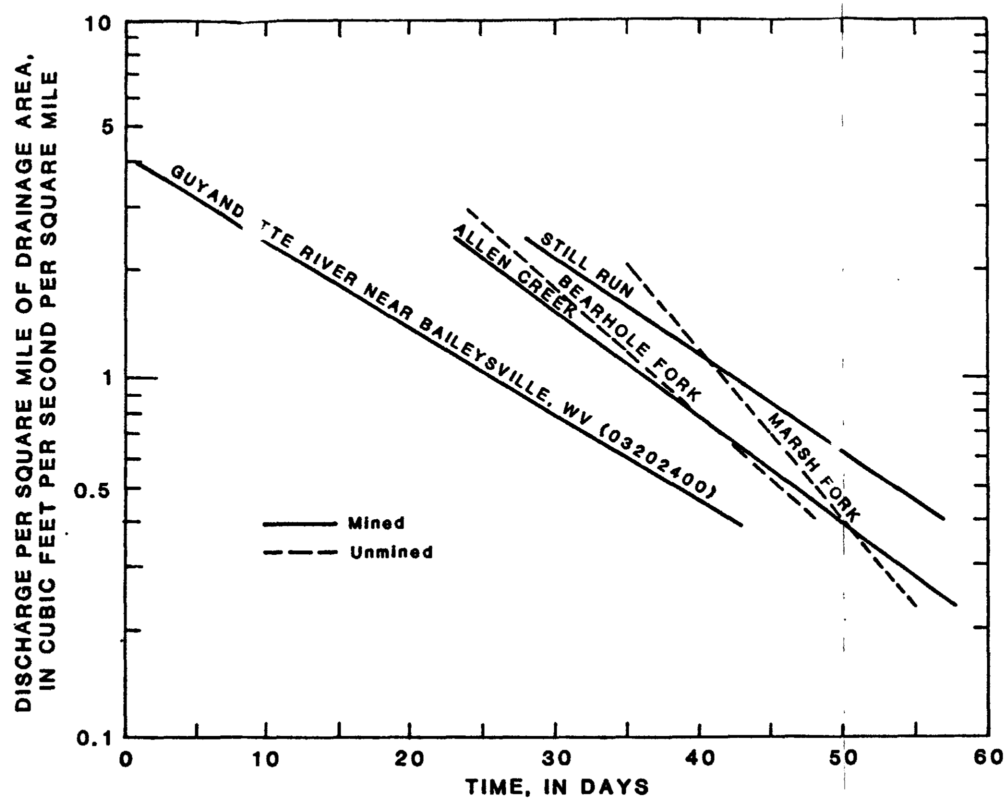


Figure 4.3-2.--Unit-base-runoff recession curves for Marsh Fork, Bearhole Fork, Still Run, Allen Creek, and for the Guyandotte River near Baileysville.

GROUND-WATER LEVELS MONITORED IN MINED AND UNMINED BASINS

Ground-water levels in the study area were recorded on seven shallow wells and two abandoned deep-mine shafts. Hydrographs of monthly mean water level reflect effects of mining, precipitation, evapotranspiration, and nearby pumpage.

The locations of observation wells (sites 122, 158, 79, 50, 43, 30, and 63), mine shafts (sites 36 and 54), and precipitation-gaging stations (sites 2, 32, 61, 78, and 118) in the study area are shown in figure 4.4-1. Data were collected at each site by a continuous recorder. Hydrographs of monthly mean ground-water levels shown in figures 4.4-2 through 4.4-6 indicate influences on the ground-water system by precipitation, evapotranspiration, nearby pumpage, and to some extent mining. Total monthly precipitation, in inches, measured in each study basin is also shown in figures 4.4-2 through 4.4-5.

Ground-water levels in the basins fluctuate in response to seasonal variations in precipitation and evapotranspiration. Lowest ground-water levels occurred in late summer and autumn--periods of lowest precipitation and highest evapotranspiration. Ground-water levels rose during the winter when precipitation increased and evapotranspiration losses decreased. Also, superimposed on these seasonal trends were the effects of pumping from the ground-water system and mining.

The observation well at site 158 in Twin Falls State Park is located in a well field which supplies irrigation water for a public golf course. The well field is used during the late spring, summer, and fall. Thus, water levels in this area are lower than normal during these periods of increased pumpage (fig. 4.4-5). Recharge to the ground-water system occurs in winter and early spring, raising the water table to the pre-pumping level. This seasonal pumping causes the water level in the observation well to fluctuate over a wider range than wells in areas unaffected by pumping stress.

Figure 4.4-6 contains a hydrograph of the maximum and minimum daily water level in the observation well at site 79 and a graph of daily precipitation at site 78. The water level responds to precipitation and seasonal changes. It is also affected by the pumping of the mine water-supply well located about 150 ft away. This well is pumped intermittently at rates ranging from 20 to 250 gal/min and supplies water for the washhouse and shop of the Number 3 Pocahontas coal mine. The effects of this pumping can be seen on the hydrographs of figures 4.4-6 and 4.4-7 and are as follows: (1) The water level rises and falls about 0.5 ft/d (the distance between the maximum and the minimum water-level line of fig. 4.4-6). (2) The water level experiences a weekly cycle, declining during the 5-day work week and recovering on the weekends, when the mine shuts down. (See fig. 4.4-6.) (3) The water level also experiences a daily cycle during the work week, declining after each shift

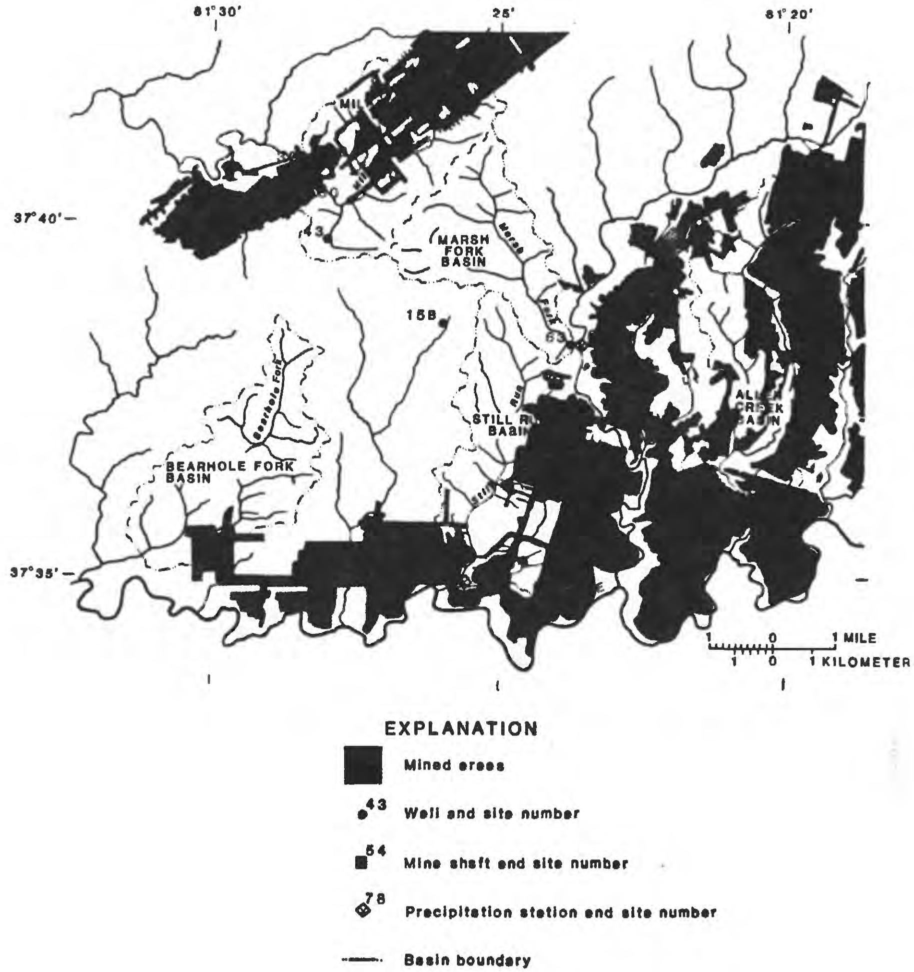


Figure 4.4-1.--Location of observation wells, mine shafts, precipitation gages, and mined areas in study area.

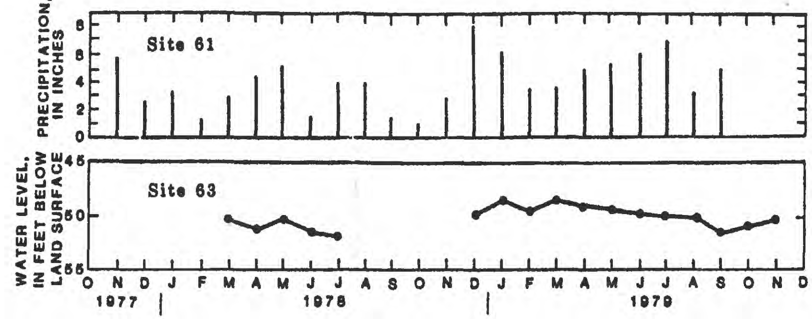


Figure 4.4-2.--Monthly mean water level in observation well at site 63 and precipitation at site 61 in Marsh Fork basin.

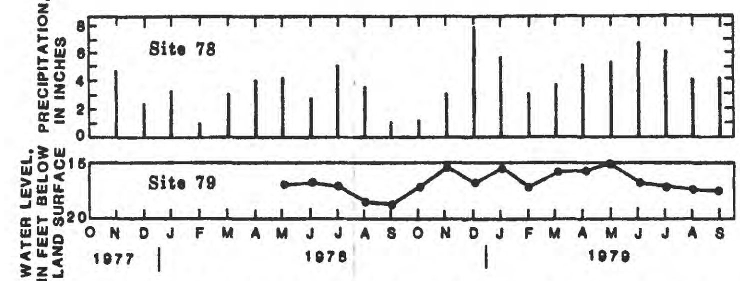


Figure 4.4-3.--Monthly mean water level in observation well at site 79 and precipitation at site 78 in Still Run basin.

ends (4:00 p.m., midnight, 8:00 a.m.), when miners use the wash house facilities. (See fig. 4.4-7.) Thus, the ground-water system in this area is affected by the coal mining operation even though the well site is not undermined.

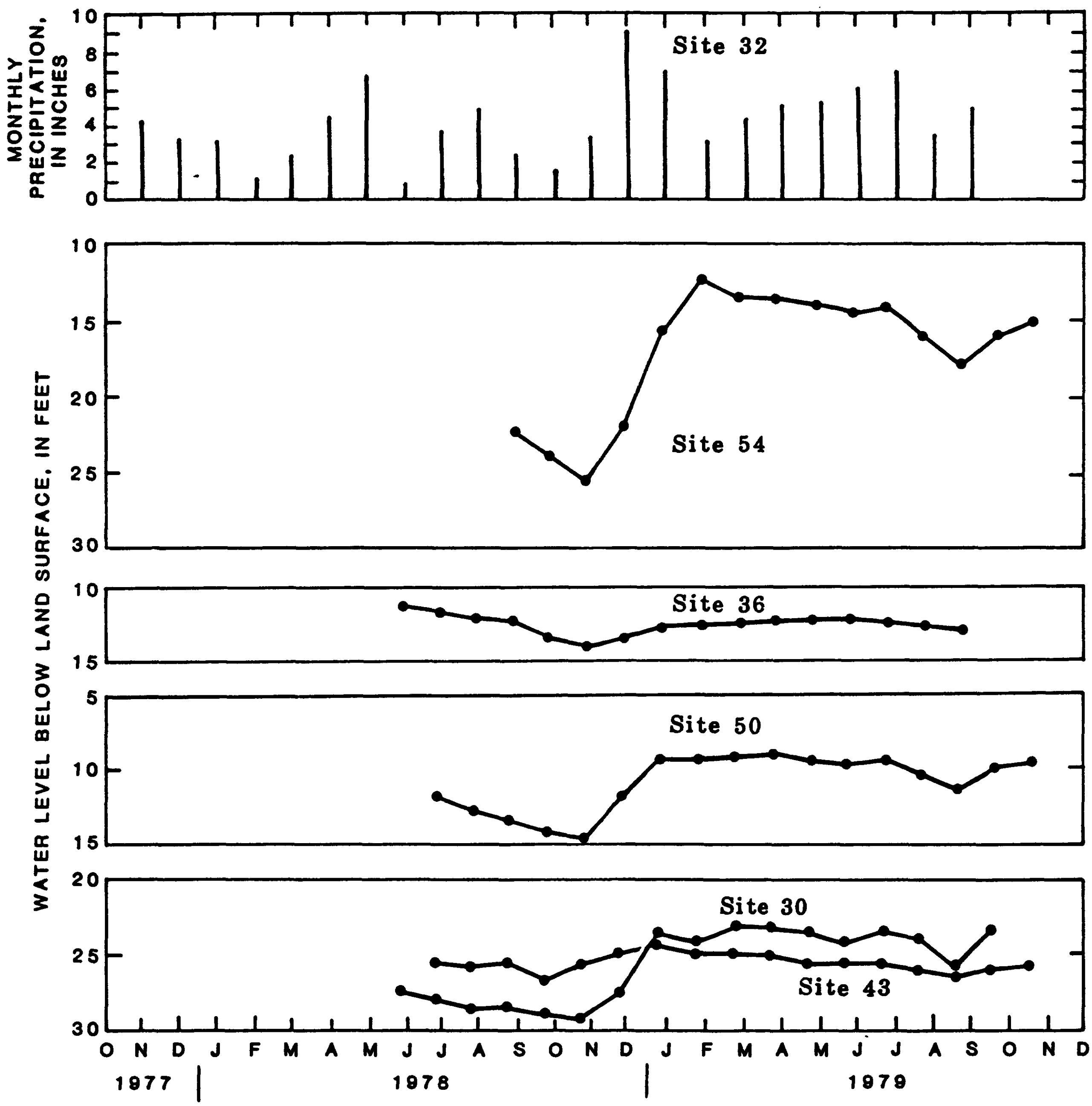


Figure 4.4-4.--Monthly mean water levels in observation wells at sites 30, 43, and 50, mine shafts at sites 36 and 54, and precipitation at site 32, in Milam Fork basin.

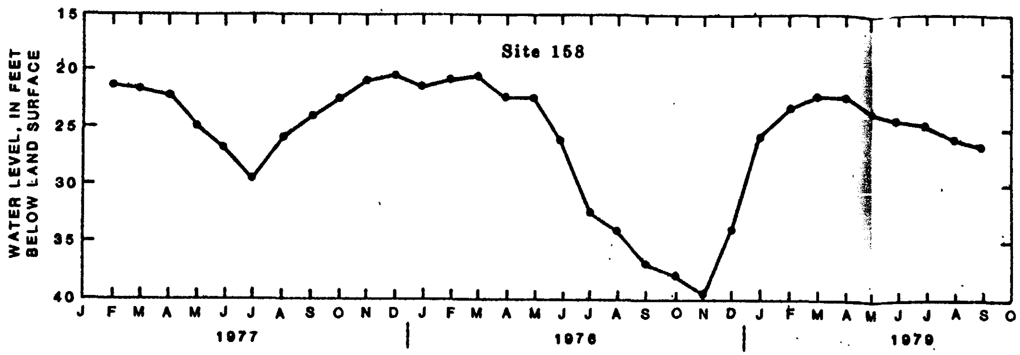


Figure 4.4-5.--Monthly mean water level in observation well at site 158 in Twin Falls State Park.

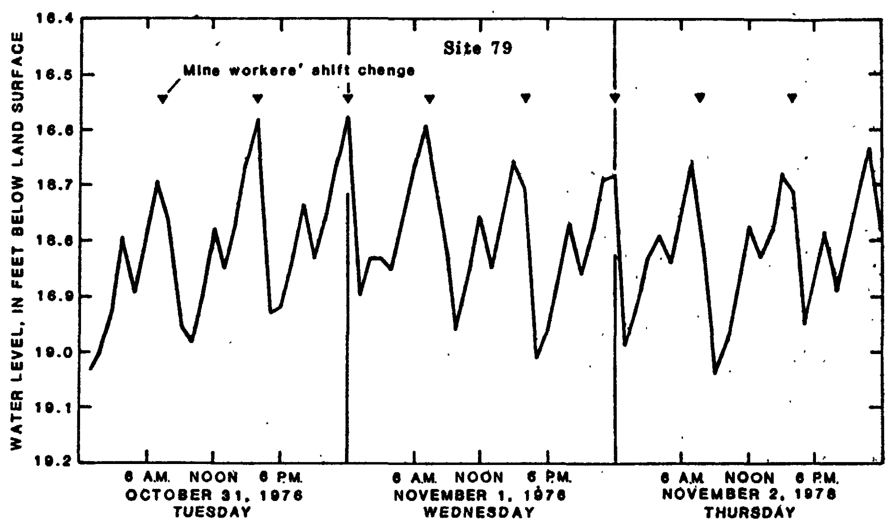


Figure 4.4-7.--Hourly water level in observation well at site 79.

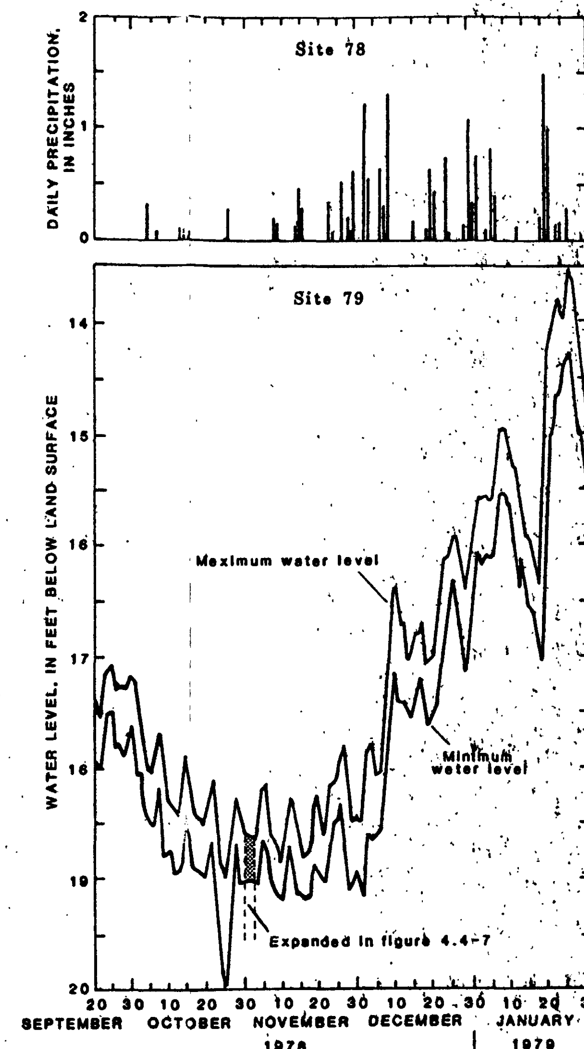


Figure 4.4-6.--Daily water level in observation well at site 79 and precipitation at site 78.

4.5 Specific Capacities

SPECIFIC CAPACITIES OF WELLS MAY BE AFFECTED BY IRON PRECIPITATION AND BY DEEP MINING

Specific capacities of wells may be affected by iron precipitation and by deep mining. Freely draining or pumped deep mines act as ground-water sinks, and drain fractured, water-bearing strata above or adjacent to the mines. Dormant well bores may be coated and plugged by iron precipitates.

Specific capacity tests were performed on the wells shown in figure 4.5-1, and the results are shown in table 4.5-1. In unmined areas, specific capacities are highest in wells which tap central valley bedding-plane fractures (sites 156, 158, and 153), whereas wells at the base of valley walls or wells in smaller tributary valleys (sites 154, 43) have lower specific capacities. The lower specific capacities of two wells (sites 30, 106) overlying deep mines can be explained by leakage of water from stress-relief fractures into the mine voids, and by clogging of water-bearing fractures by iron precipitates and bacterial growths in the vicinity of the well bore.

Even though specific capacity may be lower in undermined areas, Hobba (1981) has shown that aquifer transmissivity often is increased because of increased fracturing of rock strata above the deep mines. This increased fracturing is particularly evident in areas where coal pillars, which support overlying strata, have been removed during the final stages of mining. This fracturing may hydraulically connect the mine to near surface stress-relief fractures.

Wells available for specific capacity testing in the mined basins (sites 30, 106, 122) had been unpumped for several years prior to the tests. The long period of dormancy may have allowed significant amounts of oxygen to diffuse across the air-water interface in the well, allowing soluble iron (ferrous) to oxidize and precipitate out of solution. The precipitate (ferric hydroxide deposits) coats the well bottom and sides. The precipitate coating and slimes deposited by iron and sulfur bacteria may clog the limited number of fractures supplying the well with water--thus, inhibiting the flow of water into the well and causing a lower specific-capacity value.

Large quantities of iron precipitate coating the well bore at site 122 indicate that the specific capacity test on the well was drastically affected by iron-clogging. Iron precipitates in the discharge water indicated that tests on wells at sites 79 and 50 were probably affected somewhat by clogging. Tests on wells at sites 106 and 30 were affected both by clogging and by leakage to underlying deep mines.

Table 4.5-1.--Summary of specific-capacity tests for selected wells

[Site numbers correspond to those in figure 5.5-1]

Site[a]	Specific capacity, in gallons per minute per foot after pumping for: 10 minutes	1 hour	1 day	Location	Status of deep mining
158	97	45	9.8	Valley-----------	Unmined.
156	98	44	8.9	Valley-----------	Unmined.
153	53	21	11	Valley-----------	Unmined.
154	3.4	2.6	1.7	Tributary valley-	Unmined.
79	2.5	1.3	.71	Valley-----------	Active mines in adjacent hillsides.
50	3.0	2.4	2.4	Valley-----------	Inactive flooded mine about 470 feet below well bottom.
43	1.7	1.7	1.7	Valley wall------	Unmined.
30	.14	.05	-----	Valley-----------	Inactive flooded mine about 37 feet below well bottom.
106	.32	.07	-----	Valley wall------	Active mines in hillsides and 70 feet below adjacent valley.
122	.40	.11	-----	Valley-----------	Active and inactive mines in adjacent hillsides.

[a] All wells at these sites are cased through the soil zone and are uncased from the soil-rock interface downward.

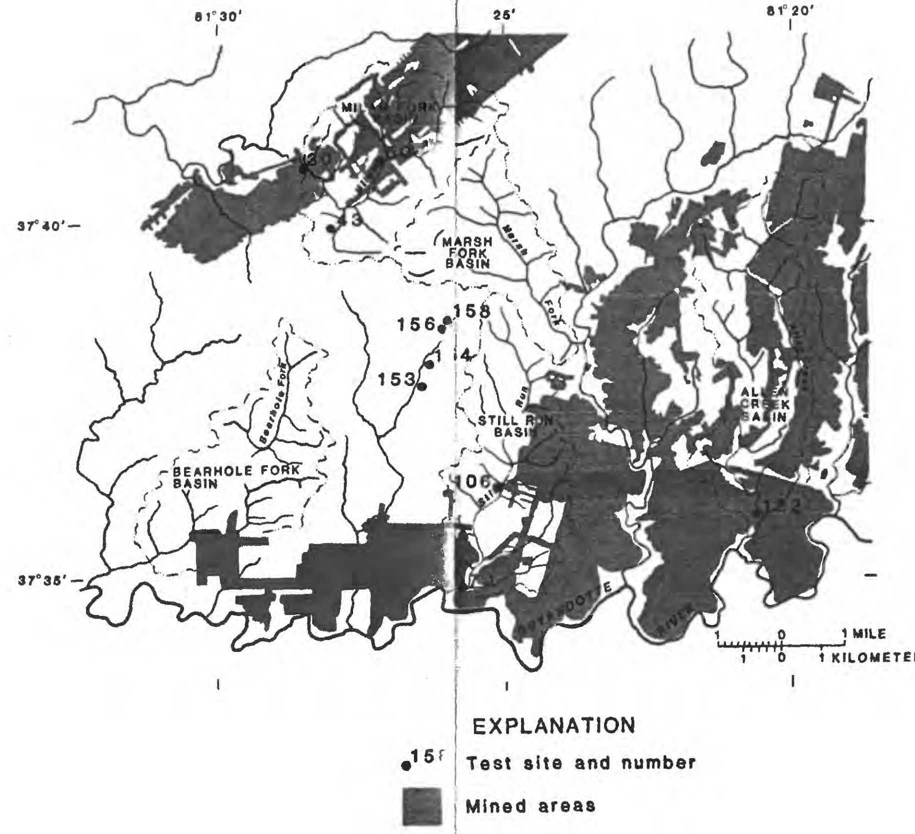


Figure 4.5-1.--Location of specific-capacity test sites and mined areas.

4.6 Ground-Water Flow in Allen Creek and Still Run Basins

DEEP MINES IN ALLEN CREEK AND STILL RUN BASINS SIGNIFICANTLY ALTER GROUND-WATER FLOW SYSTEM

Ground-water availability and flow direction are altered by deep mines in the Allen Creek and Still Run basins. Deep coal mines can intercept and divert infiltrating water, which would normally be stored in central-valley aquifers, to streams.

Deep mines in Allen Creek and Still Run basins act as ground-water sinks by allowing ground water to flow toward mine voids. The water is subsequently pumped from or freely drains from the deep mines to settling ponds and then to the streams. Often, deep mines cross stream basin boundaries, and ground water infiltrating into such mines may be diverted from one stream basin to a discharge point in an adjacent stream basin. This is referred to as interbasin transfer of ground water. Quantifying interbasin transfer of ground water is difficult because the exact source and (or) amount of discharged water cannot be accurately determined. Many mines have pumps equipped with automatic float switches that operate the pumps intermittently, to eliminate excess water in the mines, no records of pumpage are kept.

Deep-mined areas in Allen Creek are shown on figure 4.6-1 and a cross section near the mouth of Allen Creek basin is shown in figure 4.6-2.

The deep mines shown in figure 4.6-2 differ in age. Mines in the Number 3 Pocahontas Seam are old abandoned mines, in which supporting coal pillars were removed. Mines in the Number 4 Pocahontas Seam were active during the early part of this study, and mines in the Number 6 Pocahontas Seam are of intermediate age and abandoned. The ground-water flow pattern through the multiply deep-mined area is complex. Subsidence fractures extend from the abandoned mine in the Number 3 Pocahontas Seam to the ridge top. Precipitation infiltrates through these fractures through the active mine in the Number 4 Pocahontas Seam and downward to the abandoned mine in the Number 3 Pocahontas Seam. The abandoned mine in the Number 3 Pocahontas is flooded and discharges water by gravity into Allen Creek. The flooded mine also supplies water, through pumps, for domestic use by area residents and for use in the active mine in the Number 4 Pocahontas Seam. Excess water in the active Number 4 Pocahontas Seam mine (1) drains by gravity, down-dip along the coal-mine floor to a discharge point outside the Allen Creek basin, (2) is discharged, through pumps, to Allen Creek, and (3) seeps, through fractures, down to the flooded Number 3 Pocahontas mine.

The quantity of water involved in the above cycle is small compared to the quantity encountered by the Number 4 Pocahontas Seam mine on the southeast side of Allen Creek. As is shown in figure 4.6-2, the Number 4 Pocahontas Seam mine passes beneath a tributary valley. A relatively large quantity of water was encountered by the mine in this area (probably from valley stress-relief fractures) and forced its abandonment. Presently, the Numbers 4, 3, and 6 Pocahontas Seam mines freely drain through a spoil bank into Allen Creek.

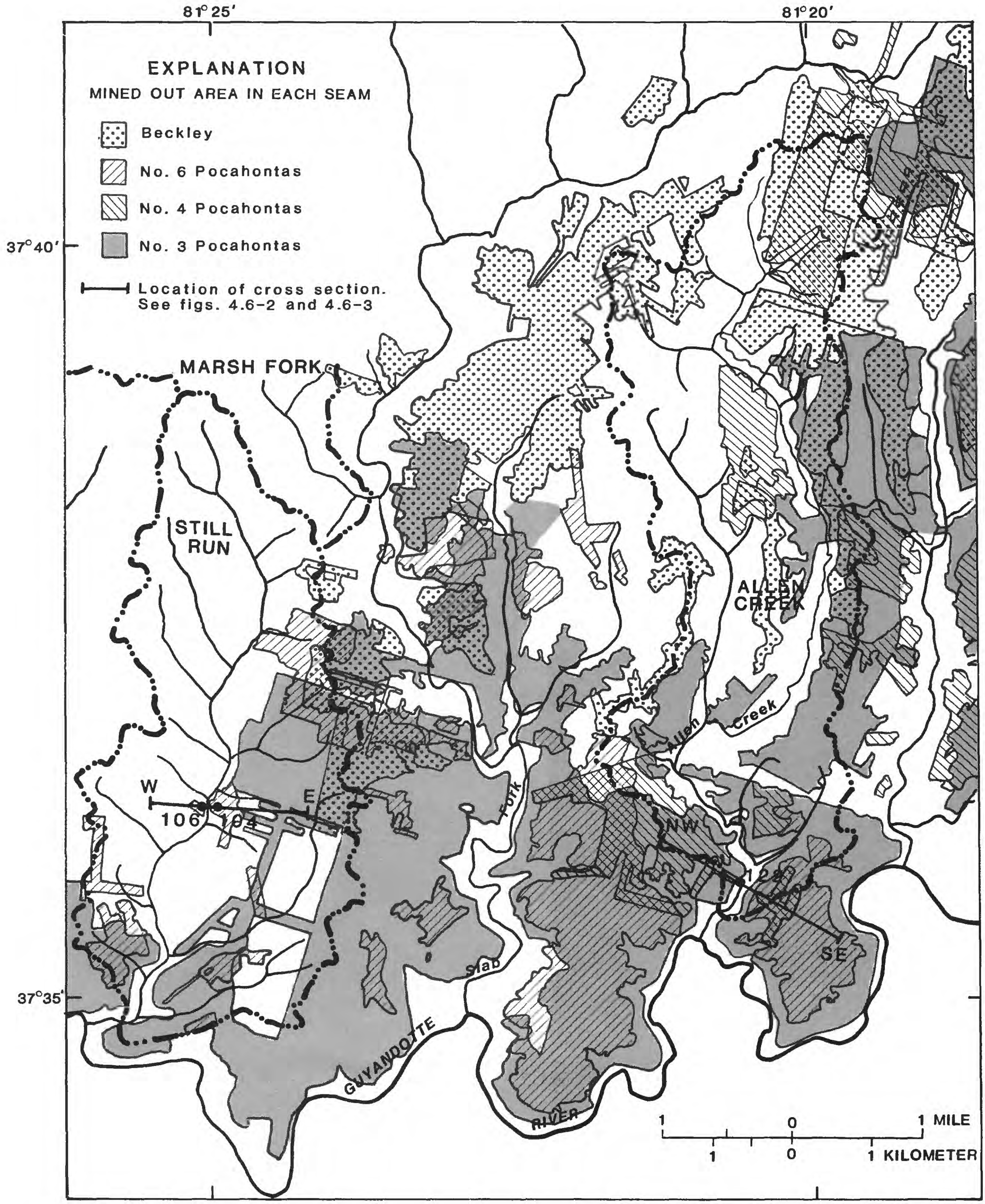


Figure 4.6-1.--Extent of deep mines in the study area.

Still Run basin is not as heavily mined as the Allen Creek basin, 31.7 percent versus 51.4 percent, and therefore the ground-water flow regime is not quite as complex.

U.S. Geological Survey personnel inspected mine interiors, measuring and sampling ground-water inflow, and found that mine interiors were surprisingly dry. Valley-wall stress-relief fractures in the unmined barrier of coal, which is left between hillside coal outcrops and mine voids within the hillside, may allow infiltrating rainfall to recharge valley-bottom aquifers. Points where ground water flows into the mines coincide with areas of fractured and unstable roof rock. These points of inflow occur at locations:

- Where mines pass beneath valleys and intersect midvalley stress-relief fractures.
- At drift mine entrances, located at hillside coal outcrops, which intersect hillside stress-relief fractures.

In general, ground-water inflow to mines beneath valleys was continuous, while inflow near mine entries occurred in direct response to precipitation.

A cross section from east to west and showing active deep mines across the Still Run basin is shown in figure 4.6-3. Mine engineers report that plans to extend the Number 3 Pocahontas Seam mine beneath Still Run were cancelled when large quantities of ground-water inflow hindered mining operations. The section of the Number 3 mine near Still Run was abandoned and is now used as a collection area for excess water. The mine is dewatered daily by a pump which removes about 1,000 gal/min for several hours a day. The well at site 106 on the east side of Still Run dried up when the mine passed beneath it, and water level and water yield declined in the well at site 104, probably as a result of ground water drained through fractures into the mine.

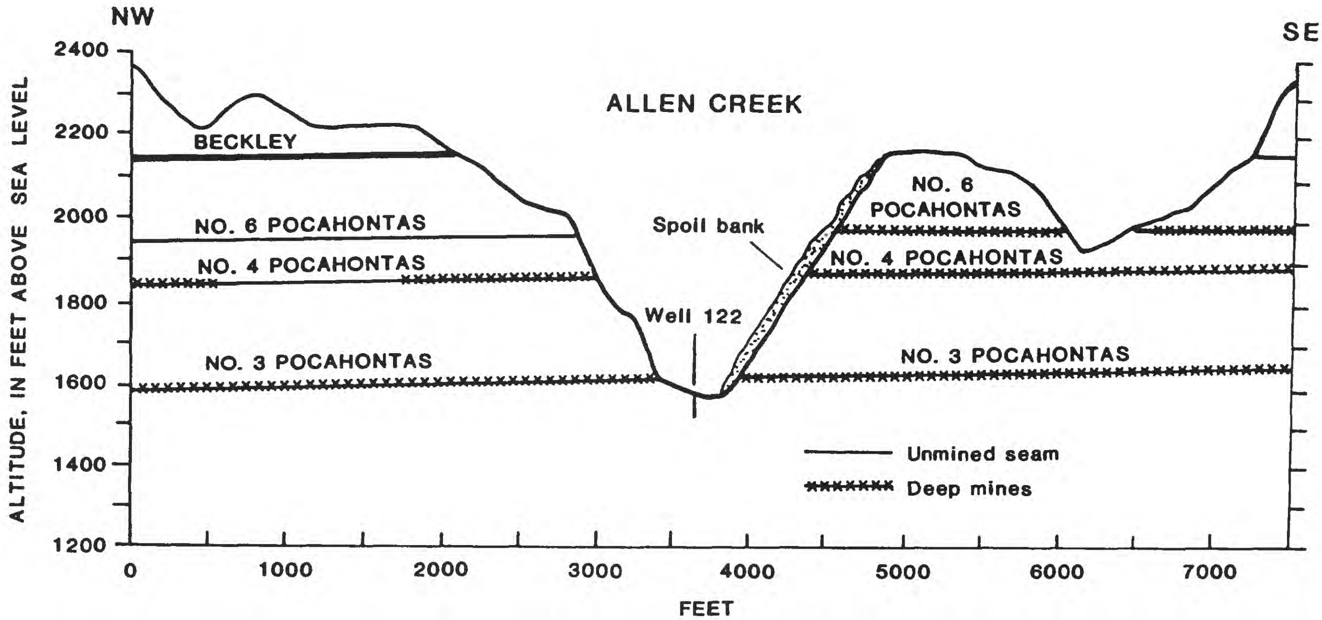


Figure 4.6-2.--Cross section on line NW-SE across Allen Creek basin.

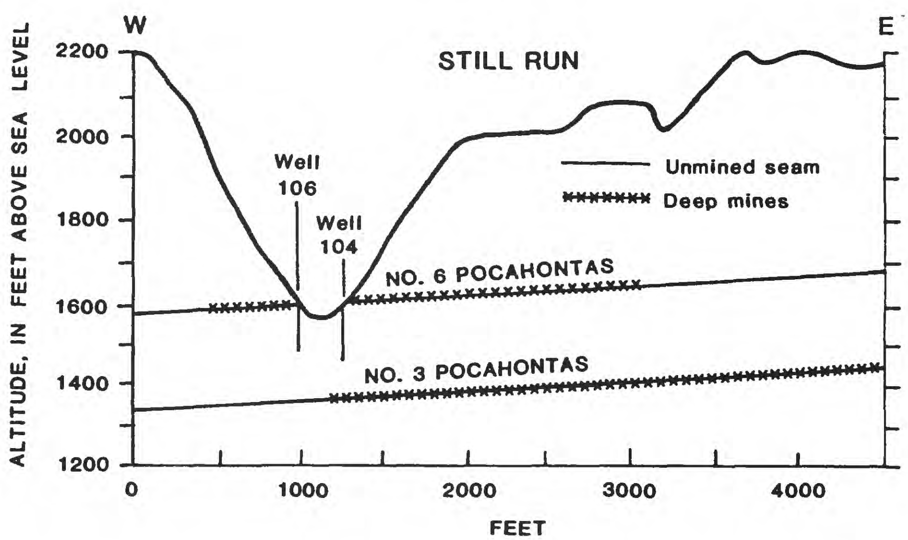


Figure 4.6-3.--Cross section on line W-E across Still Run basin.

4.7 Ground-Water Flow in Milam Fork Basin

INACTIVE DEEP MINES IN MILAM FORK BASIN MAY SIGNIFICANTLY ALTER GROUND-WATER FLOW SYSTEM

Hydrologic data collected in the Milam Fork basin indicate that inactive deep mines affect the ground-water flow system, depending upon their size and location. Inactive deep mines located entirely below drainage have very little effect on the ground-water flow system. Inactive deep mines located wholly or partially above drainage have a significant effect upon the ground-water flow regime and on well performance in this basin.

A cross section that roughly traverses from west to east across Milam Fork basin and part of the adjacent Laurel Fork basin (fig. 4.7-1) is shown in figure 4.7-2. A large part of the Milam Fork basin (31.8 percent) has been deep mined in the Beckley Seam. A much smaller part of the basin (5.4 percent) has been deep mined in the Sewell Seam. Because the Sewell Seam mine is closer to the land surface, it has a greater effect on the flow and availability of ground water in parts of the basin.

The cross section in figure 4.7-2 shows that the areally larger mine in the Beckley Seam is about 500 ft below the streams in this basin. The mine gradually filled with water after being abandoned in July 1960, but it does not discharge water into any stream. It exists as a water-filled void in saturated low permeability rock. The Beckley Seam mine void is hydraulically connected to the rock strata between the mine and land surface by an unlined, 30-ft diameter mine shaft at site 54. A daily hydrograph of the water level in the shaft at site 54 and a shallow midvalley (70-ft deep) observation well at site 50 are remarkably similar (fig. 4.7-3). Both the 600-ft deep shaft and the 70-ft deep well respond to precipitation at about the same time. Therefore, good hydraulic connection exists between the mine void in the Beckley Seam, the mine shaft, and the midvalley fractures, which are the aquifers tapped by the well at site 50. Other shallow wells drilled in the valley above this mine are excellent water-supply wells. They often have water levels at or above land surface. The ground-water conditions in this part of the Milam Fork basin are very similar to the artesian ground-water conditions existing in the unmined valley at Twin Falls State Park. (See secs. 4.2 and 4.5.)

Ground-water also seeps into the abandoned mine in the Sewell Seam. (See fig. 4.7-2.) This mine diverts ground water from Milam Fork basin and discharges it from mine openings at the outcrop of the Sewell Seam in the adjacent basin. A daily hydrograph of the water level in the mine shaft at site 36, which is open, unlined, and taps the Sewell Seam is shown in figure 4.7-3. The water level changed very little during December of 1978, a month when the regional ground-water levels in the area rose in response to large amounts of precipitation. The nearly constant water level (from 154 to 152.5 ft below land surface) indicates that water seeping into this mine is not accumulating, but drains over a small anticlinal crest in the Sewell coal seam and out the mine openings to the west. The water level in the shaft (site 36) reflects the level of ponded water in the mine void. In the valley above the mine several wells that were either dry holes or inadequate for domestic supply have been drilled. These wells tap midvalley bedding-plane separations that are being drained by the mined-out Sewell Seam.

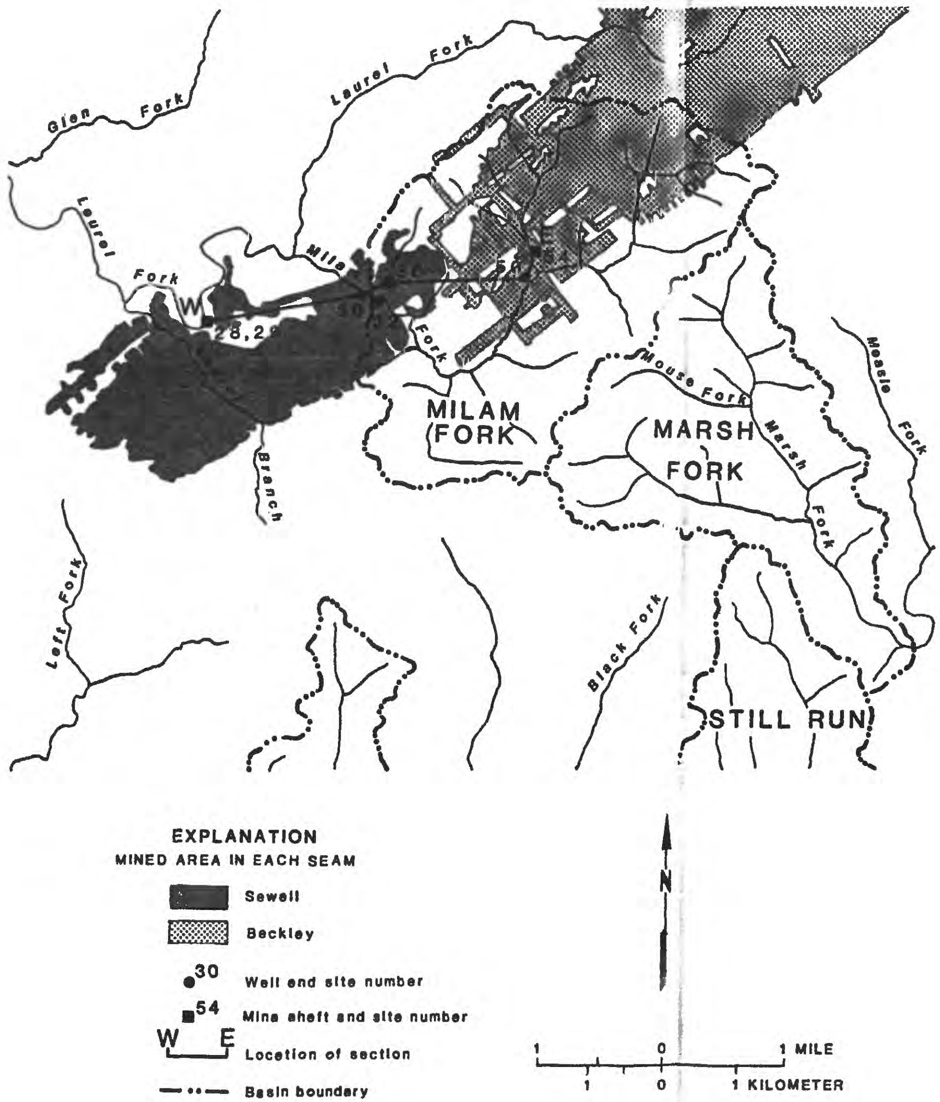


Figure 4.7-1.--Extent of deep mines in Milam Fork basin.

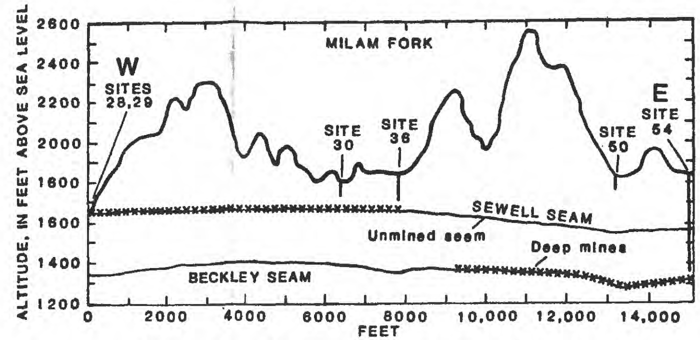


Figure 4.7- .--Cross section on line W-E in Milam Fork basin.

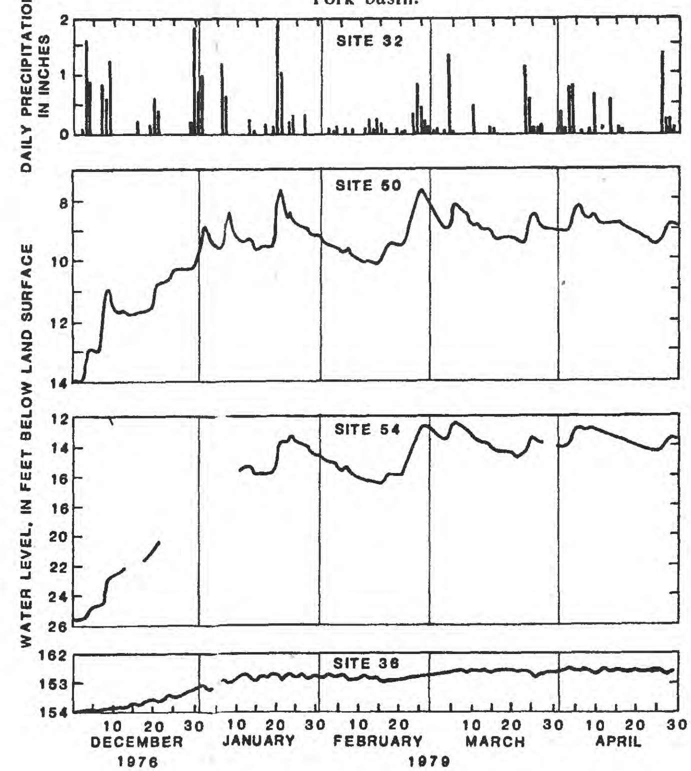


Figure 4.7-3.--Water level in well at site 50, and in mine shafts at sites 36 and 54, and the precipitation at site 32.

5.0 SURFACE WATER

5.1 Peak Discharge

MINING REDUCES UNIT PEAK DISCHARGE

Unit peak discharge was less for the mined Allen Creek and Still Run basins than for the basins with little or no mining. Data suggest that the percentage of the peak reduction is directly proportional to the amount of mining in the basin and varies inversely with the magnitude of the peak.

Streamflow data for the five basins in the study area indicate that mining possibly reduces peak discharge. Figure 5.1-1 graphically illustrates that unit peak discharge is less in Allen Creek basin, the basin with the most mining, than in the other four basins. The figure also shows that Still Run, second in amount of mining, also has reduced unit peak discharge. This suggests that the percentage of peak reduction is directly proportional to the amount of mining present in the basin. The figure also shows that the percentage of peak reduction is greater for smaller peaks and, thus, also suggests that the percentage of peak reduction varies inversely with the size of the storm peak. Further inspection of figure 5.1-1 shows that the large peaks are not significantly reduced, indicating that the reduction of peak discharge by mining may be limited during large or high-intensity rainstorms. Peak discharge data used to develop curves shown in figure 5.1-1 were selected on the basis of uniform areal coverage of storms over all the study basins and on the similarity of accumulated rainfall totals.

Table 5.1-1 shows that both mean and median peak discharge and unit peak discharge are less for Allen Creek basin than for the other four basins. Note that median peak discharge and unit peak discharge for Still Run basin are also relatively low.

Mining may reduce unit peak discharge by either retarding or diverting runoff. Surface mines may retard storm runoff by ponding water on strip benches. Ponded water has been visually observed on strip benches in Allen Creek and Still Run basins, and some miniature wetlands have developed on the strip benches that slope back into the hillside. Small drainage channels have also been observed to cut across some of the benches. During storms with greater amounts of runoff, these channels drain ponded water from the benches. Thus, peak discharges from larger storms show the least reduction due to mining.

Mine operators have constructed numerous sedimentation ponds in the basins. Most contain spillways and thus do not completely obstruct runoff. A large, partially-breached pond was observed on Right Fork of Allen Creek. Such ponds could possibly reduce peak discharge for smaller storms.

Deep mining can also reduce peak discharge by diverting potential storm runoff into underground mines through subsidence fractures. Mining engineers have reported that water infiltrates through fractures into active mines in the Allen Creek basin during rainstorms. Many active mines in Allen Creek are underlain by inactive mines which have reportedly collapsed in places, thus, causing or enlarging fractures that allow rapid infiltration of water into the mines. Hobba (1981) showed that mine collapse causes fracturing of overlying rock that increases infiltration.

Table 5.1-1.--Summary of peak discharge for 23 selected storms

Discharge characteristic	Allen Creek [a]20,51	Still Run [a]5,32	Milam Fork [a]1,37	Marsh Fork [a]0,0	Bearhole Fork [a]0,6
Mean peak discharge[b]----------	116	174	159	155	153
Median peak discharge[b]--------	47	75	92	80	80
Mean unit peak discharge[c]-----	14	24	24	32	24
Median unit peak discharge[c]---	6	10	14	16	13

[a] Mining indicators: percent surface mined, percent deep mined.
[b] In cubic feet per second.
[c] In cubic feet per second per square mile.

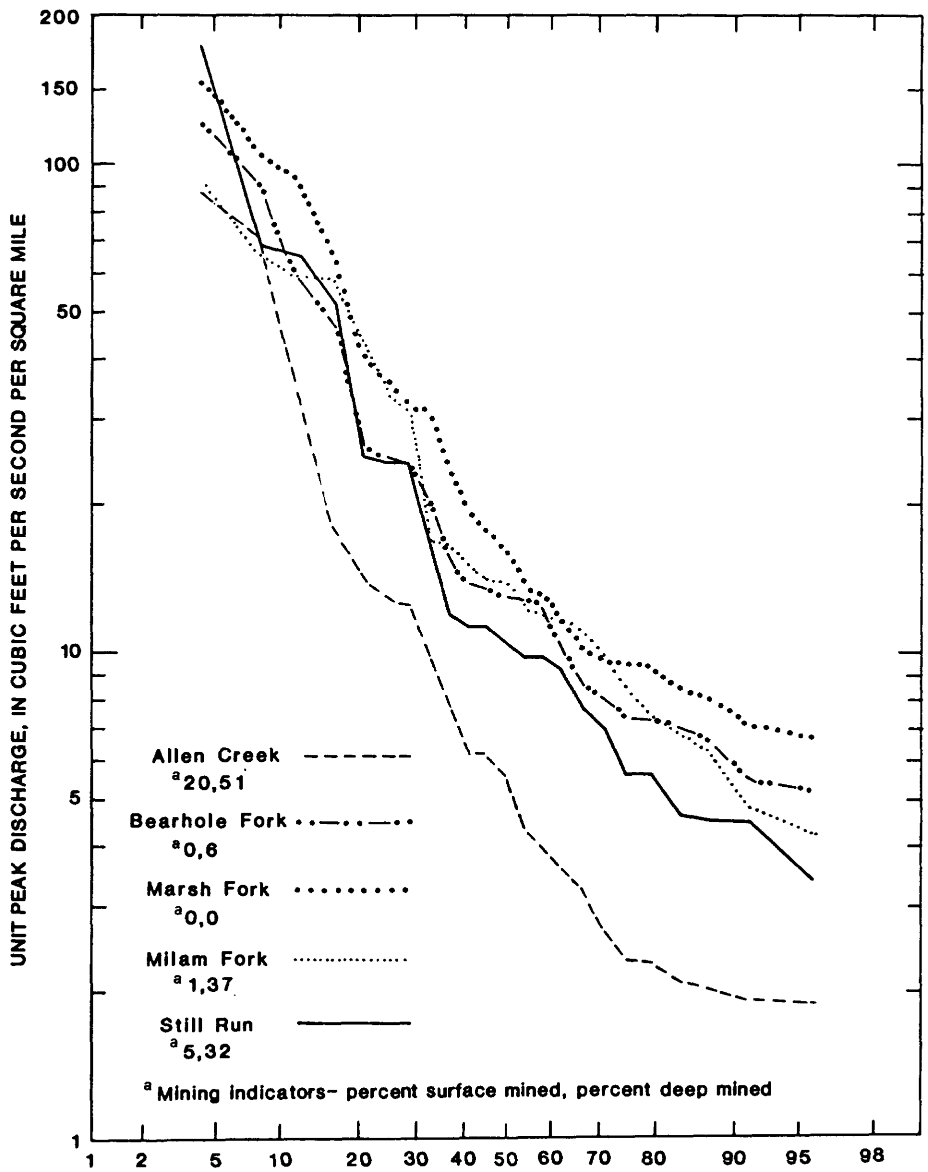


Figure 5.1-1.--Frequency of unit peak discharge for selected storms.

5.2 Storm Runoff

STORM RUNOFF LESS IN MINED BASINS THAN IN UNMINED BASINS

Runoff from selected storms was less in basins with greater amounts of mining. Allen Creek, the basin with the greatest amount of mining, had the smallest mean storm runoff (0.74 inch) of the study basins. In contrast, Marsh Fork and Bearhole Fork, basins with little or no mining, had mean storm runoffs of 1.62 and 1.36 inches, respectively.

Storm runoff for six selected storms was less in basins with greater amounts of mining as shown in table 5.2-1. Allen Creek, the basin with the greatest amount of both surface and deep mining, had the smallest mean storm runoff for the selected storms (0.74 in.) and the least runoff for five of the six selected storms. Still Run basin, which also has significant amounts of mining, had the second smallest mean storm runoff (1.05 in.). Table 5.2-2 shows the precipitation for the six storms, and table 5.2-3 shows the storm runoff as a percentage of the precipitation. Storms were selected on the basis of dry antecedent conditions and similar precipitation amounts among the five basins.

As discussed in section 5.1, surface mining can possibly reduce storm runoff by ponding water on strip benches. The pond behind a partially breached dam on the Right Fork of Allen Creek can also retard and, thus, reduce storm runoff in that basin. Similarly, underground mines can also reduce storm runoff by diverting potential runoff into underground mines through subsidence fractures.

The storm of November 2, 1979, was analyzed in greater detail (table 5.2-4 and fig. 5.2-1). This storm is ideal for comparison purposes, because precipitation totals and antecedent moisture conditions in each basin were similar. Precipitation for this storm varied from a minimum of 1.01 inches in Allen Creek to a maximum of 1.28 inches in Still Run, but runoff varied from a minimum of 0.27 inch in the mined Allen Creek basin to a maximum of 0.89 inch in the unmined Marsh Fork basin. The low storm runoff observed at Allen Creek is attributed to a combination of less precipitation, more water storage in surface mined areas, and more runoff diverted into deep mines through subsidence fractures.

The streamflow hydrographs for each of the basins during November 2-8, 1979, shown in figure 5.2-1, illustrate the drastic reduction of peak flow between mined and unmined basins in the study area. The peak discharge observed at Marsh Fork, which has a drainage area about half that of Allen Creek, was about six times greater than that observed at Allen Creek. All streamflow after November 8 was attributed to groundwater discharge. Deep-mine pumpage appears as small rises on the Still Run hydrograph during November 5-8.

Table 5.2-1.--Runoff for selected storms, in inches

Storm period	Allen Creek ^{a}20,51	Still Run ^{a}5,32	Milam Fork ^{a}1,37	Marsh Fork ^{a}0,0	Bearhole Fork ^{a}0,6
December 20-27, 1978 (two storms)-	0.46	0.66	1.33	1.18	1.07
January 20-22, 1979---------------	2.00	1.76	3.38	3.74	2.43
March 23-29, 1979-----------------	.86	1.06	1.35	1.29	1.17
June 21-23, 1979------------------	.59	1.97	2.13	2.63	2.18
July 4-7, 1979--------------------	.21	.35	.30	.28	.75
November 26-29, 1979--------------	.35	.50	.74	.60	.54
Total for above storms----------	4.47	6.30	9.23	9.72	8.14
Mean----------------------------	.75	1.05	1.54	1.62	1.36

[a] Mining indicators--percent surface mined, percent deep mined.

Table 5.2-2.--Precipitation for selected storms, in inches

Storm period	Allen Creek ^{a}20,51	Still Run ^{a}5,32	Milam Fork ^{a}1,37	Marsh Fork ^{a}0,0	Bearhole Fork ^{a}0,6
December 20-27, 1978[b] (two storms)-	1.74	1.97	-----	2.11	1.99
January 20-22, 1979---------------	2.54	2.68	3.05	3.20	2.70
March 23-29, 1979-----------------	1.66	1.83	1.99	1.89	1.84
June 21-23, 1979------------------	2.12	3.35	3.40	2.55	3.86
July 4-7, 1979--------------------	1.43	1.83	2.43	1.27	2.11
November 26-29, 1979--------------	.84	.82	.77	.85	.65
Total for above storms----------	10.33	12.48	11.64	11.87	13.15
Mean----------------------------	1.72	2.08	2.33	1.98	2.19

[a] Mining indicators: percent surface mined, percent deep mined.
[b] Includes precipitation on December 19.

Table 5.2-3.--Runoff as a percentage of precipitation for selected storms

Storm period	Allen Creek ^{a}20,51	Still Run ^{a}5,32	Milam Fork ^{a}1,37	Marsh Fork ^{a}0,0	Bearhole Fork ^{a}0,6
December 20-27, 1978 (two storms)-	26	34	----	56	54
January 20-22, 1979---------------	79	66	[b]111	[b]117	90
March 23-29, 1979-----------------	52	58	68	68	64
June 21-23, 1979------------------	28	59	63	[b]103	56
July 4-7, 1979--------------------	15	19	12	22	36
November 26-29, 1979--------------	42	61	96	71	83
Mean percentage---------------	40	50	70	73	64
Total runoff as a percentage of total precipitation for six storms----------------------	43	50	80	82	62

[a] Mining indicators: percent surface mined, percent deep mined.
[b] Values greater than 100 percent are partially attributed to snowmelt, antecedent precipitation, or precipitation not recorded by the basin rain gage.

Table 5.2-4.--Storm of November 2, 1979

Characteristics	Allen Creek ^{a}20,51	Still Run ^{a}5,32	Milam Fork ^{a}1,37	Marsh Fork ^{a}0,0	Bearhole Fork ^{a}0,6
Peak discharge (cubic feet per second)-	16	79	77	94	83
Rainfall of November 2 (inches)--------	1.01	1.28	1.16	1.25	1.14
Runoff of November 2-8 (inches)--------	.27	.55	.77	.89	.77
Runoff as a percentage of rainfall-----	27	43	66	71	68

[a] Mining indicators: percent surface mined, percent deep mined.

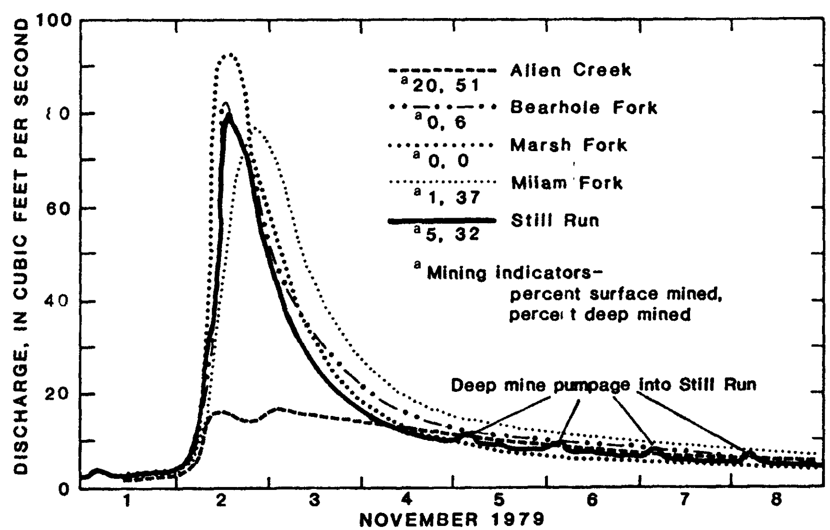


Figure 5.2-1.--Hydrographs of storm on November 2, 1979.

5.3 Flow Duration

MINING HAS A MODERATING EFFECT UPON STREAMFLOW

Basins affected by mining have fewer days of high flows and low flows than do basins that have little or no mining.

Allen Creek, the basin with the greatest amount of mining, had fewer days of high flows and low flows than basins with lesser amounts of mining or no mining. Figure 5.3-1 shows that Allen Creek had fewer days with streamflow exceeding 2 ft^3/s and fewer days with streamflow less than 0.1 ft^3/s than the remaining basins for the period January 1978 to December 1979. Figure 5.3-1 also shows that Still Run, the basin with the second greatest amount of mining, had fewer days with high flows and low flows than basins with little or no mining.

The effect of mining on high flows in the basins is similar to the effect on peaks and storm runoff. The ponding of water on strip benches can reduce high flows, and fractures associated with deep mines can divert potential runoff to underground mines and, thus, also reduce high flows.

Mining also appears to augment low flows and, thus, reduce their occurrence. Water that has infiltrated into underground mines is later pumped out of working mines, often directly into streams within the basins. Water also drains from abandoned mines into streams in the basins. During periods of relatively low flow, as much as 34 percent of the streamflow in Allen Creek has been attributed to mine drains and pumps.

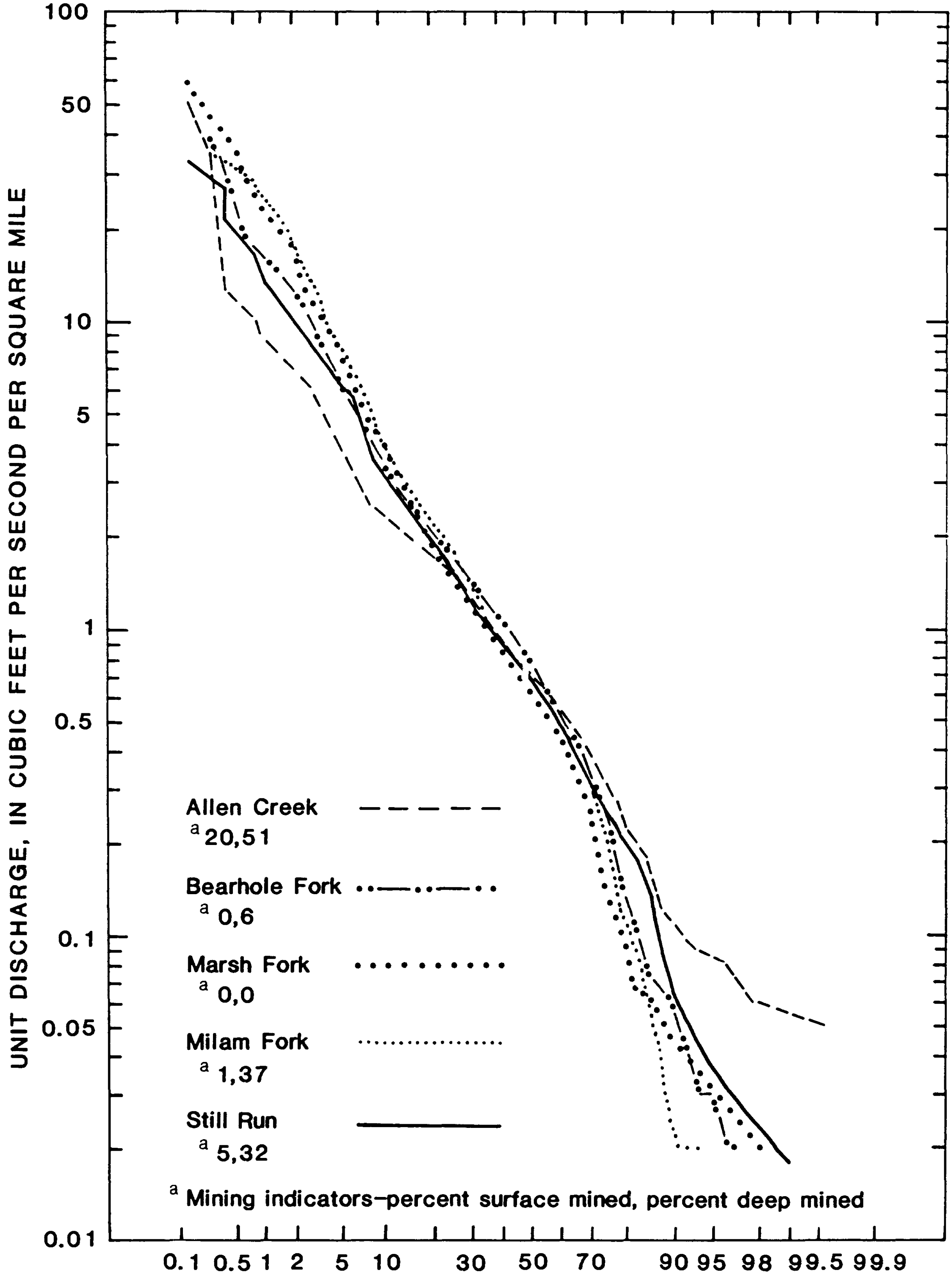


Figure 5.3-1.--Duration of daily streamflow in the study basins.

5.4 Mine Pumpage into Still Run

MINE PUMPAGE AFFECTS STILL RUN STREAMFLOW

Mine water pumped into Still Run causes daily fluctuations in streamflow and increases the total daily volume of streamflow in Still Run during dry periods of the year.

Water pumped from a coal mine in Still Run basin increased streamflow by 2.5 times the normal base flow during the period September 15-17, 1979. Streamflow increased rapidly to about 2.5 ft^3/s shortly after pumping began; when pumping stopped, streamflow slowly decreased to the normal base flow of about 1 ft^3/s (fig. 5.4-1). Pumping increased the total daily volume of streamflow by about 30 percent during this period. The daily fluctuation of streamflow can cause similar fluctuations in amounts of sediment transported by the stream and can cause changes in water quality. The fluctuations in sediment, pH, and specific conductance can, in turn, limit the members of the aquatic community in downstream reaches to species able to tolerate or adapt to daily variations in water-quality and sediment concentrations.

No rainfall occurred for several days before or during the 3-day period. All streamflow other than that contributed by the pumping can be attributed to normal ground-water discharge in the basin.

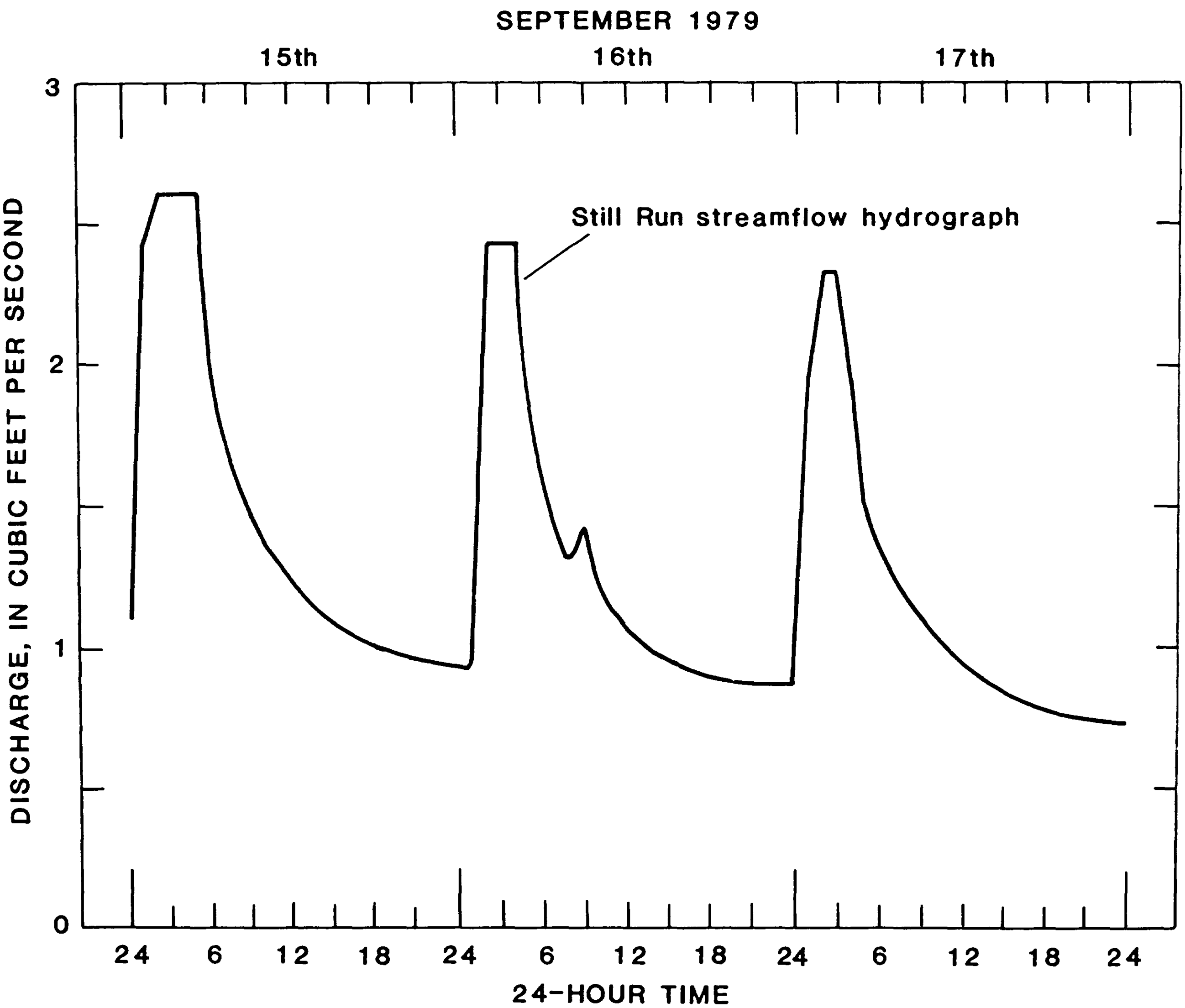


Figure 5.4-1.--Effect of mine pumping on streamflow in Still Run.

RUNOFF ACCOUNTS FOR APPROXIMATELY HALF OF THE BASINS' WATER BUDGET

Runoff comprised from 46 to 57 percent of the water leaving the five basins. Evapotranspiration, interbasin transfer of water, and underflow probably accounted for the remainder of the water.

In a simplified water budget, which assumes no change in surface- and ground-water storage, the water entering a basin equals the water leaving the basin (fig. 5.5-1). Precipitation is the major source of water that enters a basin, and evapotranspiration and runoff are the primary ways in which water leaves a basin. Evapotranspiration includes all water losses by evaporation and transpiration by plants to the atmosphere. Runoff includes all surface water that flows out of the basin by way of the main stream channel. Interbasin transfer of water and underflow are also components in the water budgets of the five study basins.

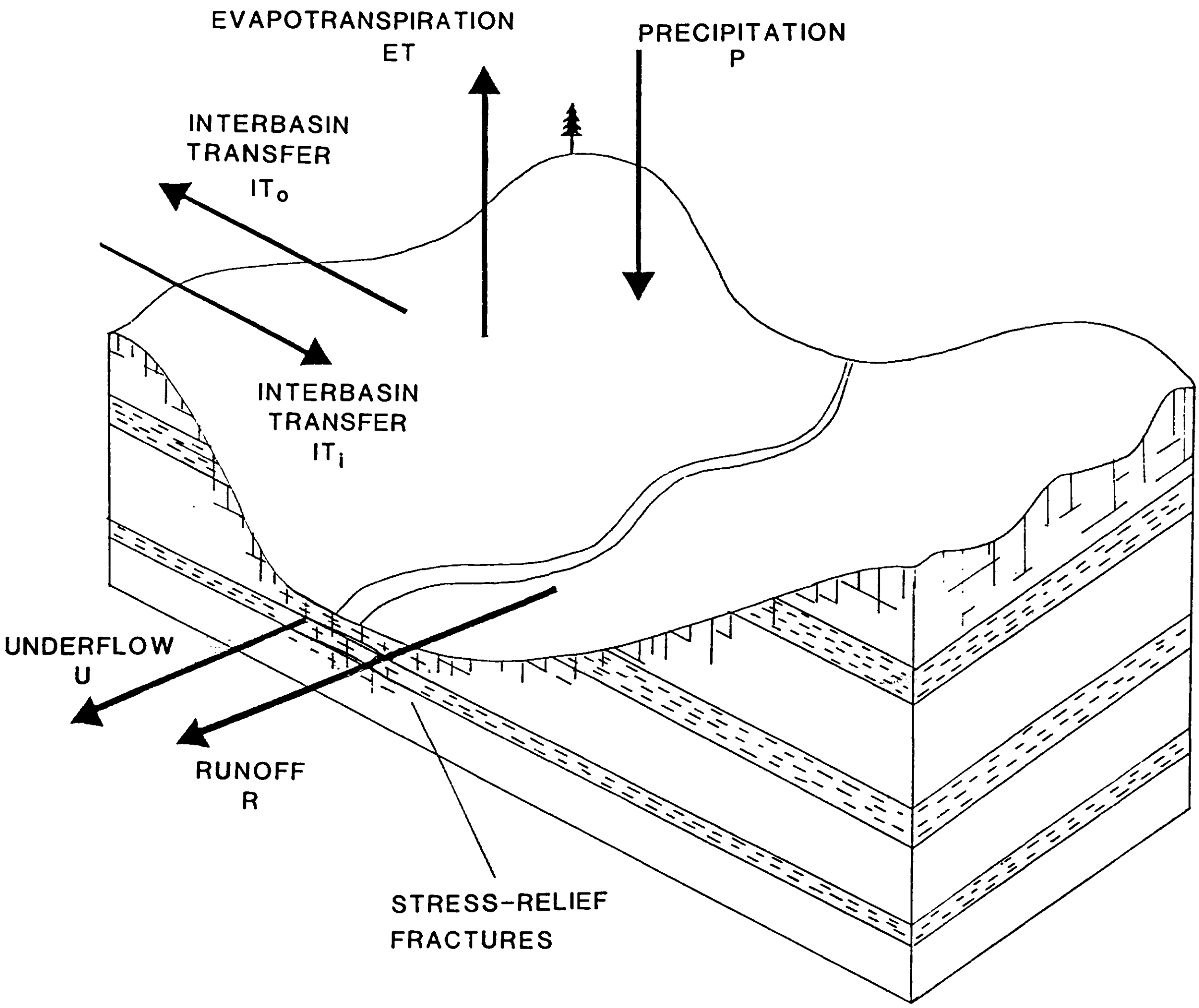
Interbasin transfer of water occurs in mined areas when water either freely drains, or is pumped, from underground mines to areas outside the basin. Thus, interbasin transfer of water can either add or remove water in a water budget. Underflow is ground water that flows through relatively shallow voids and fractures that underlie stream channels. Underflow thus removes water from a basin. Stress-relief fractures underlying Appalachian stream valleys probably enhance the underflow potential in all basins in the study area.

A summary of runoff and precipitation data measured from December 1977 to December 1979 in the five study basins is given in table 5.5-1. Runoff accounted for about 46 to 57 percent of the water leaving the basins. The remainder is attributed to evapotranspiration, interbasin transfer of water (from the basin), and underflow losses. Interbasin transfer of water out of Allen Creek probably accounts for the low amount of runoff measured in that basin.

Table 5.5-1.--Summary of runoff and precipitation in study basins, December 1977 to December 1979

Characteristics	Allen Creek [a]20,51	Still Run [a]5,32	Milam Fork [a]1,37	Marsh Fork [a]0,0	Bearhole Fork [a]0,6
Runoff (inches)-------------------------	38	48	58	55	49
Precipitation (inches)------------------	83	94	102	97	97
Runoff as a percentage of precipitation-	46	51	57	57	51

[a] Mining indicators: percent surface mined, percent deep mined.



$$P+IT_i=R+U+IT_o+ET$$

Figure 5.5-1.--Simplified water budget.

6.0 WATER QUALITY

6.1 Effects of mine discharge on streams

MINE DISCHARGE SUBSTANTIALLY AFFECTS QUANTITY AND QUALITY OF SURFACE WATER IN ALLEN CREEK AND STILL RUN BASINS

Mine discharges in Allen Creek and Still Run basins contributed about 34 and 14 percent, respectively, of the basin outflow during the period October 22-26, 1979. Mines contributed 57 and 58 percent, respectively, of the dissolved calcium load in Allen Creek and Still Run outflow during the same period.

The water which enters underground mine workings may be removed by gravity drainage, or it may be pumped out. These mine discharges significantly augment streamflow in the study basins. Discharges from 22 active mines in Allen Creek and Still Run basins were measured and sampled for major dissolved chemical constituents during the period October 22-26, 1979. Streamflow at the basin outlets of Allen Creek and Still Run during this period correspond to streamflow that can be expected to be equaled or exceeded about 70 percent of the time at the respective sites.

Mine discharge in Allen Creek basin during the period October 22-26, 1979, contributed 1.19 ft^3/s to the basin outflow, or 34 percent of the total outflow. Mine discharge in Still Run basin contributed 0.33 ft^3/s, or 14 percent of the total basin outflow during the same period. A number of mine-discharge pumps in both Allen Creek and Still Run basins were not operating during the period, but were measured on other occasions. The estimated potential discharge from all mine sources during this period (if measured concurrently) can be expected to be about 4.1 and 2.8 ft^3/s in Still Run and Allen Creek basins, respectively. Hypothetically, at median streamflow conditions, or at that flow which is equaled or exceeded 50 percent of the time, the potential mine discharge in Still Run basin during October 22-26 would comprise about 80 percent of the basin outflow. Under the same conditions, mines in Allen Creek basin would contribute nearly half (46 percent) of the basin outflow. The proportion of basin outflow that is contributed by mine discharge, at least potentially, is substantial. Some of this mine discharge would have reached the streams as naturally discharging ground water even if there were no mines in the study area.

Mine discharges contributed a considerable quantity of chemical constituents to the total basin outflow during the period October 22-26, 1979 (table 6.1-1). For example, mines in Still Run contributed 58 percent of the load of calcium (about 0.043 ton/d) to the total basin outflow and about 30 percent of the load of sulfate (about 0.258 ton/d). Mines in both Allen Creek and Still Run basins also contributed about 40 percent of the magnesium load in the basin outflow. The quantity of chemical constituents contributed by mines in Allen Creek and Still Run basins to total basin outflow probably is highly variable, but substantial.

Table 6.1-1.--Solute-load contribution from mine discharges to total solute load at basin outlet of Allen Creek and Still Run basins, October 22-26, 1979

Constituent	Percent of total solute load contributed by mine drains	
	Still Run	Allen Creek
Sodium--------------------	16	26
Calcium-------------------	58	57
Magnesium-----------------	40	41
Potassium-----------------	24	39
Sulfate-------------------	30	41
Bicarbonate---------------	16	44
Chloride------------------	15	39

6.2 Major Inorganic Constituents

CONCENTRATIONS OF MOST MAJOR CONSTITUENTS WERE HIGHER IN MINED BASINS

Allen Creek and Still Run basins, which were heavily mined, contained significantly higher mean concentrations of calcium, magnesium, potassium, and sulfate at the basin outlets than did Marsh Fork and Bearhole Fork basins, which were predominantly unmined. Mine discharges in Allen Creek and Still Run basins contained greater mean concentrations of bicarbonate, sulfate, sodium, potassium, calcium, and magnesium than did wells in the respective basins.

The major inorganic constituents in water include sodium, calcium, magnesium, potassium, chloride, bicarbonate, sulfate, and fluoride. These constituents influence the ionic balance, pH, hardness, and dissolved solids content of water and affect the suitability of water for different purposes. The concentrations of the major constituents are influenced by geology, land use (particularly mining), wastewater discharge, and streamflow characteristics.

The concentration of major inorganic elements in surface water at the basin outlets were evaluated statistically using the analysis of variance test (ANOVA) to determine what water-quality relationships, if any, might exist between basins. A significance level of 0.05 was used in this test. Where the ANOVA test indicated that significant differences existed, Duncan's Multiple-Range Test was used to show which basins contained similar constituent concentrations. The results are shown in table 6.2-1.

The mean concentrations of calcium, magnesium, potassium, sulfate, and chloride in streams differed significantly between heavily-mined basins (Allen Creek and Still Run) and predominantly unmined basins (Marsh Fork and Bearhole Fork). Milam Fork, which was partially mined by underground and surface methods, had no mine discharges or refuse piles within the basin before 1979, and in many respects had similar surface-water chemical characteristics found in predominantly unmined basins. Surface water at the basin outlets of heavily-mined basins (Allen Creek and Still Run) contained two to four times the mean concentration of calcium, magnesium, potassium, and sulfate found at outlets of predominantly unmined basins (Marsh Fork and Bearhole Fork). Streams in Allen Creek and Still Run basins, however, contained lower mean chloride concentrations than streams in unmined basins. The mean concentrations of sodium in Allen Creek, Still Run, and Milam Fork basins, were not significantly different, but were about four times higher than in Marsh Fork and Bearhole Fork basins. Mean bicarbonate concentration was lowest in predominantly unmined basins.

The anomalously high concentrations of sodium and bicarbonate in Milam Fork basin may reflect lithologic differences between rocks in Milam Fork and the other basins, and (or) ion-exchange processes. (See sec. 6.12.)

Table 6.2-1.--Mean chemical concentrations at the basin outlets of Allen Creek, Still Run, Milam Fork, Marsh Fork, and Bearhole Fork basins, October 1, 1977 to December 31, 1979

[Mean concentrations of constituent[a], in milligrams per liter]

Basin	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride
Allen Creek [b](20,51)-	27.2	12.3	43.6	2.9	117	110	1.6
Still Run [b](5,32)----	15.5	6.2	36.3	1.9	62	89	1.8
Milam Fork [b](1,37)---	7.0	2.9	40.6	1.5	111	9.5	10.9
Marsh Fork [b](0,0)----	6.9	2.5	9.2	1.5	32	8.5	10.4
Bearhole Fork [b](0,6)-	5.4	2.0	9.3	1.5	29	8.1	6.2

[a] Mean constituent concentrations connected by open bracket lines were not significantly different at the 0.05 level of significance.

[b] Mining indicator (percent surface mined, percent deep mined).

Table 6.2-2.--Concentration of major constituents in mine discharges and water in wells in the study basins, October 1, 1977 to December 31, 1979

[Mean concentration of constituent, in milligrams per liter]

Basin	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride
Allen Creek [a](20,51) (wells)--	27	10.4	21	2.5	39	129	7.5
(mines)--	69	24	36	3.6	137	235	1.4
Still Run [a](5,32) (wells)-----	12.4	3.5	4.0	1.1	40	10	3.1
(mines)-----	59	21	192	4.3	247	43.8	3.4
Milam Fork [a](1,37) (wells)----	14	5.1	49	1.5	145	17	17
Marsh Fork [a](0,0) (wells)-----	16	6	35	1.5	60	5.4	68
Bearhole Fork [a](0,6) (wells)--	14	3.3	17	1.1	82	8.5	5.9

[a] Mining indicator (percent surface mined, percent deep mined).

Major constituent concentrations in water from wells and mine drains in the study basin are shown in table 6.2-2 and are depicted by Stiff diagrams in figure 6.2-1. Mine discharges contained greater concentrations of bicarbonate, sulfate, sodium, potassium, calcium and magnesium than water in wells in the same basin. The mean chloride concentration was not greatly different between water in wells and mine discharges in Still Run basin. As shown by the Stiff diagrams (fig. 6.2-1), the wells and mines in Allen Creek basin produced largely calcium-sulfate type water. Wells in Still Run basin produced calcium-bicarbonate water, while mine discharges produced primarily sodium sulfate type water. Wells in Milam Fork, Marsh Fork, and Bearhole Fork basins produced sodium chloride or sodium bicarbonate type water. Because mine discharges contribute a large portion of the total surface-water flow in Allen Creek and Still Run basins (34 and 14 percent, respectively, under low streamflow conditions), mines substantially affect the concentration of major chemical constituents in Allen Creek and Still Run.

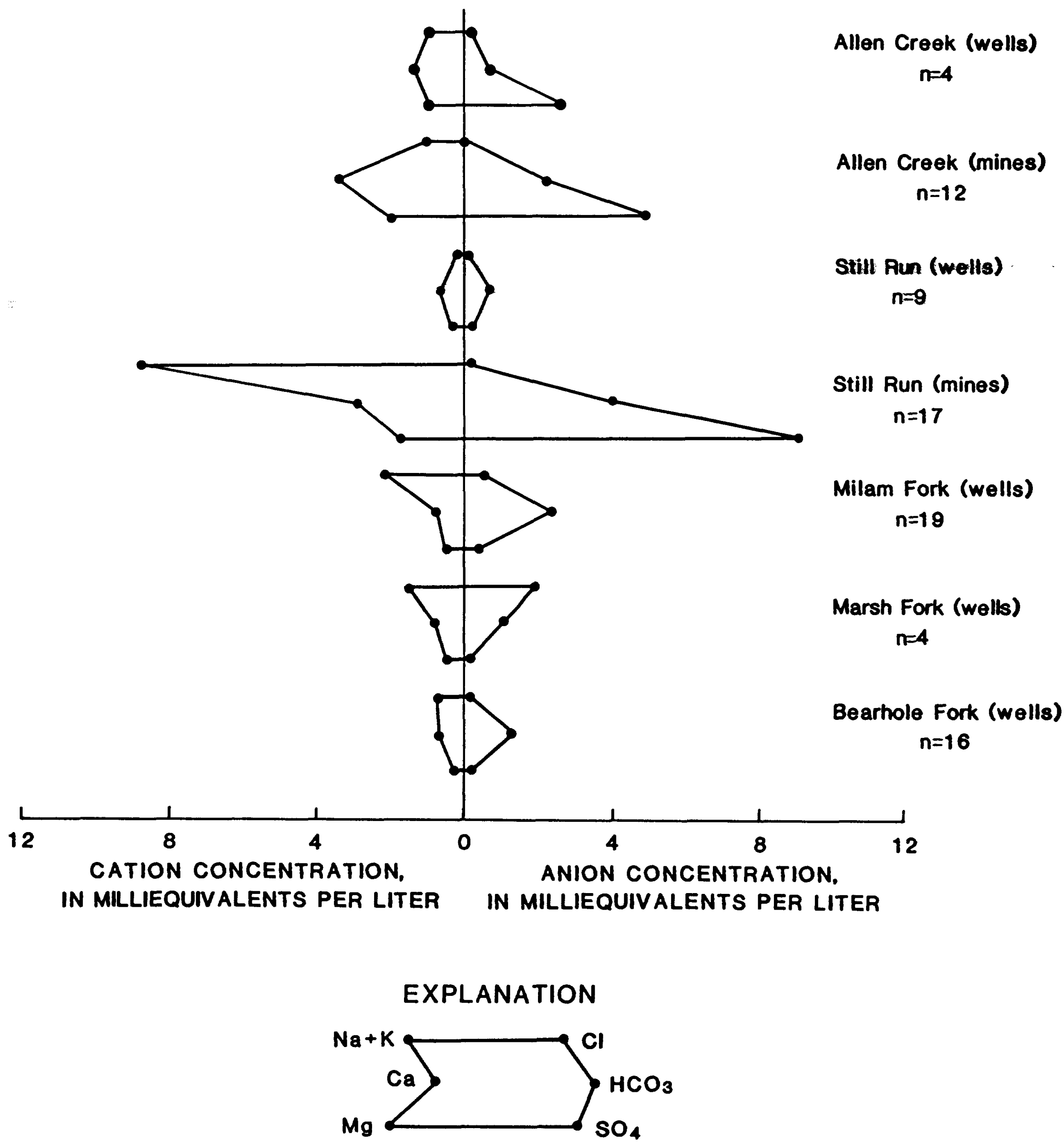


Figure 6.2-1.--Mean-ion concentrations in mine and well water, in study basins, October 1, 1977 to December 31, 1979.

6.3 Specific Conductance

SPECIFIC CONDUCTANCE OF SURFACE WATER WAS SIGNIFICANTLY HIGHER IN MINED BASINS THAN IN UNMINED BASINS

Specific conductance of surface water was significantly higher at the outlets of Allen Creek and Still Run basins, which were intensely mined, than in Marsh Fork and Bearhole Fork basins, which were essentially unmined. Specific conductance correlated strongly with concentrations of calcium, magnesium, sodium, alkalinity, dissolved solids, and hardness, but poorly with chloride, sulfate, and instantaneous streamflow.

Specific conductance is a general indicator of the quantity of ionized minerals in solution and has long been used as a general indicator of water-quality conditions. The specific conductance of rainfall is typically less than 20 µmho/cm, reflecting the low concentration of dissolved minerals and gases. Streams in the study area had conductivity values ranging from 32 to 830 µmho/cm, which was within the range of values reported by Chisholm (Bader and others, 1977) for streams throughout the Guyandotte River basin. Ground water in the study area generally had a higher specific conductance, ranging from 50 to more than 1,000 µmho/cm, reflecting greater mineral content than that found in streams.

Water-quality parameters, including specific conductance, were analyzed statistically to examine what water-quality differences might exist between basins. Where ANOVA tests indicated that water-quality differences between basins existed (at a significance level of 0.05), Duncan's Multiple-Range Test was used to show which basins contained similar constituent values (table 6.3-1).

Allen Creek basin had the highest mean specific conductance in surface water, 410 µmho/cm. Still Run, Milam Fork, Marsh Fork, and Bearhole Fork basins had lower mean specific conductance: 260, 133, 109, and 87 µmho/cm, respectively. The mean specific conductance of surface water in the most intensely mined basins, Allen Creek and Still Run, differed significantly from the predominantly unmined basins, Marsh Fork and Bearhole Fork, and from Milam Fork basin, which contained abandoned underground mines. Although Milam Fork basin was mined prior to 1960 and in 1979, no mine discharges or refuse piles are located in the basin. In many respects Milam Fork had similar water quality to the unmined basins. For example, the mean specific conductances of surface water at the outlets of Milam Fork and Marsh Fork basins (133 and 109 µmho/cm, respectively) were not significantly different at the 95 percent confidence level.

Wells in the study area tap either the Pocahontas or New River Formation of the Pottsville Group. Domestic wells had a mean specific conductance of 380 µmho/cm, which was greater than the mean specific conductance of most streams in the study area. This is within the range of ground-water specific conductance (minimum 45 µmho/cm, mean 269 µmho/cm, maximum 930 µmho/cm) reported by Bader (1983)

Table 6.3-1.--Mean specific conductance in surface water at basin outlets, October 1, 1977 to December 31, 1979

Basin	Number of data observations	Mean specific conductance[1] (micromhos per centimeter)
Allen Creek [2](20,51)--	47	410]
Still Run [2](5,32)-----	55	260]
Milam Fork [2](1,37)----	121	133]
Marsh Fork [2](0,0)-----	66	109]]
Bearhole Fork [2](0,6)--	53	87]

[1] Means connected by open-bracket lines are not significantly different at the 0.05 level of significance.
[2] Mining indicator (percent surface mined, percent deep mined).

Table 6.3-2.--Correlation between specific conductance and selected variables

Variable	Correlation coefficient (r) with specific conductance[1]
Calcium, dissolved (mg/L)-----------------	0.9499
Magnesium, dissolved (mg/L)---------------	.9265
Sodium, dissolved (mg/L)------------------	.9230
Alkalinity, total (mg/L)------------------	.9033
Sulfate, dissolved (mg/L)-----------------	.6574
Chloride, dissolved (mg/L)----------------	-.0903
Dissolved solids, residue at 180°C (mg/L)-	.9860
Hardness, total as $CaCO_3$ (mg/L)-----------	.9551
Instantaneous streamflow (ft^3/s)----------	-.6333

[1] Data at basin outlet were used to compute correlation coefficient (r).

for wells unaffected by mining or saltwater in the Guyandotte River basin. Mine discharges in Allen Creek and Still Run basins were more highly mineralized than domestic wells in the same basins (fig. 6.2-1) and had a much higher specific conductance (mean 735 µmho/cm).

Specific conductance strongly correlates with the concentrations of water-quality constituents such as calcium, magnesium, sodium, alkalinity, dissolved solids, and hardness (table 6.3-2). A strong correlation does not necessarily infer a cause-and-effect relationship, but indicates that related variables increase or decrease at similar rates. Chloride, sulfate, and instantaneous streamflow had a poorer correlation with specific conductance than did water-quality properties such as dissolved solids and hardness, possibly because of the effects of oil and gas drilling, intermittent mine discharges, and road deicing.

The specific conductance of surface water was highly variable within each basin. Specific conductance measurements at synoptic sites are shown in figure 6.3-1. The highest specific conductance values were generally observed at the basin outlets and in tributaries downstream from areas of mining.

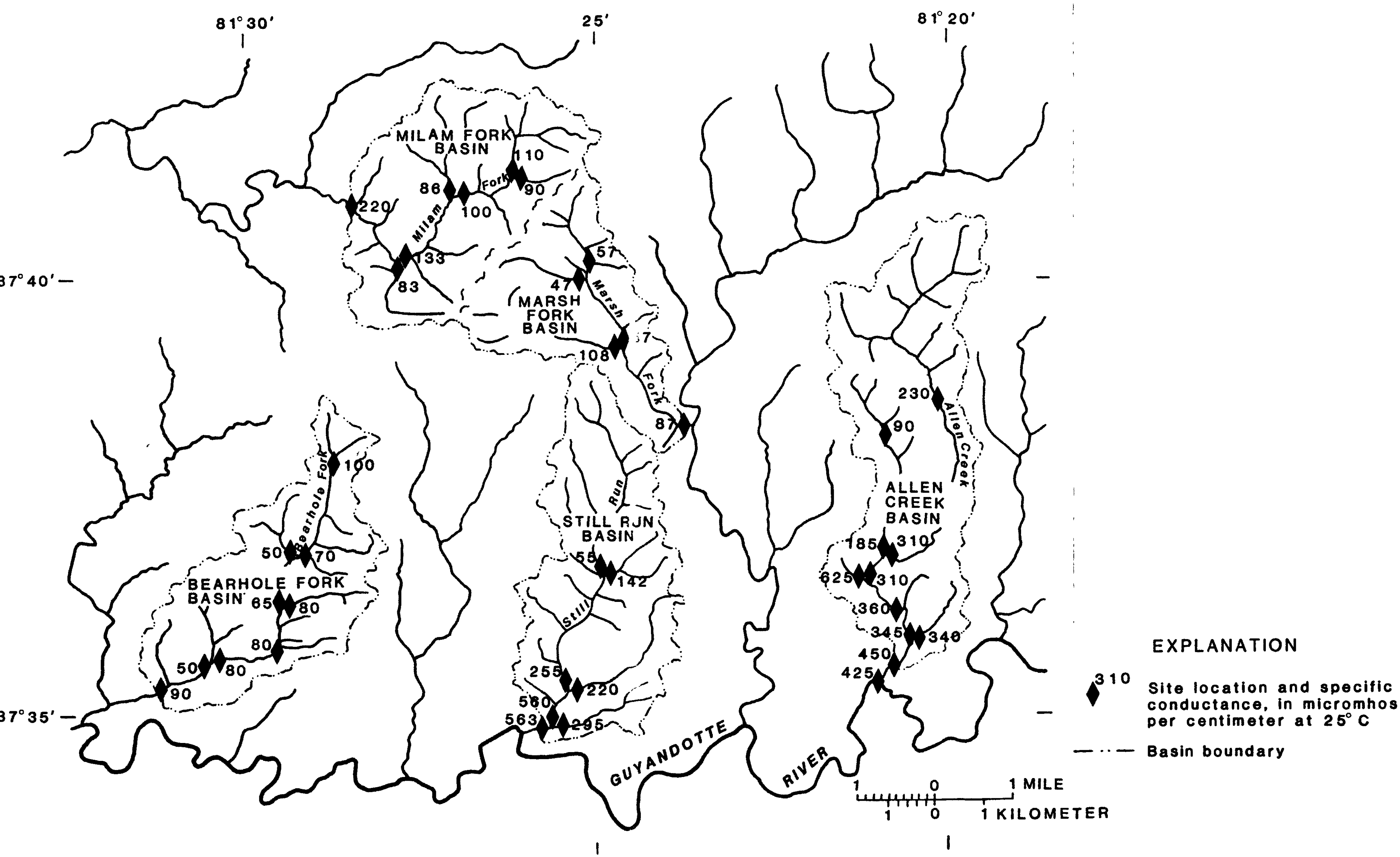


Figure 6.3-1.--Specific conductance at synoptic surface-water sampling sites, October 22-26, 1979.

DISSOLVED SOLIDS GREATEST IN INTENSELY-MINED BASINS

Dissolved solids concentration in surface water differed significantly between the predominantly unmined and mined basins, and among the mined basins. Allen Creek basin, which was heavily mined, had the greatest mean dissolved solids concentration (268 milligrams per liter), and solute yield (158 tons per square mile per year). Bearhole Fork basin, which was predominantly unmined, had the lowest mean dissolved solids concentration (54 milligrams per liter) and solute yield (22 tons per square mile per year).

Dissolved solids concentrations at the five basin outlets were analyzed using statistical methods to determine if significant differences existed between basins. Where the ANOVA test indicated that differences between basins existed at the 0.05 significance level, Duncan's Multiple-Range Test was performed to show which basins contained similar dissolved solids concentrations (table 6.4-1). The results shown in table 6.4-1 indicate that significant differences in mean dissolved solids concentrations exist between mined and predominantly unmined basins, and between individual mined basins.

The mean dissolved solids concentrations in predominantly unmined basins (Bearhole Fork and Marsh Fork) were not significantly different at a significance level of 0.05. Bearhole Fork and Marsh Fork had the lowest mean concentrations, 54 and 63 mg/L, respectively. Mean dissolved solids concentrations in the mined basins ranged from 136 (Milam Fork) to 268 mg/L (Allen Creek). The basin with the greatest amount of surface and underground mining (Allen Creek) had the greatest mean dissolved solids concentration, 268 mg/L. Milam Fork contains abandoned underground mining, which occurred prior to 1960. However, no mine discharges or refuse piles were located in Milam Fork basin before 1979, which in many respects has surface-water chemical characteristics similar to that in the unmined basins.

The yield of dissolved solids was also greater in mined basins. Allen Creek had the greatest yield, 158 tons/mi^2/yr as shown in figure 6.4-1. Bearhole Fork and Marsh Fork basins had the lowest dissolved solids solute yield, 22 and 37 tons/mi^2/yr, respectively. The yield at Allen Creek was similar to that reported for the Guyandotte River basin above Baileysville (160 tons/mi^2/yr), an area with numerous active surface and deep mines and abandoned deep mines (Bader and others, 1980, p. 84).

Dissolved solids concentration is affected by variations in streamflow. High dissolved solids concentrations occur at low flow, and low dissolved solids concentrations occur at high flow. A strong inverse relation between streamflow and dissolved solids concentration exists in the study area [coefficient of determination (r^2) greater than 0.80]. Using equations developed by regression analysis and the appropriate streamflow duration curve, the concentration of dissolved solids at different flows can be estimated (table 6.4-2). At low flow dissolved solids concentration of surface water draining

Table 6.4-1.--Mean dissolved solids concentration in surface water at basin outlets, October 1, 1977 to December 31, 1979

Basin	Number of data observations	Mean dissolved solids concentration,[1] in milligrams per liter
Allen Creek [2](20,51)--	21	268]
Still Run [2](5,32)-----	21	186]
Milam Fork [2](1,37)----	20	136]
Marsh Fork [2](0,0)-----	23	63]
Bearhole Fork [2](0,6)--	21	54]

[1] Means connected by open-bracket lines are not significantly different at the 0.05 level of significance.
[2] Mining indicator (percent surface mined, percent deep mined).

Table 6.4-2.--Dissolved solids duration, October 1, 1977 to December 31, 1979

Basin	Percent of time dissolved solids concentration value was equaled or exceeded, in milligrams per liter								
	99	95	90	75	50	25	10	5	1
Allen Creek [a](20,51)--	126	153	176	200	245	300	400	440	500
Still Run [a](5,32)-----	30	45	58	82	123	195	370	520	680
Milam Fork [a](1,37)----	26	35	47	66	94	147	320	380	[b]ND
Marsh Fork [a](0,0)-----	24	31	36	45	54	76	100	111	[b]ND
Bearhole Fork [a](0,6)--	19	24.5	28	34	44	74	84	103	[b]ND

[a] Mining indicator (percent surface mined, percent deep mined).
[b] ND, not determined.

Allen Creek and Still Run basins can be expected to approach or exceed 500 mg/L, the maximum recommended concentration in drinking water (U.S. Environmental Protection Agency, 1979). At median flow (50 percent duration), the estimated dissolved solids concentration ranged from 44 to 245 mg/L and was greatest in mined basins (table 6.4-2).

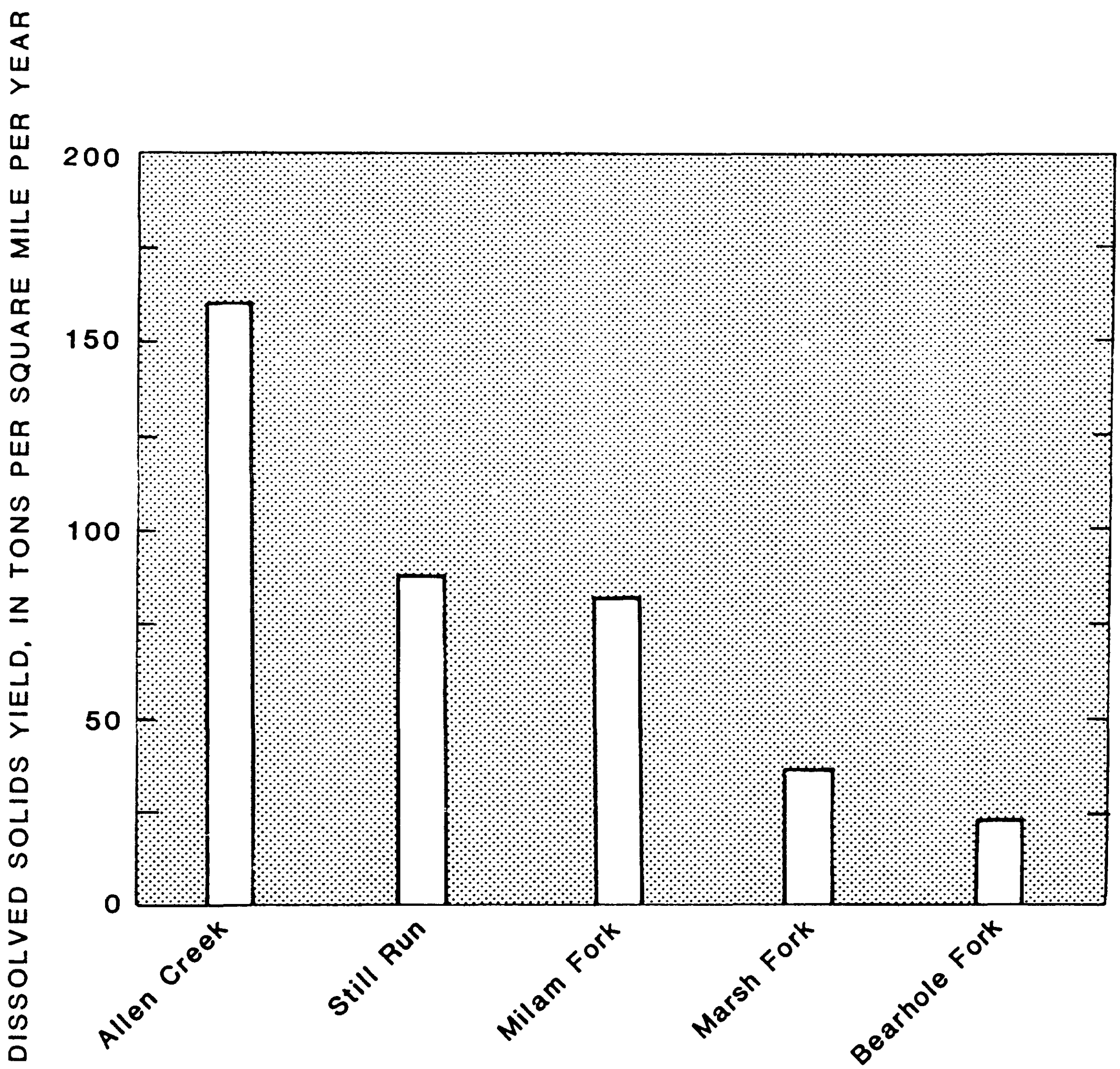


Figure 6.4-1.--Dissolved-solids yield at basin outlets, October 1, 1977 to December 31, 1979.

6.5 pH

THE pH OF SURFACE WATER WAS HIGHEST IN INTENSELY-MINED BASINS

The median pH of surface water was highest in Allen Creek, Milam Fork, and Still Run basins, which were intensely mined. Marsh Fork and Bearhole Fork basins, which were predominantly unmined, generally had lower median pH values.

Most surface water in the Guyandotte River basin has a pH that ranges from 5.7 to 8.9 (Ehlke and others, 1981). The pH of water is affected by the solution of minerals and gases. Precipitation usually is acidic because of the solution of atmospheric CO_2 and emissions from the combustion of fossil fuels, principally SO_2 and oxides of nitrogen. The dissolution of carbonate minerals such as $CaCO_3$ (limestone) in the rock of the basins raises the pH in surface and ground water to alkaline levels (pH > 7.0).

The pH of surface water in the study area was analyzed by statistical methods to determine what water-quality relations might exist between basins (table 6.5-1). Surface water in Allen Creek basin was the most alkaline with a median pH of 7.6. Still Run, Milam Fork, Marsh Fork, and Bearhole Fork basins had lower median pH values, 7.4, 7.4, 7.3, and 6.9, respectively. Using the Kruskal-Wallis test (a nonparametric statistical test), the pH values in Allen Creek, Still Run, Milam Fork, Marsh Fork, and Bearhole Fork basins were shown to differ at the 95 percent confidence level. Basins having the greatest amount of underground mining (Allen Creek, Milam Fork, and Still Run) had the highest median pH. Predominantly unmined basins (Marsh Fork and Bearhole Fork) had the lowest median pH.

The pH of surface water varied widely within basins (fig. 6.5-1). Allen Creek and Still Run basins, which were heavily mined, had higher pH values near the basin outlets than in the headwaters, while the other basins were more variable (fig. 6.5-2). In general, the pH of ground water unaffected by mining was less variable and more acidic than the pH of surface water. The narrow range of pH in ground water probably reflects similar lithology. All wells in the study basins tap the Pocahontas or New River Formations of the Pottsville Group. The pH of mine discharges in Still Run and Allen Creek basins were highly variable, ranging from 3.0 to 8.0. The median pH of 22 active mines was 7.0, or about 0.5 pH unit higher than the median pH of ground water in Allen Creek and Still Run basins.

Present mine safety regulations require the coating of interior mine surfaces with powdered limestone ($CaCO_3$) to reduce the potential for coal dust explosions. (See sec. 6.6.) The solution and hydrolysis of the limestone causes the water to become alkaline as follows:

$$CaCO_3 + H_2O \rightleftharpoons Ca^{+2} + HCO_3^- + OH^-$$

and

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

The same reaction occurs wherever carbonate-containing rock in the

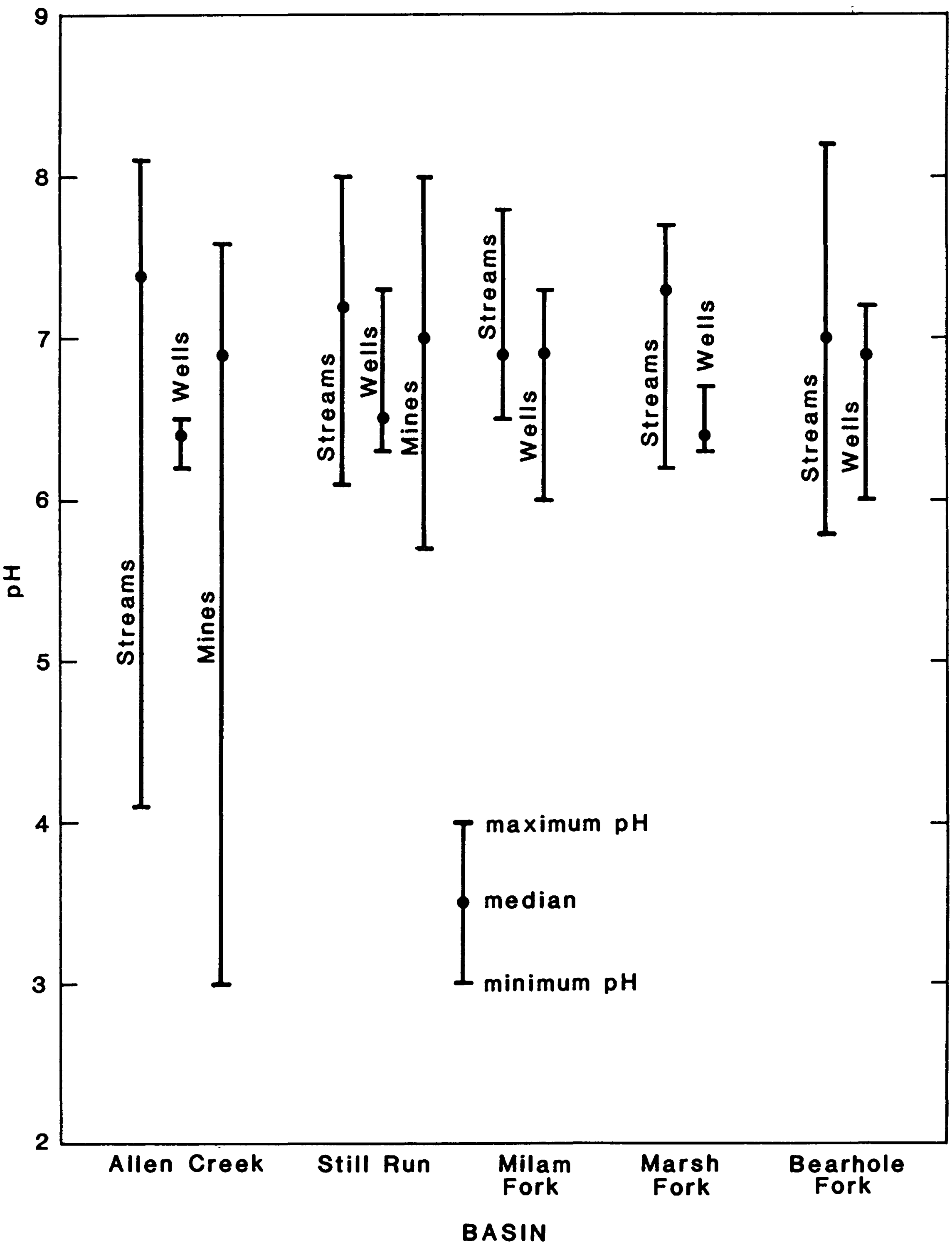


Figure 6.5-1.--Range and median of pH in streams, wells, and mine discharges in study basins, October 1, 1977 to December 31, 1979.

basin may be found. For this reason, the pH of mine discharge tends to be higher than the pH of most ground water in the study area. Because of the quantity of mine discharge contributed to streamflow in Allen Creek and Still Run basins, underground mining may increase the pH of surface water.

Table 6.5-1.--Median pH of surface water at basin outlets, October 1, 1977 to December 31, 1979

Basin	Median pH	Basin	Median pH
Allen Creek [a](20,51)---	7.6	Milam Fork [a](1,37)------	7.4
Still Run [a](5,32)------	7.4	Bearhole Fork [a](0,6)----	6.9
Marsh Fork [a](0,0)------	7.3		

[a] Mining indicator (percent surface mined, percent deep mined).

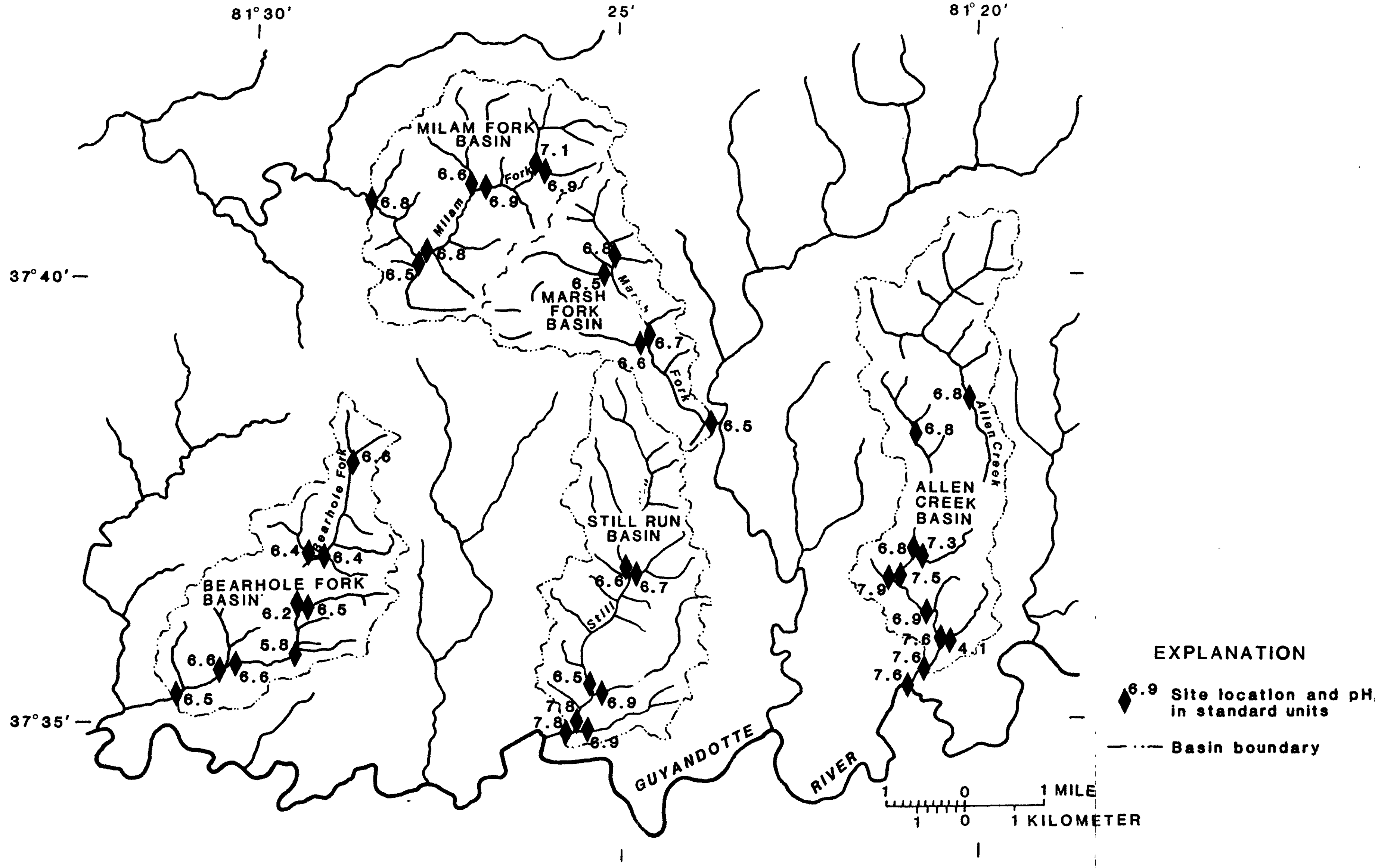


Figure 6.5-2.--The pH at synoptic surface-water sampling sites, October 22-26, 1979.

6.6 Limestone Dust in Mines

LIMESTONE DUST CAUSES NEUTRALIZATION OF ACID PRODUCED DURING OXIDATION OF PYRITE

Large quantities of limestone (rock dust) were used in underground mines in Allen Creek and Still Run basins in 1978 and 1979. Solution of the rock dust probably caused neutralization of significant quantities of acid produced during mining.

Mining regulations require the coating of interior mine surfaces with powdered limestone (rock dust) to prevent coal-dust explosions. Figure 6.6-1 shows a typical application of rock dust in a coal mine. Considerable quantities have been used in Still Run and Allen Creek basins in recent years (table 6.6-1). Powdered limestone (calcium carbonate), which is readily dissolved, can significantly influence the chemical characteristics of both mine discharges and the basin outflow.

The major chemical reactions that affect the pH and major chemical constituent concentrations in mine drainage include the solution of minerals contained in geological strata above the coal and in rock dust as follows:

$$FeS_2 + 7/2\ O_2 + H_2O \xrightarrow{\text{bacteria}} Fe^{+2} + 2SO_4^{-2} + 2H^+ \qquad (1)$$

$$CaCO_3 + H_2O \rightleftharpoons Ca^{+2} + HCO_3^- + OH^- \qquad (2)$$

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \qquad (3)$$

Reaction (1) is generalized for pyrite (FeS_2), but other sulfide minerals that contain silver, gold, barium, beryllium, bismuth, molybdenum, and nickel can also occur in measurable quantities in coal (West Virginia Geological and Economic Survey, written commun., 1981). Reaction (1) also is an initial reaction from which a complied sequence of bacterially catalyzed reactions can proceed. The complete cycle results in the production of four equivalents of hydrogen ion (H^+) for each mole of pyrite oxidized.

Rock dust can have a buffering effect on the mine drainage with respect to pH because of the ease of solution and the quantities of rock dust involved. During 1979, about 377 and 1,919 tons of rock dust were applied to interior mine surfaces in underground mines in Allen Creek and Still Run basins (table 6.6-1). Equations (2) and (3) indicate how neutralization of hydrogen ion produced by oxidation of sulfides occurs. Estimates of sulfate loads contributed by mines to streams in Still Run and Allen Creek basins are 94 and 156 tons per year, respectively. (See sec. 6.1.)

Assuming that the oxidation of sulfides produces large amounts of hydrogen ion (contained in sulfuric acid) in mine drainage, the theoretical neutralizing effects of the application of large quantities of rock dust may be estimated as follows: The 94 tons or 8.53×10^7 g of sulfate discharged from mines in the Still Run basin are equivalent to 8.89×10^5 moles of $SO_4^{=}$ as shown below.

$$\frac{8.53 \times 10^7 \text{ g}}{96 \text{ g/mole}} = 8.89 \times 10^5 \text{ moles of } SO_4^{=}$$

Because the oxidation of pyrite produces twice as many moles of H^+ as $SO_4^{=}$, approximately 1.78×10^6 moles of H^+ are produced. The number of moles of $CaCO_3$ available to neutralize acid in deep mines in the Still Run basin is:

$$\frac{(1919 \text{ tons } CaCO_3) \times (907184.7 \text{ g/ton})}{100 \text{ g/mole}}$$

$$= 1.74 \times 10^7 \text{ moles of } CaCO_3$$

But, because 1 mole of $CaCO_3$ neutralizes 2 moles of H^+, the total neutralizing capacity of the $CaCO_3$ is doubled, so that the amount of rock dust available exceeds the amount needed for neutralization by about 20 times as shown below:

$$\frac{(1.74 \times 10^7 \text{ moles of } CaCO_3) \times 2 \text{ equivalents/mole}}{1.78 \times 10^6 \text{ moles } H^+ \times 1 \text{ equivalent/mole}} \times 20$$

The solution of rock dust depends on many environmental variables such as thickness of application and location in mine (wet or dry area). However, the amount of rock dust available, including that applied in previous years, is much greater than the quantity actually needed for neutralization. For this reason, the pH of active mine drains tended to be higher than the pH of domestic wells in Allen Creek and Still Run basins. Abandoned mine drains, which probably were not treated with rock dust in the recent past, generally had pH values similar to those in nearby domestic wells. In several cases, discharge from abandoned mine drains had lower pH values. For example, discharge from an abandoned mine (site 36) in Milam Fork basin had a pH of 6.0, while the median pH of nearby domestic wells was 6.9.

Table 6.6-1.--Amount of rock dust (powdered limestone) used during mining in Allen Creek and Still Run basins, 1978-79

Basin	1978	1979	Basin	1978	1979
Allen Creek--	381	377	Still Run---	1,413	1,919

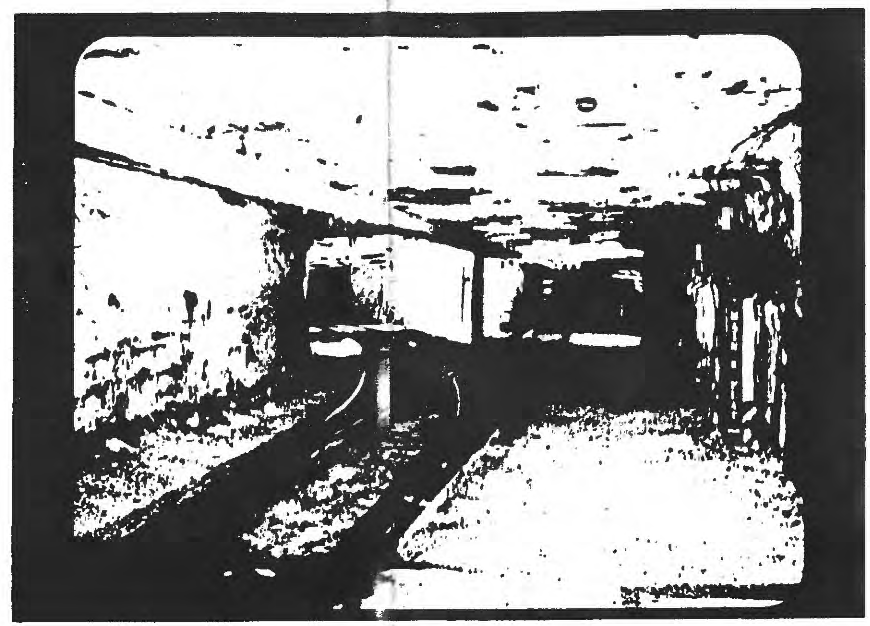


Figure 6.6-1.--Deep-mine walls and roof coated with limestone dust. (Photograph courtesy of the U.S. Department of Labor, Mining Safety and Health Administration.)

6.7 Sulfate

MINE DISCHARGES ARE A MAJOR SOURCE OF SULFATE IN ALLEN CREEK AND STILL RUN BASINS

The mean concentration of sulfate in surface water was significantly higher in Allen Creek and Still Run basins, which were heavily mined, than in Marsh Fork and Bearhole Fork basins, which were predominantly unmined. A major source of sulfate in Allen Creek and Still Run basins was from mine discharge.

Sulfate, which is usually the dominant anion in mine drainage, is commonly used as an indicator of coal-mine drainage. Because concentrations of sulfate above 250 mg/L may have a laxative effect, the recommended limit in drinking water is 250 mg/L (U.S. Environmental Protection Agency, 1979).

The concentration of sulfate at the basin outlets was analyzed using analysis of variance (ANOVA) and Duncan's Multiple Range Tests to determine what water-quality relations might exist (at a significance level of 0.05) between basins. The results of these tests are given in tables 6.7-1 and 6.7-2. Surface water in Allen Creek and Still Run basins contained the greatest mean sulfate concentrations, 110 and 89 mg/L, respectively. Milam Fork, Marsh Fork, and Bearhole Fork basins contained lower mean sulfate concentrations, 9.5, 8.5, and 8.1 mg/L, respectively. Basins with the greatest amount of mining (Allen Creek and Still Run) contained significantly greater mean sulfate concentrations in surface water than did predominantly unmined basins (Marsh Fork and Bearhole Fork). Milam Fork basin, which was partially mined by underground and surface methods, had no mine discharges or refuse piles within the basin before 1979; the mean concentration of sulfate in surface water in Milam Fork basin was 9.5 mg/L, which was not significantly different from unmined basins. In a previous study, Chisholm (U.S. Geological Survey, written commun., 1980) reported a mean sulfate concentration of 127 mg/L and a range of 5.7 to 1,400 mg/L in surface water throughout the Guyandotte River basin. Mean sulfate concentrations in surface water for all basins in the study were less than the mean for the entire Guyandotte River basin reported by Chisholm.

The major source of sulfate is the oxidation of sulfides, mainly pyrite (FeS_2), contained in coal, shale, and sandstone throughout the area. Pyrite in mine refuse piles and in active and abandoned coal mines is oxidized when exposed to oxygen and moisture. The reaction rate depends on the activity of *Thiobacillus*, and occurs as follows:

$$FeS_2 + H_2O + 7/2\ O_2 \xrightarrow{\text{bacteria}} Fe^{+2} + 2H^+ + 2SO_4^{-2}$$

Water from wells in Milam Fork, Marsh Fork, and Bearhole Fork basins contained mean sulfate concentrations less than 17 mg/L, about the same as the mean sulfate concentration in surface water in the respective basins. Mine discharges generally had a much greater mean sulfate concentration than did surface water and water from wells. Discharges from 22 mines in Allen Creek and Still Run basins had mean sulfate concentrations of 235 and 438 mg/L, respectively, or about 2 to 5 times the concentration in surface water at the basin outlets.

Discharges from these 22 mines accounted for 34 to 14 percent of the total basin outflow in Allen Creek and Still Run basins, respectively, during a period of low streamflow. Thus, a major source of sulfate in surface water draining heavily mined basins (Allen Creek and Still Run) was probably from underground mine discharges.

Concentrations of sulfate at synoptic surface-water sampling sites (fig. 6.7-1) did not vary appreciably in Bearhole Fork and Marsh Fork basins. All surface waters sampled in these basins had less than 10 mg/L of sulfate during the sampling period. Sulfate concentrations were more variable in Allen Creek and Still Run basins, ranging from less than 10 mg/L to over 200 mg/L. Sulfate concentrations over 60 mg/L were generally found in areas of active coal mining.

The concentration of sulfate in surface water varies with streamflow. High sulfate concentrations occur during low flow, and low sulfate concentrations occur at high flow. Using equations developed by regression analysis and the appropriate streamflow duration curves, the concentration of sulfate at different flows can be estimated (table 6.7-3) in Still Run basin. About 10 percent of the time (corresponding to 90 percent streamflow duration), the sulfate concentration can be expected to exceed 170 mg/L in Still Run basin.

Table 6.7-1.--Mean, median, and range of sulfate concentrations in surface water at basin outlets, October 1, 1977 to December 31, 1979

[Dissolved sulfate concentration, in milligrams per liter]

Basin	Median	Mean[1]	Range
Allen Creek [2](20,51)-----	110	110]	63 to 160
Still Run [2](5,32)--------	74.5	89]	16 to 210
Milam Fork [2](1,37)-------	9.6	9.5 ⎤	2.4 to 14
Marsh Fork [2](0,0)--------	8.1	8.5 ⎦ ⎤	6 to 14
Bearhole Fork [2](0,6)-----	7.5	8.1 ⎦	5.7 to 15

[1] Means connected by open-bracket lines were not significantly different at the 0.05 level.
[2] Mining indicator (percent surface mined, percent deep mined).

Table 6.7-2.--Mean and range of sulfate concentrations in water from wells and mine discharges during period October 1, 1977 to December 31, 1979

[Dissolved sulfate concentration, in milligrams per liter]

Basin	Mean	Range
Allen Creek [a](20,51) (wells)-------	129	72 to 140
(mines)-------	235	32 to 880
Still Run [a](5,32) (wells)----------	10	1.5 to 160
(mines)----------	438	21 to 1,900
Milam Fork [a](1,37) (wells)---------	17	2.7 to 83
Marsh Fork [a](0,0) (wells)----------	5.4	2.4 to 7.0
Bearhole Fork [a](0,6) (wells)-------	8.5	1.2 to 42

[a] Mining indicator (percent surface mined, percent deep mined).

Table 6.7-3.--Duration of sulfate concentration in surface water at the outlet of Still Run basin, October 1, 1977 to December 31, 1979

Basin	Percent of time sulfate concentration was equaled or exceeded, in milligrams per liter								
	99	95	90	75	50	25	10	5	1
Still Run	12.7	19.5	25.5	36.5	56	90	170	240	312

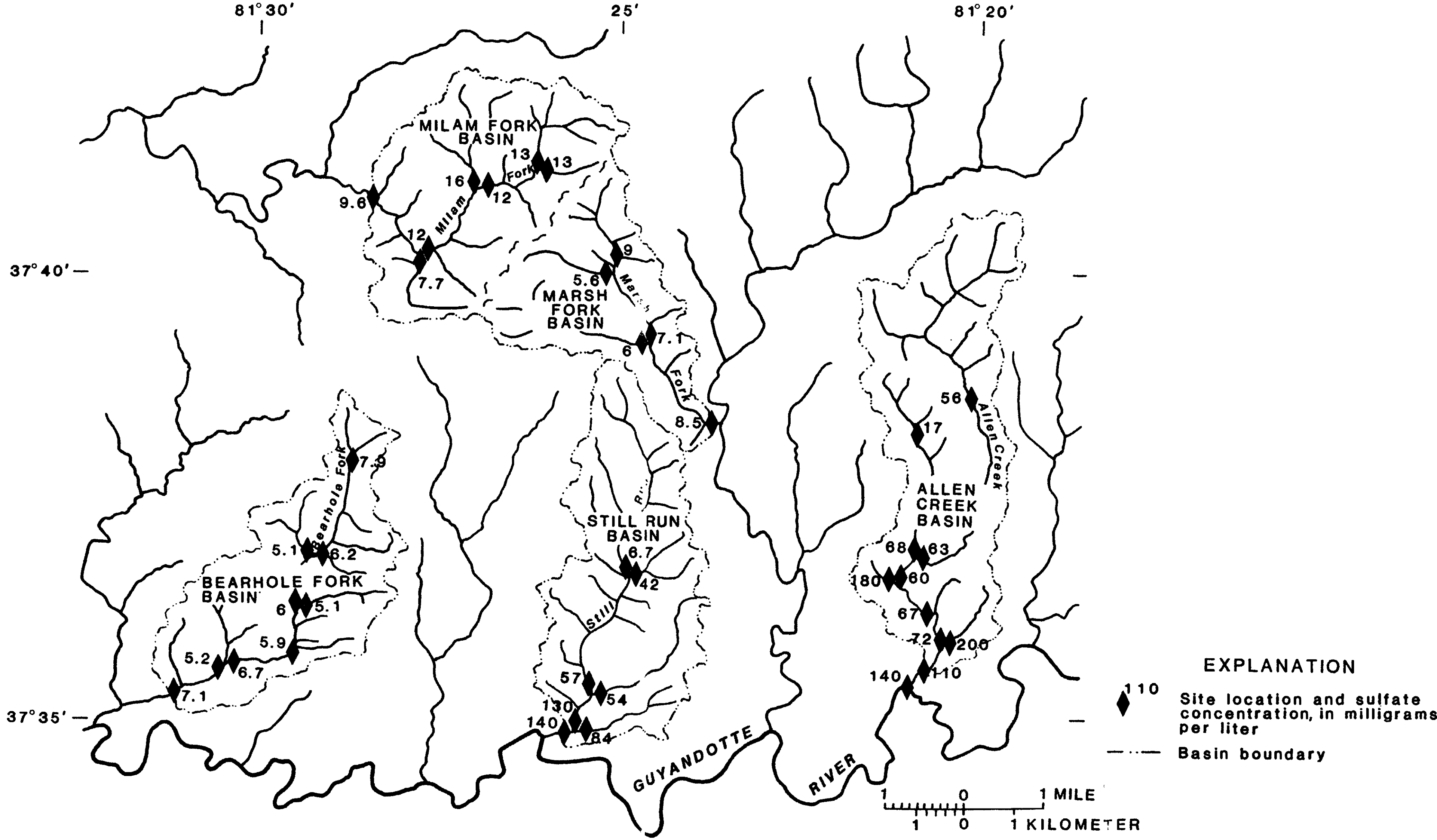


Figure 6.7-1.--Sulfate concentration at synoptic surface-water sampling sites, October 22-26, 1979.

6.8 Iron

MEAN DISSOLVED IRON CONCENTRATIONS OF SURFACE WATER IN MINED AND PREDOMINANTLY UNMINED BASINS WERE SIMILAR

Mean dissolved iron concentration of surface water in Allen Creek and Still Run basins, which were heavily mined, did not differ significantly from the mean iron concentration in Marsh Fork and Bearhole Fork basins, which were predominantly unmined. Mean total iron concentration in surface water differed significantly among all basins and was greatest in Allen Creek.

Iron is a common trace element in surface and ground water throughout the Guyandotte River basin. High iron concentration not only adds a disagreeable taste to the water but can also clog pipes and stain fixtures and laundry. Excessive concentrations also affect fish and other aquatic life. The recommended maximum concentration of iron in drinking water is 300 µg/L (U.S. Environmental Protection Agency, 1979). West Virginia water-quality standards for trout streams allow a maximum of 500 µg/L total iron while all other streams are allowed a maximum of 1,000 µg/L total iron. A detailed explanation of the West Virginia water-quality standards is available from the West Virginia State Water Resources Board (West Virginia State Water Resources Board, 1980). Because mine discharges and drainage from coal and mine spoil piles often contain excessive concentrations of iron (Martin and others, 1980, Helgesen and Razem, 1980, Gale and others, 1976), iron is required to be monitored under NPDES (National Pollution Discharge Elimination System) permits.

Dissolved and total iron concentrations in streams (at the basin outlet) and in ground-water throughout the study area were analyzed statistically to determine if water-quality differences at a significance level of 0.05 existed among basins. The results of the statistical tests are given in tables 6.8-1 and 6.8-2. The mean concentration of dissolved iron in surface water ranged from 84 µg/L in Allen Creek basin to 216 µg/L in Milam Fork basin. Mean dissolved iron concentration in Allen Creek and Still Run basins, which were heavily mined, did not differ significantly from mean concentrations in Marsh Fork and Bearhole Fork basins, which were predominantly unmined. The relatively high mean concentration of dissolved iron in Milam Fork basin (216 µg/L), could reflect slight lithologic differences in the rocks between Milam Fork and the other basins. It also may be due to the reported dewatering of overburden above the deep mines in Milam Fork basin prior to 1960, when the mines were active.

Residents in the Milam Fork area report that well yields decreased as deep mining progressed beneath them. This may have allowed oxidation of iron-bearing minerals exposed in the overburden as a result of water declines. Reportedly, iron-laden seeps developed on the surface about a year after an extensive deep mine in the basin was abandoned and 700-foot deep vertical shafts tapping the mine, and the mine voids had filled with

Table 6.8-1.--Mean concentration of dissolved and total iron in surface water at basin outlets, October 1, 1977 to December 31, 1979

[Mean iron concentration, in micrograms per liter]

Basin	Dissolved[1]	Total[1]
Allen Creek [2](20,51)-----------	84	860
Still Run [2](5,32)-----------	100	420
Milam Fork [2](1,37)-----------	216	730
Marsh Fork [2](0,0)-----------	135	355
Bearhole Fork [2](0,6)-----------	100	440

[1] Means connected by open-bracket lines were not significantly different at a significance level of 0.05.
[2] Mining indicator (percent surface mined, percent deep mined).

Table 6.8-2.--Mean concentration of dissolved iron in water from wells and mine discharges in study basins, October 1, 1977 to December 31, 1979

[Mean dissolved iron concentration, in micrograms per liter]

Basin	Wells	Mine discharges
Allen Creek [a](20,51)--------------	11,925	2,323
Still Run [a](5,32)-----------------	10,179	872
Milam Fork [a](1,37)----------------	4,892	-----
Marsh Fork [a](0,0)-----------------	3,065	-----
Bearhole Fork [a](0,6)--------------	4,736	-----

[a] Mining indicator (percent surface mined, percent deep mined).

water. The mean concentrations of total iron ranged from 355 µg/L in Marsh Fork at the basin outlet to 860 µg/L in Allen Creek basin. Mean total iron concentration in surface water differed significantly at a significance level of 0.05 among all basins.

Ground water throughout the Guyandotte River basin typically contains a higher concentration of iron than does surface water. The solubility of iron is dependent on a complex redox potential Eh-pH relation. Iron, like most metals, becomes more soluble as the pH becomes more acidic and as the Eh of water decreases. For example, the solubility of iron is several orders of magnitude greater at pH 6.0 than at pH 8.0. Most ground water in Allen Creek, Still Run, Marsh Fork, and Bearhole Fork basins had a lower pH than surface water. (See fig. 6.5-2.) Consequently, the mean concentration of dissolved iron ranged from about 3,100 µg/L in Marsh Fork wells to about 12,000 µg/L in Allen Creek wells, or about 23 to 142 times the concentration of dissolved iron in surface water at the respective basin outlets.

Mining can affect the concentration of iron in streams in several ways. Underground coal mining creates large quantities of spoil material, which, along with coal that has been mined, is deposited on land surface in large piles. Leachate from these piles has been reported to contain iron in excess of 1,000 mg/L (Krothe and others, 1980). When the iron-rich discharge enters a stream, the iron is oxidized from the ferrous (Fe^{+2}) to the ferric (Fe^{+3}) state, which is much less soluble, and precipitation occurs, forming the yellowish-red deposits often observed in stream channels near mining areas. In general, iron adsorbs to the surface of suspended-sediment particles and, like the sediment, is transported out of the basin during periods of high streamflow (Feltz, 1980).

Mine discharge also can be a source of high iron concentrations. Mine discharge in Allen Creek basin had a mean dissolved iron concentration of about 2,300 µg/L, or about 28 times the mean concentration of dissolved iron in surface water in the same basin. Hypothetically, the maximum potential mine discharge in Allen Creek basin totals about 2.8 ft^3/s (if all known discharge sources are measured concurrently), which corresponds to about 46 percent of the total streamflow at the basin outlet at median streamflow (50 percent duration) conditions. The exact percentage contribution of mine discharge to streamflow is highly variable, depending on climatic conditions, but probably is substantial.

Concentration of dissolved iron at synoptic surface-water sampling sites was highly variable. Dissolved iron concentration ranged from 50 to 1,000 µg/L (fig. 6.8-1). The range of concentration (70 to 1,000 µg/L) was greatest in Allen Creek basin, which was heavily mined. The least variation (100 to 300 µg/L) occurred in Marsh Fork and Bearhole Fork basins, which were predominantly unmined.

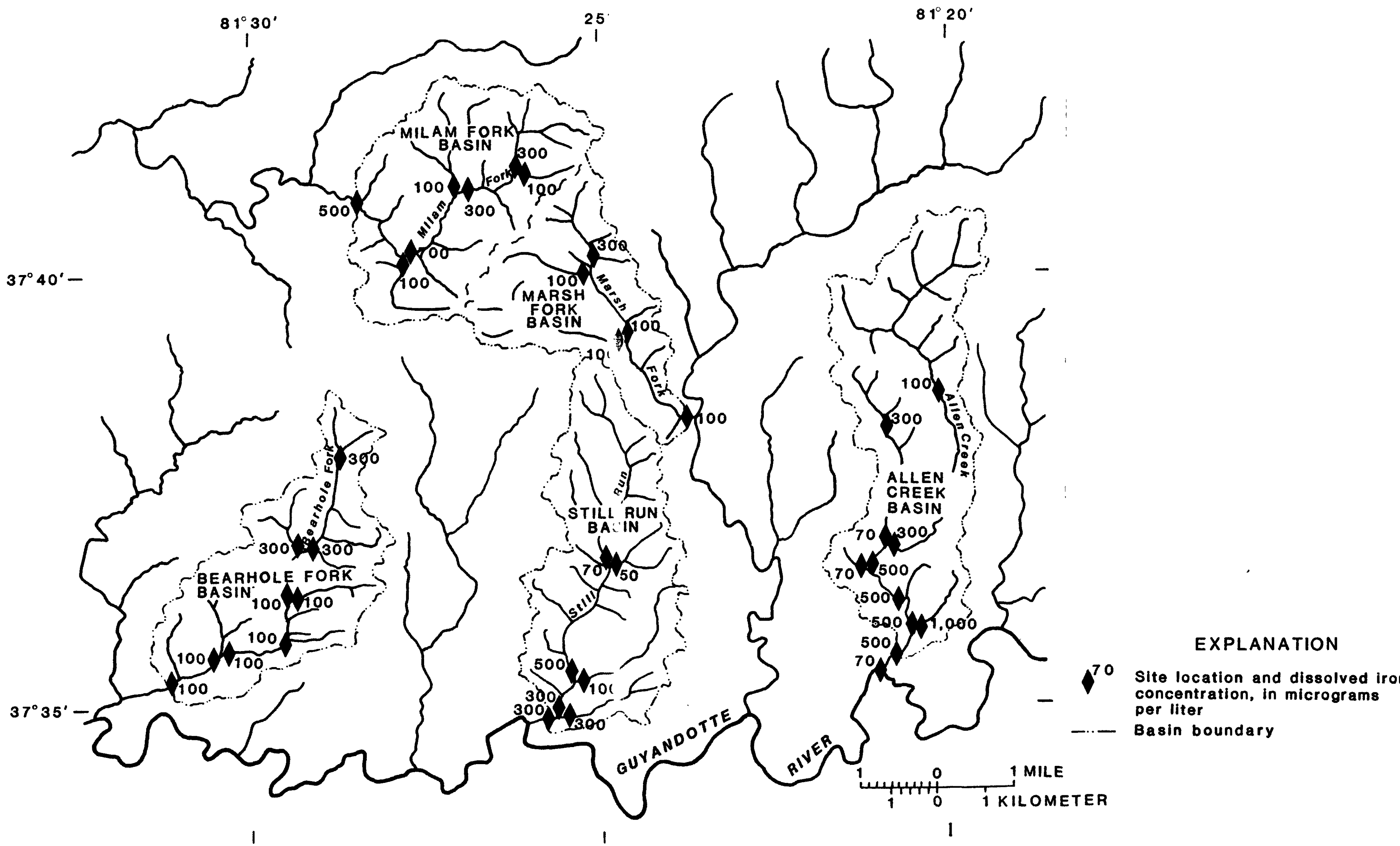


Figure 6.8-1.--Dissolved iron concentration at synoptic surface-water sampling sites, October 22-26, 1979.

6.9 Manganese

MANGANESE CONCENTRATIONS ARE GREATER IN MINED BASINS THAN IN UNMINED BASINS

Dissolved manganese concentration in surface water was significantly greater in Allen Creek and Still Run basins, which were heavily mined, than in Bearhole Fork and Marsh Fork basins, which were predominantly unmined. Mine discharges probably are a substantial source of manganese in Allen Creek and Still Run basins.

Manganese is an objectionable but common trace element in ground and surface water throughout the Guyandotte River basin. Minute concentrations can impart a disagreeable taste to water and can stain fixtures. Surface water in Allen Creek, Still Run, and Milam Fork basins commonly exceeded the recommended manganese concentration of 50 µg/L for drinking water during the study (U.S. Environmental Protection Agency, 1979).

Dissolved manganese concentration in surface water at the basin outlets was analyzed statistically to determine if water-quality differences (at a significance level of 0.05) existed between basins. Results of these tests are given in tables 6.9-1 and 6.9-2. The mean concentration of manganese ranged from 30 µg/L in Marsh Fork basin to 439 µg/L in Allen Creek basin. The mean manganese concentration for streams in Marsh Fork and Bearhole Fork basins, which were predominantly unmined, differed significantly from the mean manganese concentration in Allen Creek and Still Run basins, which were heavily mined (30 and 44 µg/L versus 439 and 111 µg/L, respectively). Mean manganese concentration in surface water also differed significantly between mined basins.

Ground water generally contained a greater concentration of dissolved manganese than did surface water. Manganese commonly occurs as the oxide (MnO_2) and hydroxide ($Mn(OH)_2$) in sedimentary rocks. The solubility of manganese is complicated owing to the many stable complex ions which may be formed, and has been described elsewhere (Hem, 1970). At a pH of 7.0, manganese is largely in the manganous (Mn^{+2}) state, which is much more soluble than Fe^{+2} at the same pH. According to Hem (1970), manganese forms stable (soluble) complexes with bicarbonate and sulfate, both of which are commonly present in relatively high concentrations in mine discharge. For this reason manganese generally is present in high concentration in mine discharge.

Mine discharge in Allen Creek and Still Run basins generally had a high concentration of manganese (table 6.9-2). The mean concentration of dissolved manganese in mine discharge in Allen Creek and Still Run basins was 1,276 and 1,128 µg/L, respectively, or about 3 and 10 times the concentration of dissolved manganese in surface water in the respective basins. Hypothetically, mine discharge in Allen Creek basin totals about 2.8 ft^3/s (if all known discharge sources are measured concurrently), which corresponds to about 46 percent of the total streamflow at the basin outlet at median streamflow (50 percent duration) conditions. For this reason, the contribution of manganese concentration in mine discharge to streams is probably substantial.

The concentration of dissolved manganese at synoptic surface-water sampling sites ranged widely--from 10 to 3,000 µg/L (fig. 6.9-1). The greatest range and the highest manganese concentration were observed in Allen Creek basin (70 to 3,000 µg/L), which also was the most heavily mined basin.

Table 6.9-1.--Mean dissolved manganese concentration in surface water at basin outlets, October 1, 1977 to December 31, 1979

[Mean dissolved manganese concentration, in micrograms per liter]

Basin	Mean[a]
Allen Creek [b](20,51)----------------------	439
Still Run [b](5,32)------------------------	111
Milam Fork [b](1,37)-----------------------	71
Bearhole Fork [b](0,0)---------------------	44
Marsh Fork [b](0,6)------------------------	30

[a] Means connected by open-bracket lines were not significantly different at a significance level of 0.05.
[b] Mining indicator (percent surface mined, percent deep mined).

Table 6.9-2.--Mean dissolved manganese concentration in water from wells and mine discharges in study basins, October 1, 1977 to December 31, 1979

[Mean dissolved manganese concentration, in micrograms per liter]

Basin	Wells	Mine discharges
Allen Creek [a](20,51)-----------	982	1,276
Still Run [a](5,32)--------------	920	1,128
Milam Fork [a](1,37)-------------	645	-----
Bearhole Fork [a](0,0)-----------	469	-----
Marsh Fork [a](0,6)--------------	5,155	-----

[a] Mining indicator (percent surface mined, percent deep mined).

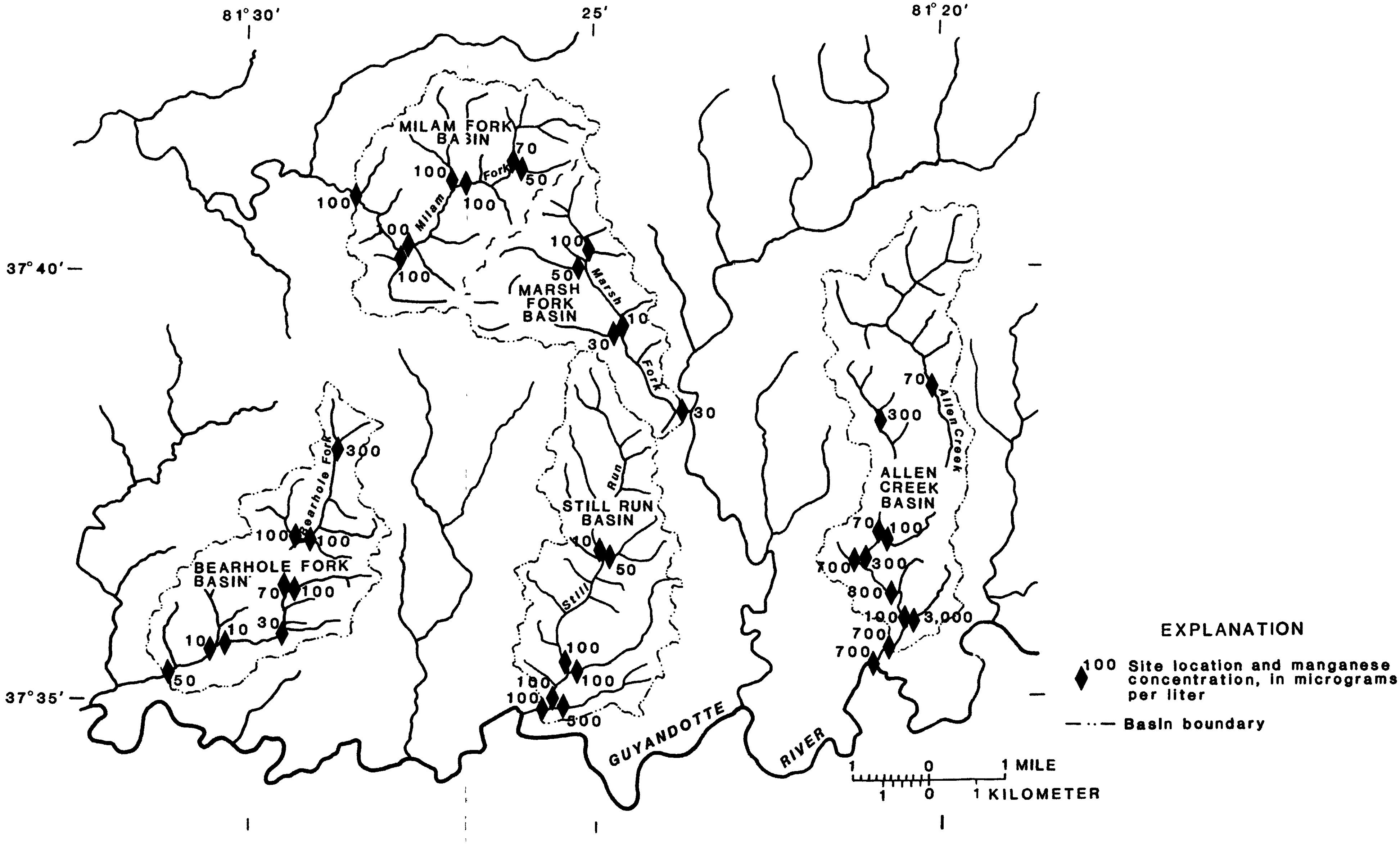


Figure 6.9-1.--Dissolved manganese concentration at synoptic surface-water sampling sites, October 22-26, 1979.

6.10 Trace Elements

SOME TRACE ELEMENTS EXCEEDED QUALITY CRITERIA FOR PUBLIC SUPPLY OR STREAM STANDARDS

Most trace elements occur in higher concentration in mine water than in streams. Iron, manganese, and lead concentrations exceeded quality criteria for some surface water.

Trace elements are derived from the solution of minerals in shallow rock in the basin and from atmospheric deposition. Many of the trace elements are essential to the growth of flora and fauna in very low concentration but may be toxic in higher concentration. Ground water generally has a higher concentration of trace elements than does surface water. The solution of trace elements is dependent on the Eh-pH relation. A low pH and Eh generally favors solution of most trace elements. For this reason, acidic drainage from mines and spoil and coal storage piles commonly has higher concentrations of trace elements than normally occur in either surface water or ground water in the area.

Trace elements are included in regulations pertaining to water quality because of their reported toxicity to people, aquatic plants, and animals. The U.S. Environmental Protection Agency set maximum permissible and maximum recommended levels for selected trace elements in drinking water (U.S. Environmental Protection Agency, 1979). In West Virginia these regulations are administered by the State Board of Health and apply only to drinking water supplied to the public by water treatment plants (West Virginia State Board of Health, 1978). Interstate and intrastate surface-water quality regulations are different and are administered by the West Virginia Department of Natural Resources, although the regulations were established by the State Water Resources Board (West Virginia State Water Resources Board, 1980).

Water samples were analyzed for dissolved trace-element concentrations using the ICAP (inductively coupled argon plasma) technique described by Garbarino and Taylor, 1979. Detection levels differ from the atomic absorption (AA) technique and are given in table 6.10-1 for each element.

The minimum, median, and maximum concentrations of trace elements in surface and mine water are also shown in table 6.10-1. The median concentration of most trace elements in surface water was generally far less than the water-quality criteria for streams and drinking water. Exceptions were iron, manganese, and lead, which exceeded quality criteria in a number of samples. The median concentration of iron, manganese, and tin in surface water generally exceeded 0.1 milligram per liter. Some of these trace elements probably enter surface water through the oxidation of sulfide minerals (FeS_2, PbS, Cu_2S, and ZnS) in the rock.

Mine-water samples were from mine interior pools, seeps, flooded shafts, and drains. Most trace elements in these samples were present in somewhat higher concentration than in surface water in the same basin. Some mine samples exceeded the quality criteria for copper, iron, lead, manganese, nickel, aluminum, cadmium, silver, and zinc. Generally, higher concentrations of trace elements were associated with low pH conditions. For example, a mine drain (site 136) from the abandoned Beckley Seam in the Allen Creek basin had a pH of 4.3, a manganese concentration of 3 mg/L, 3 mg/L of lead, 3 mg/L of tin, 0.3 mg/L of iron, 3 mg/L of aluminum, and 0.3 mg/L of zinc. Drainage from these sources may impair the quality of surface water, particularly at low flow. If untreated, water from some of these mines would not be suitable as drinking-water sources. Because streams in Allen Creek and Still Run Basins receive measurable flow from mines, the generally higher concentration of some elements such as tin and lithium may reflect mine drainage in those basins.

Table 0.10-1.--Trace element concentrations in surface water and mine discharges in the study basins, October 1, 1977 to December 31, 1979

[Concentrations, in milligrams per liter]

Constituent	Detection level	Allen Creek (surface water)			Milam Fork (surface water)			Milam Fork (mines)			Still Run (surface water)			Still Run (mines)			Boarhole Fork (surface water)			Marsh Fork (surface water)			Quality Criteria	
		Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Criterion	Reference
Aluminum (Al)	0.05	<0.05	<0.05	3.0	<0.05	<0.05	<0.05	<0.05	0.07	0.10	<0.05	<0.05	0.07	<0.05	<0.05	>10.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.5	(1)
Antimony (Sb)	.03	<.03	<.05	.05	<.03	<.03	<.03	<.03	<.03	.07	<.03	<.03	.03	<.03	<.03	.10	<.03	<.03	<.03	<.03	<.03	<.03		
Barium (Ba)	.005	.03	.05	.10	.03	.05	.10	.05	.70	.70	.05	.05	.10	.03	.05	.:0	.03	.05	.05	.03	.03	.05	1.0	(1,3)
Beryllium (Be)	.001	.001	.001	.01	<.001	.001	.003	<.001	<.002	.005	.001	.003	.003	.001	.003	.05	<.001	.001	.003	<.001	<.001	.001		
Boron (B)	.005	.03	.03	.03	.01	.03	.03	.03	.07	.10	.01	.03	.05	.01	.05	.10	.005	.03	.07	.01	.01	.03		
Cadmium (Cd)	.001	<.001	<.001	.005	<.001	<.001	.003	<.001	.001	.005	<.001	<.001	.001	<.001	<.001	.03	<.001	<.001	.003	<.001	<.001	.001	.010	(3)
																							.00004-.010	disc.(1)
Chromium (Cr)	.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	.05	(1,3)
Cobalt (Co)	.005	<.005	.01	.10	<.005	.01	.01	<.005	.01	.01	<.005	<.005	.01	<.005	.01	1.0	<.005	<.005	.01	<.005	.01	.01		
Copper (Cu)	.01	<.01	<.01	.30	<.01	<.01	<.01	<.01	.01	.07	<.01	<.01	<.01	<.01	<.01	1.0	<.01	<.01	.01	<.01	<.01	<.01	1.0	(2)
																							.005 - .145	total (1)
Gallium (Ga)	.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	.10	<.03	<.03	<.03	<.03	<.03	<.03		
Germanium (Ge)	.03	<.03	.03	.10	<.03	<.03	<.03	<.03	<.03	.05	<.03	<.03	.03	<.03	.05	.3	<.05	<.03	<.03	<.03	<.03	<.03		
Iron (Fe)	.005	.07	.30	1.0	.10	.30	.70	.01	.05	.07	.05	.3	.5	.005	.05	>10.0	.10	.10	.30	.1	.1	.3	.300	(2)
																							.5 - 1.0	total (1)
Lead (Pb)	.03	<.03	<.03	.30	<.03	.10	.10	<.03	<.03	.07	<.03	.03	.10	<.03	<.03	.30	<.03	.05	.10	<.03	.07	.10	.05	(3)
																							.025 - .05	total (1)
Lithium (Li)	.005	<.005	.01	.30	<.005	<.005	.005	.007	.10	.10	<.005	.007	.03	.005	.07	.50	<.005	<.005	<.005	<.005	<.005	<.005		
Manganese (Mn)	.001	.07	.30	3.0	.05	.10	.10	.03	.10	.10	.01	.10	.50	.005	.03	3.0	.01	.10	.30	.01	.03	.10	.05	(2)
																							1.0	(1)
Molybdenum (Mo)	.01	<.01	<.01	.03	<.01	<.01	.01	<.01	<.01	.05	<.01	<.01	.01	<.01	<.01	.07	<.01	<.01	.05	<.01	<.01	.01		
Nickel (Ni)	.05	<.05	<.05	.30	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	1.0	<.05	<.05	<.05	<.05	<.05	<.05	.05	(1)
Silver (Ag)	.01	<.01	<.01	.03	<.01	<.01	.01	<.01	.01	.03	<.01	<.01	<.01	<.01	.03	.10	<.01	<.01	.03	<.01	.01	.03	.05	(3)
																							.002 - .024	total (1)
Strontium (Sr)	.005	.05	.30	.70	.03	.07	.10	.10	1.0	1.0	.03	.10	.30	.01	.70	3.0	.01	.03	.05	.03	.03	.05		
Tin (Sn)	.05	.30	.50	1.0	.10	.10	.10	.10	.40	.50	.07	.30	.50	.10	.50	1.0	.05	.07	.10	.10	.10	.10		
Titanium (Ti)	.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.01	<.005	<.005	<.005	<.005	<.005	<.005		
Vanadium (V)	.01	<.01	<.01	.03	<.01	<.01	<.01	<.01	<.01	.03	<.01	<.01	<.01	<.01	<.01	.05	<.01	<.01	.03	<.01	.01	.03		
Zinc (Zn)	.01	.01	.05	.30	.01																			
																							.04 - .60	total (1)
Zirconium (Zr)	.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	.005	.01	<.005	<.005	<.005	<.005	<.005	<.005		

1) West Virginia State Water Resources Board, 1980
2) U.S. Environmental Protection Agency, 1979
3) West Virginia State Board of Health, 1978

WELLS LOCATED NEAR UNDERGROUND AND SURFACE MINING HAD SIGNIFICANTLY DIFFERENT WATER QUALITY THAN WELLS FARTHER AWAY

The sodium, bicarbonate, and sulfate concentrations; sodium-calcium ratio; and specific conductance in ground-water samples collected from wells near underground mines differed significantly from wells located away from mined areas.

Chemical characteristics of water from domestic (private) wells varied considerably from basin to basin in terms of pH, specific conductance, and major and minor ions. Well characteristics (topographic location, depth, distance from mining, etc.) also varied, but all wells tapped the same major geologic unit, the Pottsville Group. If the chemical characteristics were compared only to the variable "distance from mining," domestic wells could be divided into two groups: (1) those upgradient from or at least 0.5 mi from underground or surface mines, considered essentially unaffected by mining, and (2) those underlain by, adjacent to, or within 0.5 mi downgradient from underground mines or surface mines, considered to be potentially influenced by mining.

Selected chemical characteristics of each group of wells were compared statistically to determine what, if any, water-quality differences (at a significance level of 0.05) existed between the two groups. The statistical test used for comparison was the analysis of variance (ANOVA) test. Test results and statistical inference for different test criteria are shown in table 6.11-1. The results indicate that sulfate, sodium, and bicarbonate concentrations; sodium-calcium ratio; and specific conductance differed significantly between the two groups. Conversely, the noncarbonate hardness-hardness ratio, pH, and concentrations of chloride, calcium, hardness, iron, and manganese were not significantly different between the two groups at the 0.05 level. These results should be interpreted with caution, as detailed mineralogic information on each site was not available. However, the inference is that significant water-quality differences may exist between wells located near underground and surface mining and wells located at some distance from mining areas.

Table 6.11-1.--Summary of statistical inference tests on selected ground-water samples collected within 0.5 mile of and over 0.5 mile away from underground and surface-mined areas

Chemical characteristic	Significance level	Result
Sulfate------------------	0.025	Significantly different.
Noncarbonate hardness		
Hardness-----------------	.05	Not significantly different.
Specific conductance-----	.01	Significantly different.
Chloride-----------------	.05	Not significantly different.
Calcium------------------	.05	Not significantly different.
pH-----------------------	.05	Not significantly different.
Sodium-------------------	.05	Significantly different.
Sodium		
Calcium------------------	.025	Significantly different.
Hardness-----------------	.05	Not significantly different.
Bicarbonate--------------	.025	Significantly different.
Dissolved iron-----------	.05	Not significantly different.

6.12 Sodium and Ion Exchange

HIGH CONCENTRATION OF SODIUM IN GROUND WATER PROBABLY RESULTED FROM ION EXCHANGE

High sodium concentration in ground water can result from natural upward migration of brine or can be associated with oil or gas well drilling, development and (or) abandonment, mine wastewater treatment, solution and precipitation of sodium and calcium salts, and by ion exchange. Ion exchange was the probable cause of anomalously high sodium concentration in ground water.

The major ions in ground water in the study area were calcium, sodium, bicarbonate and sulfate. In 50 of 75 ground-water samples, bicarbonate was the dominant anion, and in the remaining samples, sulfate was the dominant anion. Similarly, calcium was the dominant cation in 46 of 75 samples, while in 29 samples, sodium was dominant. For most ground water, the ion ratio for anions is bicarbonate >sulfate >chloride >fluoride, and the cation ratio is generally calcium >magnesium >sodium >potassium (Hem, 1970). The concentrations of selected chemical constituents are shown in table 6.12-1. Ground water in which sodium was the dominant cation commonly contained relatively high bicarbonate and low chloride concentrations. It is useful to establish mechanisms by which sodium could become the dominant cation to describe possible anthropogenic influences on water quality.

Possible mechanisms which may result in sodium becoming the dominant cation include:

1. Contamination of the shallow ground water, either by brine resulting from oil or gas well drilling and operation, or by road deicing chemicals.
2. Treatment of mine discharge with caustic soda (NaOH) to raise the pH.
3. Solution and later precipitation of calcium-containing minerals in ground water.
4. Ion exchange of sodium in marine shale, glauconitic sandstone, or other ion exchangers, for calcium in ground water.

Contamination of the shallow ground-water system can occur during oil and gas drilling by inadvertent infiltration of waste brine from catchment basins. Leakage from abandoned wells that tap brines under pressure at depth is another possibility (Bain, 1970). Contamination of the shallow ground water by road deicing chemicals is also well documented in the literature. These mechanisms are generally evident by the approximately 1:1 ionic ratio of sodium to chloride in milliequivalents per liter. However, in the study area this possibility does not seem likely from the data in table 6.12-1 and road deicing activities reported by local residents.

In some areas mine discharges have been treated with caustic soda (NaOH) to raise the pH to compliance levels. However, it is unlikely that this type of treatment would affect ground-water conditions except locally and, more importantly, no treatment of this nature has been done in the study area.

Solution and precipitation of calcium salts (mechanism 3) could also yield ground water with a relatively high sodium concentration. As infiltrating ground water percolates downward, solution of calcium from limestone and other minerals can occur, resulting in relatively large calcium and bicarbonate concentrations. The solution of sodium salts such as sodium carbonate, can also occur, eventually resulting in a high sodium concentration. If the concentration of calcium and carbonate become high enough, carbonate minerals such as calcite and dolomite can be formed by precipitation, which decreases the concentration of calcium relative to sodium in the water. This process can continue until the calcium concentration approaches zero, that is, the mechanism can proceed until the solution becomes saturated with sodium carbonate or bicarbonate. All ground-water samples in this study were undersaturated with sodium carbonate by several orders of magnitude. Furthermore, if the precipitation of calcite should occur according to the mechanism

$$Na_2CO_3 . 10\ H_2O + Ca^{+2} \rightleftharpoons CaCO_3 + 2\ Na^+ + 10\ H_2O$$

it can be shown that at equilibrium under standard conditions that

$$\frac{[Ca^{+2}]^{1/2}}{[Na^+]} = 1.68 \times 10^{-4} \quad \text{(Turk, 1982, p. 79).}$$

The ratio of the square root of the calcium to sodium activities indicate that the limiting ratio had not been reached. Thus, this mechanism is not supported by the data in this study.

Ion exchange can also yield ground water with relatively high sodium and low calcium concentration. In mechanism 4, calcium is dissolved from limestone and from other minerals by infiltrating ground water as previously described. As the calcium-enriched ground water percolates downward, it comes into contact with marine shale or glauconitic sandstone containing clay or other minerals having exchangeable sodium. Because sodium has a larger activity relative to calcium, the calcium is exchanged for sodium from the shale, increasing the sodium and decreasing the calcium concentration in the ground water. More calcium carbonate can dissolve, but the calcium is exchanged for sodium, which eventually yields water with relatively high sodium and bicarbonate concentrations, and a relatively low calcium concentration. In deciding if this mechanism has occurred, the calcium-to-sodium ratio should reach a limiting value as the water moves through the rocks. As shown by Turk (1982), the equilibrium of sodium and calcium between the solution and an ion exchanger (marine clay) can be expressed as:

$$\frac{[Ca^{+2}]^{1/2}}{[Na^+]} = K \frac{(CaX)^n}{(Na_2X)} = 0.16$$

In the equation, the brackets indicate the activity of the ion in solution, parentheses denote the concentration of the ion on the ion exchanger, and K and n are constants for a given ion exchanger and pairs of ions with fixed concentrations of all other ionic species at constant temperature. When equilibrium with a marine shale occurs, the exchange of calcium for sodium proceeds until the ratio of the activities approaches 0.16. Thus, the ratio of the square

Table 6.12-1.--Selected chemical characteristics of ground water in the study area

[Temperature, in degrees Celsius; pH, in standard units; and other constituent concentrations, in milligrams per liter]

Site number	pH	Water temperature	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride
4	6.3	12.0	13	3.6	6.5	1.4	48	12	2.7
6	7.4	11.5	8.1	1.7	50	.9	140	3.3	6.5
7	6.5	8.0	14	3.9	26	1.4	93	8.1	15
8	7.0	11.0	18	4.0	65	1.0	160	42	11
9	6.5	9.0	4.7	1.8	5.0	1.0	33	1.2	1.4
10	6.7	10.0	15	2.9	6.0	1.1	66	1.4	1.4
11	6.2	10.5	8.9	1.4	3.0	.8	30	3.2	1.4
13	6.8	13.0	19	3.3	18	1.1	100	2.0	6.1
15	6.5	12.5	38	10	4.7	1.4	160	5.3	1.4
16	7.1	12.0	22	2.6	3.8	.9	82	9.5	2.1
19	6.3	11.0	7.5	2.3	9.4	1.0	46	3.2	4.6
20	6.9	10.5	20	3.6	13	1.3	83	3.6	10
23	6.0	9.5	6.2	2.6	5.5	1.2	24	4.7	10
24	6.2	8.5	9.5	2.1	3.8	1.1	30	6.8	4.5
25	6.2	9.0	12	3.9	4.6	1.3	45	3.0	5.5
27	7.1	----	15	4.7	5.6	1.4	67	6.0	1.4
28	7.5	11.5	18	5.5	50	1.6	158	40	9.2
29	7.5	12.0	18	5.2	48	1.6	171	41	9.2
30	5.3	17.0	7.5	3.4	4.5	1.6	0	28	8.1
33	5.8	13.5	7.8	3.5	6.0	1.8	21	24	3.6
34	6.8	13.5	15	5.0	11	1.4	39	19	21
35	6.8	13.0	10	3.6	3.0	1.3	24	23	1.9
36	6.0	13.0	10	2.8	8.5	1.4	33	21	1.5
38	7.1	13.0	13	4.7	60	1.7	171	4.0	24
39	6.9	14.0	19	8.3	48	1.5	183	22	19
40	7.2	17.5	26	7.3	40	1.4	158	37	5.7
41	6.1	15.0	7.8	2.5	66	3.3	158	9.6	26
44	6.3	10.0	51	15	15	1.5	83	34	83
46	7.0	11.5	10	3.5	140	1.3	350	2.7	31
47	7.0	10.0	7.9	3.2	130	1.3	310	3.1	31
48	7.3	10.0	10	3.5	150	1.4	380	2.8	32
49	7.2	10.5	19	6.5	140	1.4	390	16	26
51	6.6	10.0	8.5	3.3	6.0	.9	36	19	1.8
52	6.7	12.0	9.2	3.3	12	1.0	55	16	.6
54	7.2	16.5	18	8.0	490	3.6	1,207	10	120
56	6.9	11.5	15	8.2	15	1.2	85	29	1.0
57	6.9	10.0	14	6.2	5.4	1.1	71	21	1.5
80	6.3	12.5	23	6.3	12	1.7	65	67	5.6
83	6.6	10.0	87	39	15	5.2	207	230	1.2
85	6.4	11.5	41	16	31	3.7	79	170	.8
86	3.5	10.0	230	110	290	13	0	1,900	1.0
88	6.3	11.0	47	16	140	3.3	219	330	1.6

Table 6.12-1.--Selected chemical characteristics of ground water in the study area--Continued

Site number	pH	Water temperature	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride
89	8.0	12.0	36	6.4	470	4.9	317	780	5.9
90	7.3	17.0	73	21	110	2.0	90	400	1.4
91	8.0	10.0	32	10	210	3.0	244	380	2.4
92	7.3	10.0	29	5.8	64	2.2	61	150	1.1
93	7.0	10.0	17	4.8	29	.9	106	21	1.2
94	7.6	15.0	15	4.0	820	5.7	805	1,000	10
95	7.0	13.0	65	11	48	4.8	90	210	3.3
96	7.1	13.0	32	6.4	20	2.4	79	80	.8
99	6.7	----	90	32	11	---	260	150	----
107	6.5	10.0	49	9.9	8.7	2.7	121	70	1.0
108	7.5	14.0	20	4.9	510	2.5	817	460	11
109	7.9	15.0	5.6	.5	260	4.5	427	160	5.6
116	7.9	17.0	88	43	67	8.2	134	380	3.8
121	6.6	14.0	35	15	1.3	3.3	44	140	9.6
123	6.4	12.5	20	6.5	21	1.9	45	76	8.8
124	6.3	12.0	19	7.3	16	2.1	29	72	6.2
125	6.4	10.5	50	18	22	4.8	74	180	1.4
128	6.9	11.5	74	17	26	3.2	207	150	1.6
130	7.1	12.0	39	13	91	2.5	219	190	1.0
131	6.9	7.0	48	12	7.1	3.1	71	120	.9
132	3.0	7.0	220	72	11	4.2	2	880	.4
134	6.6	11.5	71	9.8	31	3.6	305	32	1.3
136	4.3	11.0	92	49	8.3	1.9	0	460	.5
139	7.7	11.0	38	9.0	79	3.0	305	89	2.2
140	7.2	13.0	24	4.7	34	1.7	146	38	1.0
141	6.6	13.0	41	8.9	24	3.9	110	84	.8
142	6.8	11.0	40	11	13	1.6	101	88	.7
153	6.2	11.5	6.4	2.1	4.3	.8	30	1.5	3.5
154	6.6	11.5	12	2.0	7.3	.9	20	14	10
155	6.6	11.5	7.1	1.2	1.3	1.1	16	7.7	3.0
156	6.6	13.0	13	4.0	3.0	.8	42	10	1.0
157	6.7	12.0	13	3.9	2.9	.8	45	15	3.6
158	7.7	13.0	14	3.5	2.3	.7	47	14	2.4

root of the calcium-to-sodium activities for water that has been altered in this manner can be no less than 0.16. The relation between sodium activity and the ratio of the square root of the calcium-to-sodium activities for ground water samples described in table 6.12-1 is shown in figure 6.12-1.

As the sodium activity (and the sodium concentration) increases, the ratio of the square root of the calcium-to-sodium activity approaches 0.16, which, as previously noted, is the limiting ratio predicted by the above equation. Figure 6.12-1 indicates that ion exchange was the probable cause of anomalously high sodium concentrations in the study area and that, because the limit had not been reached, sodium concentrations higher than that measured in this study could occur in ground water in the study area. Thus, drainage from underground mines may contain anomalously high sodium concentration, but such high sodium concentration probably results from ion exchange, and not mining practices. In general, concentrations of sodium in ground water exceeding 100 mg/L were found only in Still Run and Milam Fork basins. Samples indicating the greatest degree of ion exchange (Ca:Na ratios were less than 1.0) were collected from mines. Water in shallow wells generally has a lesser degree of ion-exchange activity compared with water from deep mines, partly because of the lesser amount of contact time between water and minerals and because of a shallower depth of circulation.

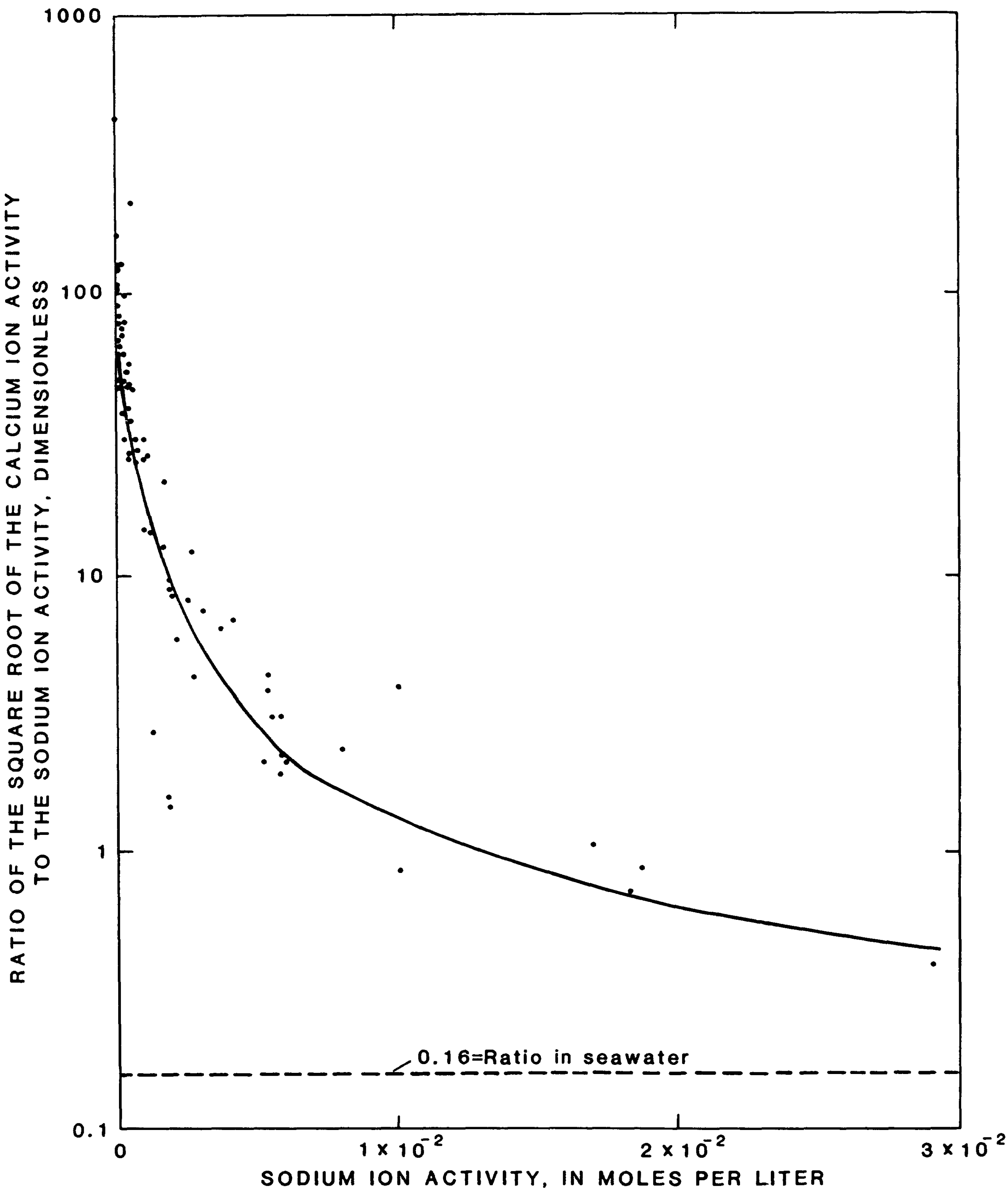


Figure 6.12-1.--Relation between sodium activity and the ratio of the square root of the calcium to sodium activities for ground water in the study area.

7.0 SUSPENDED SEDIMENT

7.1 Suspended-Sediment Load

MINED BASINS HAD THE LARGEST SUSPENDED-SEDIMENT LOAD

Still Run had a suspended-sediment load of 4,440 tons during the study period, while Allen Creek had 3,700 tons. Bearhole Fork had 2,020 tons, Milam Fork had an estimated 2,260 tons, and Marsh Fork had 1,530 tons. No correlation between suspended-sediment load and deep-mine coal production was apparent.

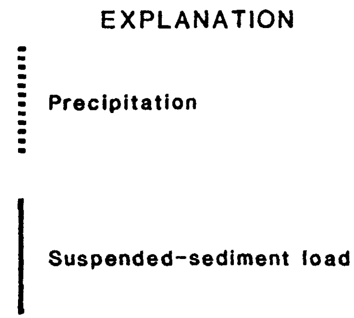
The two actively-mined basins in the study area had the greatest overall suspended-sediment load. Bearhole and Milam Forks, with some surface disturbance, were next, followed by Marsh Fork. Marsh Fork basin, which was used as a control basin, had little surface disturbance and was not as heavily populated as Bearhole and Milam Fork basins. Still Run was the least populated but had the greatest coal production during the study. (See secs. 2.4 and 2.5.) The suspended-sediment load discharged from each basin during the study period is shown in table 7.1-1. Monthly suspended-sediment load and precipitation in each basin are shown in figures 7.1-1 to 7.1-5.

No correlation exists between monthly deep-mined-coal production and monthly sediment load. This may be due, in part, to tailings produced in Still Run that are hauled out of the basin, and that most of the largest spoil pile in Allen Creek basin is downstream from the sampling site. A monthly correlation does exist, however, between precipitation and suspended-sediment load. (See figs. 7.1-1 and 7.1-2.) Two storms, one in January 1978, and the other in January 1979, occurred when the ground was frozen and covered with snow. These two storms produced sediment loads that accounted for 58 and 36 percent of the respective yearly load in Still Run basin, and 44 and 61 percent of the respective yearly load in Allen Creek basin. Within these small basins, most of the sediment load is discharged during several storms. The time of year does not seem to be significant.

Daily suspended-sediment samples were collected near the mouth of each stream. The Milam Fork sampling site was operated during storms only prior to January 1979. Sediment load for December 1978 to January 1979 was estimated by the sediment rating-curve method, as modified by Campbell and Bauder (Livesey, 1975). After late January 1979, this site was sampled daily because about 60 acres in the headwaters began to be cleared for surface mining. Mining in Milam Fork basin began in April 1979 and continued to the end of the project.

Table 7.1-1.--Suspended-sediment load in the study basins, December 1977 to December 1979

Basin	Drainage area, in square miles	Load, in tons
Still Run--------	7.12	4,440
Allen Creek------	8.43	3,700
Milam Fork-------	6.64	2,260
Bearhole Fork----	6.27	2,020
Marsh Fork-------	4.85	1,530



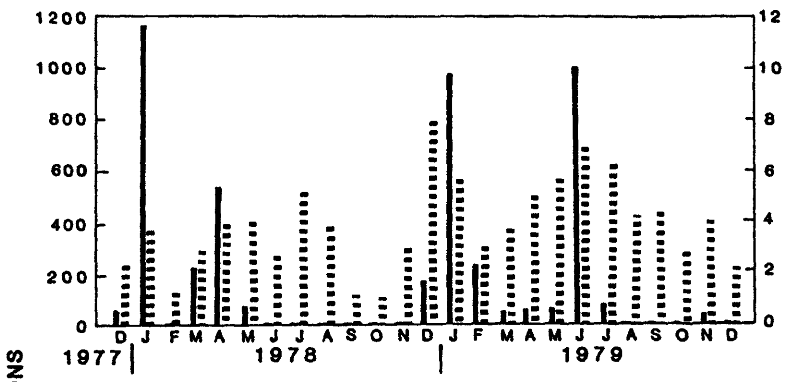


Figure 7.1-1.--Monthly suspended-sediment load and precipitation at Still Run (site 77).

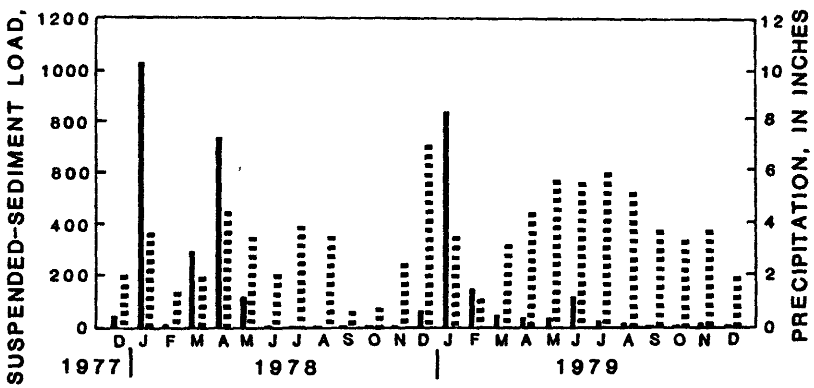


Figure 7.1-2.--Monthly suspended-sediment load and precipitation at Allen Creek (site 117).

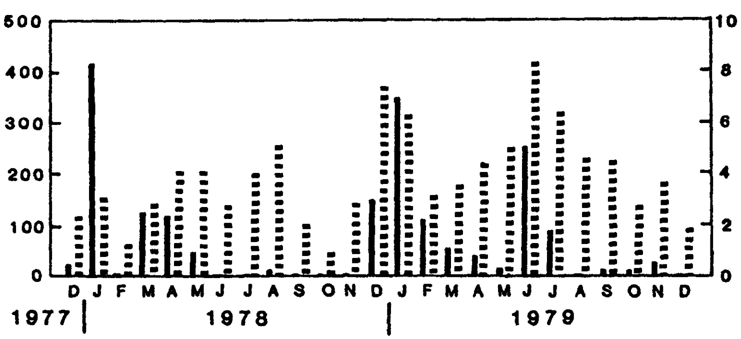


Figure 7.1-3.--Monthly suspended-sediment load and precipitation at Bearhole Fork (site 1).

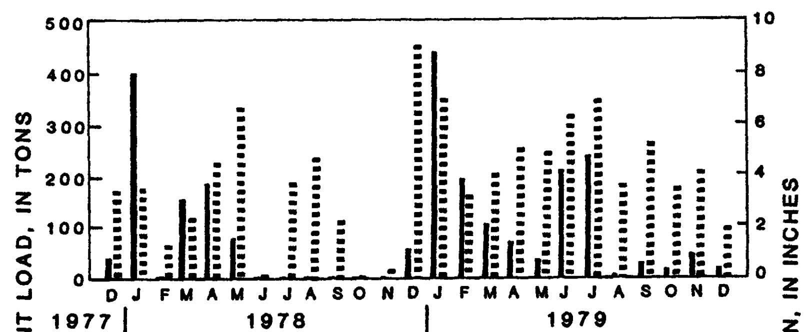


Figure 7.1-4.--Monthly suspended-sediment load and precipitation at Milam Fork (site 31)

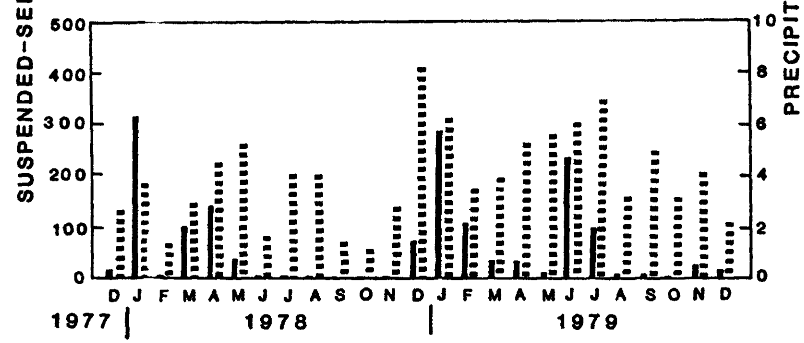


Figure 7.1-5.--Monthly suspended-sediment load and precipitation at Marsh Fork (site 60).

MINED BASINS HAD LARGEST SUSPENDED-SEDIMENT YIELD

The suspended-sediment yield from the two mined basins, Still Run and Allen Creek, was 310 and 210 tons/mi²/yr, respectively. Milam Fork, with only minor surface mining and Marsh Fork had yields of 170 and 160 tons/mi²/yr, respectively. Bearhole Fork had a yield of 150 tons/mi²/yr.

Still Run had the greatest average annual suspended-sediment yield, 310 tons/mi²/yr during the period December 1977 to December 1979 (fig. 7.2-1). Allen Creek had the second highest, 210 tons/mi²/yr (fig. 7.2-2). Still Run basin had 5.2 percent of its area disturbed by surface mining, and Allen Creek basin had 20.4 percent. Data from the West Virginia Department of Mines show that Still Run basin had no surface mining during the study but had about 58,200 tons of coal mined during 1974-77. Allen Creek basin had 16,000 tons of coal mined from surface operations during the study and 155,000 tons during 1969-79.

Suspended-sediment samples at the outflow site in Milam Fork basin were collected on a storm by storm basis from December 1977 to December 1978. From January 1979 to December 1979, suspended-sediment sampling was conducted on a daily basis. During the latter period, approximately 60 acres were surface mined, or 1.4 percent of the basin area. The basin's average annual suspended-sediment yield was estimated to be 170 tons/mi²/yr (fig. 7.2-3). Bearhole Fork basin had an average yield of 150 tons/mi²/yr (fig. 7.2-4). Marsh Fork, with almost no surface disturbance in the basin, had a yield of 160 tons/mi²/yr (fig. 7.2-5).

The differences in suspended-sediment yield between Milam Fork and Marsh Fork basins before Milam Fork was cleared for strip mining was only 2 percent (fig. 7.2-6). In July 1978, approximately 60 acres in Milam Fork basin were cleared. During the clearing but before the mining began in April 1979, the sediment yield of Milam Fork basin was 14 percent greater than that of Marsh Fork basin.

After completion of the sedimentation pond and the beginning of mining (April to December 1979), the sediment yield of Milam Fork basin was only 8 percent greater than that of Marsh Fork basin. The sedimentation pond probably caused the decrease in sediment yield in Milam Fork basin from April to December 1979.

Milam Fork was the only basin where the maximum monthly suspended-sediment yield did not occur during January 1978, it occurred in January 1979. The reason for this may be that the area to be surface mined had been cleared of trees and brush (fig. 7.2-6) prior to construction of sedimentation ponds. Allen Creek basin had 20.4 percent of its surface area mined, and thus would be expected to have a greater sediment yield than the other basins. However, because

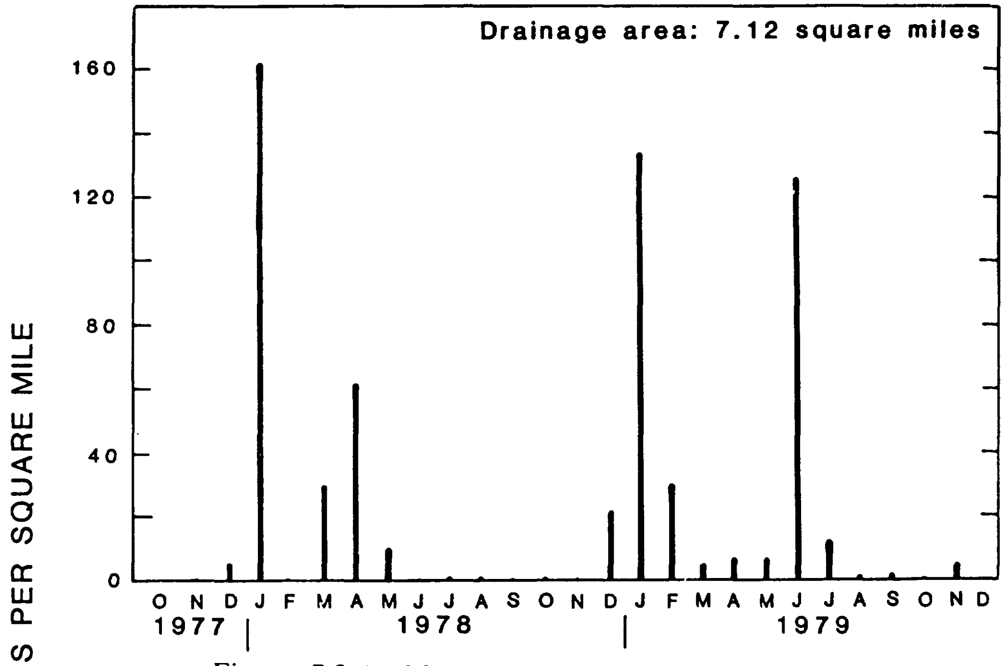


Figure 7.2-1.--Monthly suspended-sediment yield at Still Run (site 77).

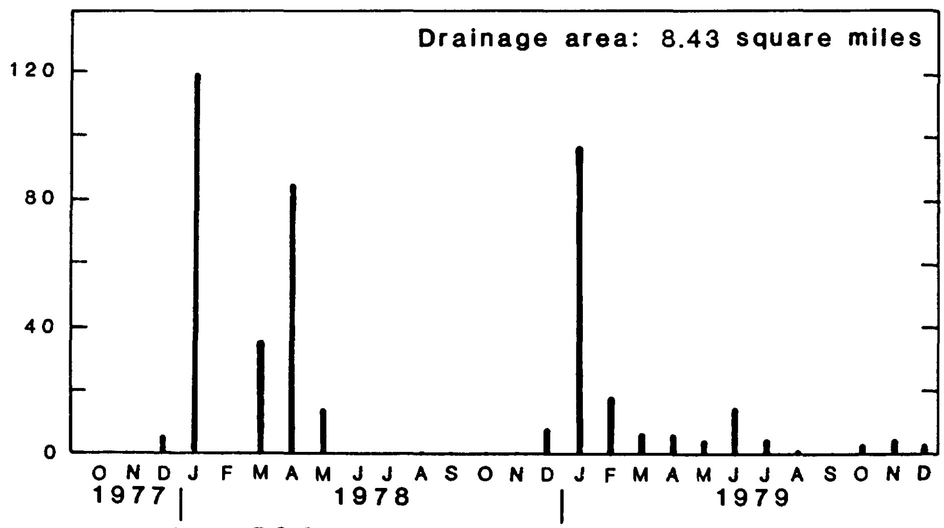


Figure 7.2-2.--Monthly suspended-sediment yield at Allen Creek (site 117).

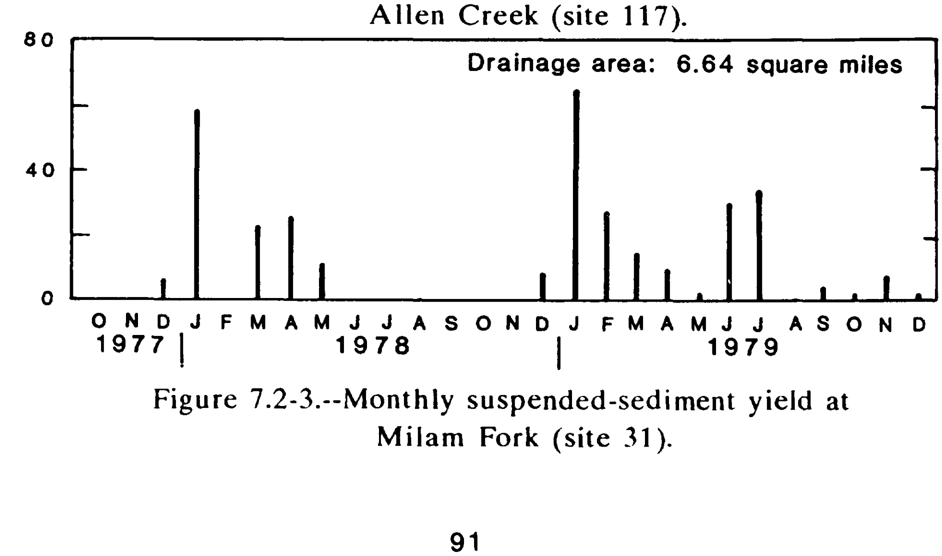


Figure 7.2-3.--Monthly suspended-sediment yield at Milam Fork (site 31).

because Allen Creek has less storm runoff than the other basins (sec. 5.2), its suspended-sediment yield was disproportionately low.

On November 22, 1977, and September 28, 1979, suspended-sediment samples were collected upstream from active mines and at the outflow gage site in Still Run basin. These samples indicated that the suspended-sediment yields at the upstream site were 0.47 and 0.05 ton/mi^2/d, respectively, compared to 2.1 and 0.25 ton/mi^2/d, respectively, at the basin outlet. This represents a fivefold increase in sediment yield between the sites.

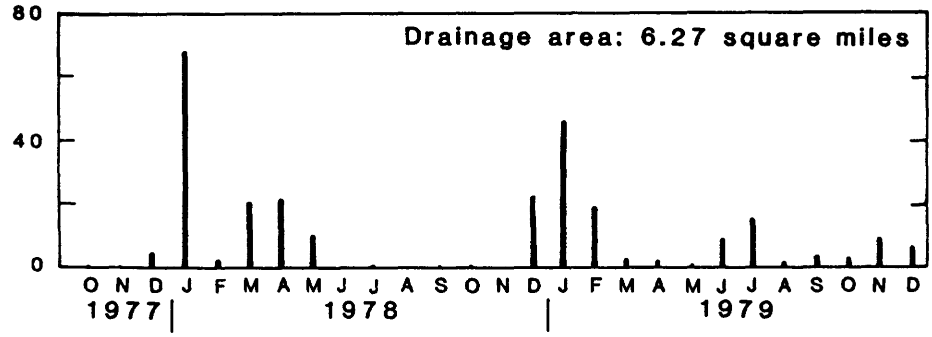


Figure 7.2-4.--Monthly suspended-sediment yield at Bearhole Fork (site 1).

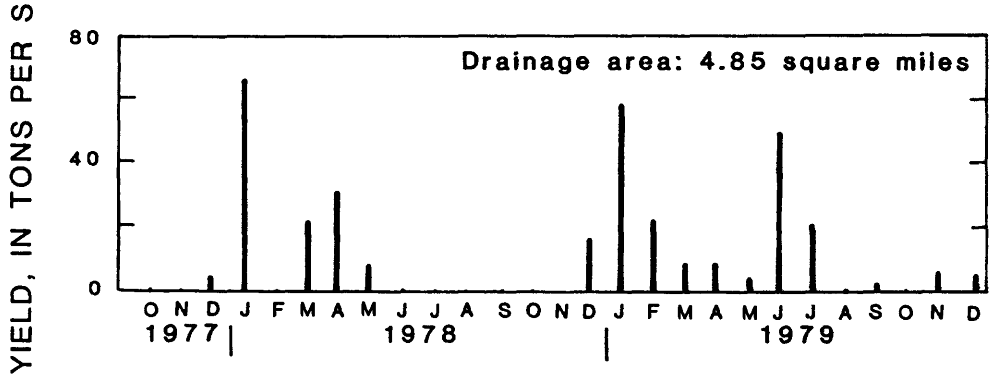


Figure 7.2-5.--Monthly suspended-sediment yield at Marsh Fork (site 60).

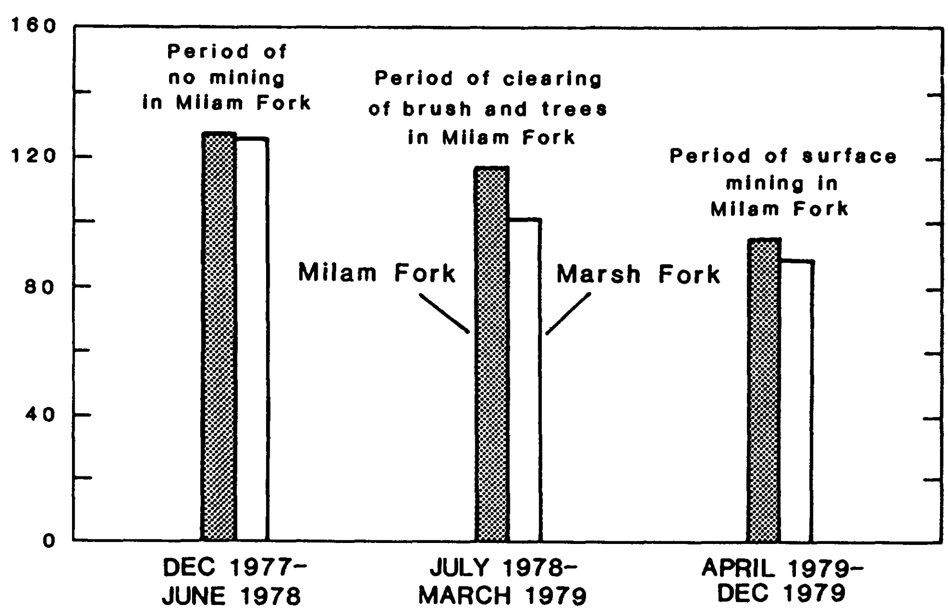


Figure 7.2-6.--Suspended-sediment yield for selected time periods at Marsh Fork and Milam Fork basins.

7.3 Silt and Clay Content

SILT AND CLAY CONTENT OF SUSPENDED SEDIMENT GREATEST IN BASINS WHOSE SURFACE WAS MOST RECENTLY DISTURBED

The silt and clay content of suspended sediment at outflow sites in Still Run, Allen Creek, and Bearhole Fork basins were 82, 91, and 96 percent, respectively.

Surface mining ceased in Still Run basin in 1976 and in Allen Creek basin in 1978, although subsurface mining continued throughout the study. Bearhole Fork had no surface mining but was disturbed by road and building construction, small logging operations, and sandstone quarry operations throughout the study.

Although the unmined basins had lower suspended-sediment yields (sec. 7.2) than the mined basins, the suspended sediment at the outflow site in Bearhole Fork basin had the greatest percentage of silt- and clay-sized particles. (See fig. 7.3-1.) Its surface was the most recently disturbed of the basins. Most of the land disturbances in Bearhole Fork basin affected the topsoil layers, which are primarily composed of small silt and clay particles that can be transported over great distances in streams and can remain suspended in water for long periods of time. These small particles of suspended sediment cause turbidity in the streams, which reduces the sunlight and decreases the oxygen that is available to aquatic life, and thus, may destroy the habitat of many forms of aquatic life.

The suspended sediment in mined basins had a greater percentage of sand-sized particles than did suspended sediment in the unmined basins (fig. 7.3-1). Sandstone exposed during surface mining is decomposed by weathering, thus, releasing sand-sized particles to streams in the mined basins. These findings are similar to those of Collier and others, 1970.

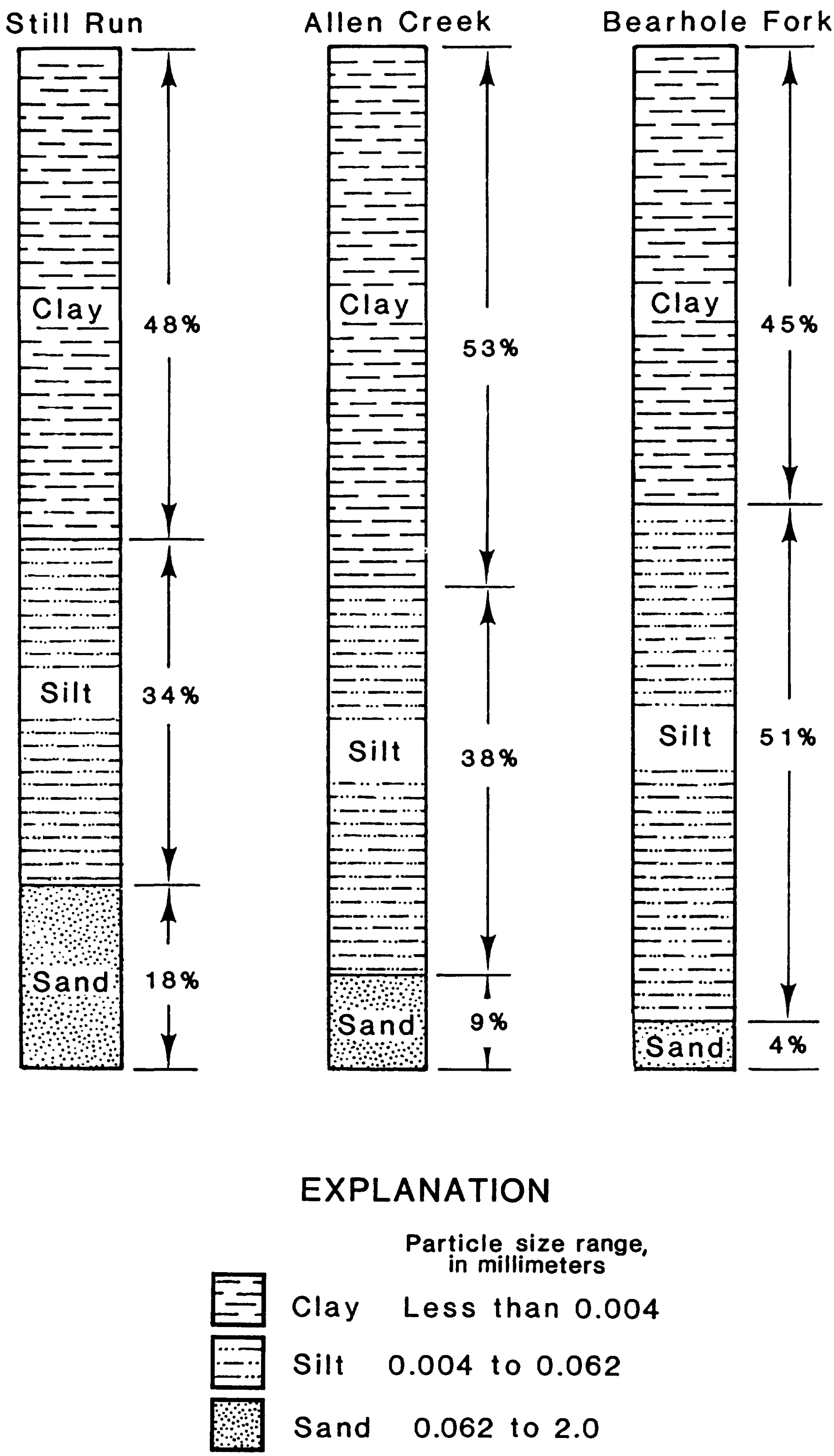


Figure 7.3-1.--Particle-size range of suspended sediment in Still Run, Allen Creek, and Bearhole Fork basins.

GENERA OF BENTHIC INVERTEBRATES GENERALLY GREATEST IN UNMINED BASIN

Marsh Fork basin generally had the greatest number of genera of benthic invertebrates, followed by Bearhole Fork, Still Run, and Allen Creek basins.

In general, the greatest numbers of genera of benthic invertebrates were found in the unmined basins. Marsh Fork, which is completely unmined, usually had the greatest number of genera. Bearhole Fork, which is predominantly unmined, had the next highest number of genera. The mined basins, Still Run and Allen Creek, generally had fewer numbers of genera.

Benthic invertebrate samples were collected along a 100-foot reach of stream at each sampling site by two people for a 45-minute period. An effort was made to sample at least three ponds and three riffles at each site. Because the purpose of the sampling was to evaluate the total benthic environment rather than any specific habitat, riffles, ponds, loose rocks, sand, permanent streambed, and leaf debris were examined for organisms.

The different genera found in basins are shown in table 8.0-1. An asterisk (*) indicates a genera that has 10 percent or more of the total population. Samples were collected in July 1977 and September 1978 from headwaters and at the gaging sites on Marsh Fork, Still Run, and Bearhole Fork basins. Allen Creek basin was sampled only in September 1978. The headwaters of Allen Creek were not sampled because of inaccessibility.

One hundred eighteen organisms were found in the Marsh Fork basin headwaters, representing 14 genera, during July 1977 sampling (table 8.0-1). Diptera were dominant in the sampling with the genus Psectrotanypus (Midge), which has a low tolerance to turbidity (Roback in Hart and Fuller, 1974), in abundance. Ninety-five organisms were found at the gage site, with 25 genera represented on the same sampling date. Ephemeroptera were dominant in the sampling, and the genus Stenonema (mayfly), which also has a low tolerance to turbidity, was the most abundant.

Sixty-three organisms, representing 10 genera, were counted at the Marsh Fork headwaters sampling site during the September 1978 sampling period. Trichoptera were dominant in the sampling with the genus Hydropsyche (caddisfly), which has a low tolerance to turbidity and sediment (Gammon, 1968), in abundance. Forty-nine organisms were counted at the gage site, representing eight genera on the same sampling date. Trichoptera were dominant in the sampling with the genera Cheumatopsyche and Hydropsyche abundant. Both are caddisflies and have low tolerance to sediment (Gammon, 1968).

Still Run basin headwaters sampling site had a count of 157 organisms, representing 22 genera for the July 1977 sampling. (See table 8.0-1.) Trichoptera were dominant in the sampling with the genera Cheumatopsyche and Hydropsyche in abundance. Both are caddisflies with a low tolerance to sediment (Gammon, 1968) Ninety-three organisms were counted at the gage site, representing 15 genera, for the same date. Trichoptera were dominant in the sampling with the genus Hydropsyche (caddisfly), which prefers low turbidity and sulfate concentrations, abundant. This genus is not tolerant of high turbidity or sediment but is found in the basin with the highest sediment load. One explanation for this may be that the large yields of sediment occurred during short time periods, after which the caddisflies recovered. Still Run basin headwaters had no organisms reported during the September 1978 sampling, possibly because they hatched or because the site had little, if any, measurable flow. Fifty-nine organisms, representing six genera, were counted at the gage site on the same date. Basommatophora were dominant in the sampling, the genus Physa (pond snail), which thrives in a pH range of 6.7 to 8.5 and a calcium-rich aquatic environment with a moderate amount of vegetation (Penneck, 1953), was abundant (table 8.0-1.)

Bearhole Fork basin headwaters sampling site had a count of 72 organisms with 26 genera represented during the July 1977 sampling. Diptera were dominant in the sampling with the genus Harnischia (midge), which has a low tolerance to turbidity, high sulfate, and low dissolved oxygen, abundant. Ninety-eight organisms, representing 13 genera, were found at the gage site on the same date. Trichoptera were dominant in the sampling with the genus Cheumatopsyche (caddisfly), which has a low tolerance to sediment, abundant.

Only one organism, Ephemerella (mayfly), was found at the Bearhole Fork headwaters sampling site in September 1978. Eighty-six organisms, representing 10 genera, were found at the gage site. Ephemeroptera were dominant at this site with the genus Stenacron (mayfly), abundant.

Allen Creek basin was only sampled in September 1978. Ninety-one organisms, representing seven genera, were found at the gage sampling site. Like Still Run, Trichoptera were dominant in the sampling with the genus Hydropsyche (caddisfly), abundant.

Table 8.0-1.--List of benthic invertebrates at sites in the study basins

[X, indicates occurrence of genus; *, indicates a genera that contains 10 percent or more of the total population of organisms]

Benthic invertebrates	Marsh Fork Basin				Bearhole Fork Basin				Still Run Basin				Allen Creek Basin
	Headwater site		Gage site		Headwater site		Gage site		Headwater site		Gage site		Gage site
	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	Sept. 1978
Coleoptera													
Ancyronyx	--	--	--	--	X	--	--	--	--	--	--	--	--
Donacia	--	--	X	--	--	--	--	--	--	--	--	--	--
Dubiraphia	--	--	--	--	X	--	--	--	--	--	X	--	--
Ectopria	X	--	--	--	--	--	--	--	--	--	--	--	--
Gyrinus	--	--	--	--	--	--	--	--	--	--	--	--	--
Helichus	--	--	--	--	X	--	--	--	--	--	--	--	--
Helophorus	--	--	--	--	X	--	--	--	X	--	--	--	--
Laccobius	--	--	--	--	--	--	--	--	--	--	X	--	--
Psephenus	--	--	X	--	--	--	--	--	--	--	--	--	--
Optioservus	--	--	--	--	X	--	--	--	--	--	--	--	--
Diptera													
Antocha	--	--	X	--	--	--	--	--	X	--	--	--	--
Atherix	--	--	X	--	--	--	X	--	--	--	X	--	--
Atrichopogon	--	--	X	--	--	--	--	--	--	--	--	--	--
Chironomus	--	--	--	--	X	--	--	--	--	--	--	--	--
Cladotanytarsus	--	--	X	--	--	--	--	--	--	--	--	--	--
Conchapelopia	--	--	--	--	X	--	--	--	X	--	--	--	X
~~Corynoneurs~~	X	--	--	--	X	--	--	--	--	--	--	--	--
Cricotopus	X	--	X	--	X	--	--	--	X	--	--	--	X
Dicranota	--	--	--	--	--	--	X	X	--	--	--	--	--
Dixa	--	X	--	--	--	--	--	--	--	--	--	--	--
Eukiefferiella	X	--	--	--	--	--	--	--	--	--	--	--	--
Harnischia	--	--	--	--	*	--	--	--	--	--	--	--	--
Hemerodromia	--	--	--	--	--	--	--	--	--	--	X	--	--
Pentaneura	--	--	X	--	--	--	--	--	--	--	--	--	--
Polypedilum	--	--	--	--	--	--	--	--	X	--	--	--	--
Psectrotanypus	*	--	--	--	--	--	--	--	--	--	--	--	--
Tanytarsus	--	--	--	--	X	--	--	--	--	--	--	--	--
Tipula	--	--	--	--	--	--	--	--	--	--	--	X	--
Unknown Genus	X	--	--	--	--	--	--	--	--	--	--	--	--

Ephemeroptera													
Ameletus	--	--	X	--	--	--	--	--	--	--	X	--	X
Baetis	--	--	X	--	X	--	X	--	*	--	X	--	--
Epeorus	--	--	--	--	--	--	--	--	--	--	X	--	--
Ephemerella	X	--	--	--	X	X	--	--	--	--	--	--	--
Heptagenia	--	--	X	--	--	--	--	--	X	--	--	--	--
Isonychia	--	--	X	--	--	--	X	--	--	--	X	--	--
Leptophelebia	--	--	--	X	--	--	--	--	--	--	--	--	--
Litobrancha	X	--	--	--	--	--	--	--	--	--	--	X	--
Paraleptophlebia	*	--	--	--	--	--	--	--	X	--	--	--	--
Pseudocloeon	--	--	--	--	--	--	X	--	--	--	--	--	--
Siphlonurus	--	--	--	--	--	--	--	X	--	--	--	--	--
Stenacron	--	--	--	--	--	--	--	*	--	--	--	--	--
Stenonema	--	X	*	X	--	--	X	--	X	--	X	--	X
Unknown Genera	--	--	X	--	--	--	--	--	--	--	--	--	--
Hemiptera													
Gerridae (family)	X	--	--	--	--	--	--	--	--	--	--	--	--
Gerris	--	*	X	X	X	--	X	X	X	--	X	--	--
Hesperocorixa	--	--	--	--	X	--	--	--	--	--	--	--	--
Rhagovelia	--	X	--	X	X	--	--	X	--	--	--	--	--
Trepobates	--	--	X	--	--	--	--	--	--	--	--	--	--
Odonata													
Aeshna	--	--	X	--	--	--	--	--	--	--	--	--	--
Agrion	--	X	--	--	--	--	--	X	--	--	X	--	--
Boyeria	--	--	--	--	--	--	--	--	X	--	--	X	--
Calopleryx	--	--	X	--	X	--	X	--	--	--	X	--	--
Cordulegaster	--	--	--	--	X	--	--	--	--	--	--	--	--
Dromogomphu	--	--	--	--	X	--	--	--	--	--	--	--	--
Octogomphus	X	--	--	--	--	--	--	--	--	--	--	--	--
Plecoptera													
Acroneuria	X	X	--	--	--	--	X	X	--	--	--	--	--
Allocapnia	--	--	--	--	--	--	--	--	X	--	--	--	--
Leuctra	--	--	X	--	--	--	--	--	--	--	--	--	--
(Neo) Phasganophora	--	X	--	--	--	--	--	--	--	--	--	--	--
Trichoptera													
Cheumatopsyche	--	--	X	*	X	--	X	--	X	--	X	--	--
Glossosoma	--	--	--	--	--	--	--	--	X	--	--	--	--
Hydropsyche	--	*	*	*	--	--	X	*	*	--	*	X	*
Microsema	--	--	--	--	--	--	--	--	X	--	--	--	--
Pycnopsyche	--	--	--	--	--	--	--	--	X	--	--	--	--
Rhyacophila	--	--	--	--	--	--	--	--	X	--	--	--	--
Megalopterans													
Chauliodes	--	X	--	--	--	--	--	--	--	--	--	--	--
Corydalus	--	--	X	--	--	--	X	--	--	--	--	--	--
Nigronia	--	--	X	--	X	--	--	X	X	--	--	--	--

Table 8.0-1.--List of benthic invertebrates at sites in the study basins--Continued

Benthic invertebrates	Marsh Fork Basin				Bearhole Fork Basin				Still Run Basin				Allen Creek Basin
	Headwater site		Gage site		Headwater site		Gage site		Headwater site		Gage site		Gage site
	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	July 1977	Sept. 1978	Sept. 1978
Araneida													
Dolomedes	--	--	--	--	X	--	--	--	X	--	--	--	--
Nematoda													
Unknown family	--	--	X	--	--	--	--	--	--	--	--	--	--
Basommatophora													
Gyraulus	--	--	--	--	X	--	--	--	--	--	--	--	--
Physa	--	--	--	--	--	--	--	--	--	--	--	*	X
Oligochaeta													
Branchiobdellidae (family)	--	--	--	--	X	--	--	--	--	--	--	--	--
Unknown genus	--	--	--	--	X	--	--	--	--	--	--	--	--
Isopoda													
Lirceus	--	--	--	*	--	--	--	--	--	--	--	--	--
Decapoda													
Astacidae (family)	--	--	--	--	X	--	--	--	--	--	--	--	--
Cambarus	X	X	--	*	--	--	--	*	X	--	--	*	X
Orconectes	--	--	X	--	--	--	X	--	--	--	X	--	--
Prospora													
Branchiobdellidae	--	--	--	--	--	--	--	--	X	--	--	--	--
Pterodrilus	X	--	--	--	--	--	--	--	--	--	--	--	--
Number of Genera------	14	10	25	8	26	1	13	10	22	0	15	6	7

9.0 SUMMARY AND CONCLUSIONS

HYDROLOGIC CHARACTERISTICS OF MINED BASINS DIFFER FROM UNMINED BASINS

The effects of mining on ground water depend on the hydraulic connection of the mine to a system of stress-relief fractures that control the natural flow and occurrence of ground water in the study area. Streams draining areas that have been both surface-mined and deep-mined have reduced high flows and increased low flows. Water discharge from mines contributes significantly to the flow and to the higher chemical load of streams in mined basins. Concentrations of sodium, sulfate, and bicarbonate; sodium-calcium ratio; and specific conductance were significantly elevated in ground water in wells located near deep mines.

The effects of surface and deep coal mining on the hydrology of small stream basins in southern West Virginia were determined by comparing data collected in unmined areas with that collected in mined areas.

Most of the sedimentary rocks in the study area and throughout much of the Appalachian Plateaus have negligible primary permeability. Valley-bottom and hillside stress-relief fractures may be the dominant controls on the natural flow and occurrence of ground water in the study area and in much of the Appalachian coal-producing regions. The most productive water wells in the study area are located on valley bottoms. Ground water enters these wells through bedding-plane separations and shear fractures. Deep mines were surprisingly dry, except where hillside mine entries intersected valley-wall fractures that transmit infiltrating precipitation, and where mines passed beneath valley floors and encountered water-bearing stress-relief fractures.

The ground-water flow system in a mined basin can be extremely complex, as in the Allen Creek basin, where water from a flooded deep mine is: (1) pumped for domestic supply, (2) pumped for use in a stratigraphically higher mine, and (3) pumped and drained into both Allen Creek and a stream in an adjacent basin. It is nearly impossible to quantify the interactions between the natural fractured-rock aquifer, and surface and deep coal mines.

Standard quantitative techniques cannot be used to analyze aquifer-test data because the basic required conditions do not exist in this fractured rock area. But, aquifer difussivity was calculated from base-runoff recession curves for the unmined basins and ranged from 47,000 to 36,000 ft^2/d for Marsh Fork and Bearhole Fork, respectively. Aquifer diffusivity values were not calculated for mined basins because mine-discharge water is pumped or allowed to drain through settling ponds into streams. Thus, measured streamflow cannot be assumed to equal natural ground-water discharge as required by most analytical equations. Runoff from individual storms was much less in the mined basins, as were the peak stream discharges for individual storms. Streams in mined basins had fewer days with high flows and low flows than streams in unmined basins.

Water pumped or drained into streams from deep mines comprised a significant percentage of streamflow--14 percent in Still Run and 34 percent in Allen Creek during the period October 20-27, 1979. At median streamflow conditions and with all known mine pumps operating, the maximum potential mine discharge would contribute about 80 percent of the streamflow in Still Run and about 50 percent of the streamflow in Allen Creek. During the low-flow period, September 15-17, 1979, one mine pump in the Still Run basin increased the streamflow 2.5 times the normal baseflow of 1 ft^3/s.

Infiltration rates increased in the mined basins by fracturing associated with deep mining. The collapse of underground mines causes fracture systems in overlying beds of rock. Water that would normally run off as streamflow infiltrates down through cracks and fractures into deep mines. The net effect is to decrease or delay storm runoff.

Storage has been affected by both deep mines and surface mines. Deep mines provide large areas for the storage of infiltrating water. Surface mines also increase storage by ponding water on strip benches and by providing storage in reclaimed areas and spoil piles. Such increased storage either decreases the amount of surface runoff or delays the runoff of precipitation in the mined basins.

Interbasin transfer of water occurs in two ways in the deep mined stream basins. Water may be pumped or may freely drain into a stream from mines located partially or wholly outside a stream basin. Conversely, water may be pumped or drain from mines within a basin to streams outside the basin. In the study area, the latter situation occurs more commonly than the former and contributes to the slightly lower measureable runoff in Allen Creek basin.

Because the study basins were both deep mined and surface mined, the separate effects of each type of mining could not be determined. However, streamflow data collected over the 2-year study period does not support the frequently stated theory that strip mining causes increased peak flows.

Pumped and freely draining deep mines contributed significant quantities of highly mineralized water to streams in the mined basins. Streams in the actively mined basins, Allen Creek and Still Run, contained two to four times the mean concentrations of calcium, magnesium, potassium, sodium, sulfate, and bicarbonate than in the predominantly unmined Marsh Fork and Bearhole Fork. Milam Fork basin, which was partially deep mined, but had no mine discharges, entries, or refuse piles within the basin, in many respects had surface-water chemical characteristics similar to the predominantly unmined basins. The mean specific conductance of surface water in the actively mined Allen Creek and Still Run basins was 410 and 260 µmho/cm, respectively. These values were considerably higher than those for surface water in Milam

Fork (133 µmho/cm), which contains abandoned mines, and for Marsh Fork and Bearhole Fork (109 and 87 µmho/cm, respectively), which are predominantly unmined. The mean dissolved-solids concentration and the yield of dissolved solids were considerably higher in the basins containing active and abandoned mines. The pH of surface water in the mined basins was higher than in the unmined basins, probably because of the large quantities of limestone dust used to coat mine interiors in order to reduce the risk of coal dust explosions. Mine discharge from active mines had higher pH values than did water draining from much older abandoned mines, where limestone dust, if applied, may have been dissolved at an earlier date.

Mean dissolved iron concentrations were similar for surface water in mined and unmined basins, probably because dissolved iron quickly precipitates in the oxidizing environment of surface water. Dissolved manganese concentration was considerably higher in surface water of the mined basins, possibly because the manganous ion (Mn^{+2}) forms stable complexes with the bicarbonate and sulfate contained in mine discharge.

Trace element concentrations were higher in mine water and were particularly high in low pH drainage from older abandoned mines.

Sulfate, sodium, and bicarbonate concentrations; sodium-calcium ratio; and specific conductance were significantly higher in ground water in wells located within 0.5 mi of underground and surface mines than those located farther away. Anomalous occurrences of sodium-bicarbonate water type in ground water and mine discharge are probably the result of ion-exchange processes.

During the period, November 1977 through December 1979, the actively mined basins, Still Run and Allen Creek, discharged the greatest suspended-sediment load of the study basins (4,440 and 3,700 tons, respectively). Milam Fork, with a very small surface mine starting near the end of the study, had a load of 2,260 tons. Suspended-sediment load from Bearhole Fork, with some surface disturbance unrelated to mining, was 2,020 tons. Marsh Fork, completely unmined, had the lowest suspended-sediment load, 1,530 tons during the study period.

The suspended-sediment yield of 310 tons/mi²/yr of drainage area was highest in Still Run basin which had 5.2 percent of its surface area disturbed by surface mining. Allen Creek, with some surface mining prior to and during the study, had a yield of 210 tons/mi²/yr. The predominantly undisturbed Milam Fork basin had a yield of 170 tons/mi²/yr and Marsh Fork, considered a control basin, had a yield of 160 tons/mi²/yr. Bearhole Fork basin had a yield of 150 tons/mi²/yr. The daily suspended-sediment yield at the mouth of Still Run was five times greater than the yield upstream from coal mines in the basin during two separate storms.

The silt and clay fraction of suspended sediment was greatest in the basin whose surface was most recently disturbed and was not necessarily related to mining activities.

Generally, the greater number of genera of benthic invertebrates was found in the unmined basins.

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GLOSSARY

Acidity--The capacity of an aqueous medium to react with hydroxyl ions, expressed in milligrams per liter as hydrogen ion (H^+) for this report. Acidity may also be expressed in milligrams per liter as calcium carbonate by multiplying the results in milligrams per liter as H^+ by 50.05.

Alkalinity--The ability of water to resist pH change caused by addition of a strong acid--a measure of the buffering capacity of water. The alkalinity of a solution is due to the presence of hydroxyl, carbonate, and bicarbonate ions and for this report is expressed in milligrams per liter as calcium carbonate.

Anion--A negatively charged ion.

ANOVA--An analysis of variance test, a parametric statistical procedure, which is a comparison of the variances associated with two or more probability distributions.

Anticline--A fold that is convex upward, with older rocks exposed toward the axis of the fold.

Aquifer--A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Aquifer, confined--An aquifer which is confined between less permeable materials. The water level in a well tapping a confined aquifer will rise above the top of the aquifer because of hydrostatic pressure.

Aquifer, unconfined--An aquifer, in which the upper surface, the water table, is exposed to atmospheric pressure.

Base flow--The discharge into a stream channel from a ground-water source. Sustained or fair-weather stream discharge.

Bedding plane--Any plane in sedimentary rock, along which sediment was deposited simultaneously.

Benthic invertebrate--For this study, an animal without a backbone that lives within or near the bottom of an aquatic environment and that is retained on a 210-micrometer mesh sieve.

Bituminous coal--A coal which ranks below anthracite, containing about 80 percent carbon and 10 percent oxygen.

Cation--A positively charged ion.

Cone of depression--The depression in the water table or potentiometric surface caused by the withdrawal of water from a well.

Coefficient of determination (r^2)--In linear regression, the square of the correlation coefficient. The coefficient of determination times 100 is the percentage of the variation of the dependent variable explained by variation of the independent variable.

Correlation coefficient (r)--A measure of the degree of association of one variable with another.

Cubic foot per second (ft^3/s)--The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is equivalent to approximately 7.48 gal/s, or 448.8 gal/min, or 0.02832 m^3/s.

Dewatering--In this report, refers to the removal of ground water from a coal seam, overburden, and adjacent rocks by deep- or surface-coal mining activities.

Diffusivity--The ratio of an aquifer's transmissivity, T, to its storage coefficient, S, and is expressed in units of feet squared per day (ft^2/d).

Dip of rock strata--The angle between the horizontal and the bedding plane, dip is measured in a vertical plane at right angles to the strike of the bedding. (See strike of rock strata.)

Discharge--The volume of water (or more correctly, volume of water plus suspended sediment) that passes a given point of a stream within a given period of time.

Instantaneous discharge--The discharge at a particular instant in time.

Mean discharge--The arithmetic mean of individual discharges during a specific period of time.

Peak discharge--The highest discharge of a flood or storm.

Median peak discharge--The median of several peak discharges at a particular stream site within a basin.

Mean peak discharge--The mean of several peak discharges at a particular stream site within a basin.

Unit peak discharge--The highest discharge of a flood or storm per unit of drainage area.

Median unit peak discharge--The median of several unit peak discharges.

Mean unit peak discharge--The mean of several unit peak discharges.

Dissolved--That material in a representative water sample which passes through a 0.45-micrometer membrane filter. This may include some very small (colloidal) suspended particles as well as the amount of substance present in true chemical solution. Determinations of "dissolved" constituents are made on samples of filtered water.

Dissolved solids--The weight of residue resulting from the evaporation of a water sample at 180°C (degrees Celsius), and is expressed in milligrams per liter. It is also referred to as residue on evaporation at 180°C or total dissolved solids. The dissolved solids concentration may be related to the specific conductance and to other chemical characteristics of a water sample.

Diversity index--A nondimensional value relating the numbers of individuals of all species present to the number of species present at a site.

Drainage area--That area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream, upstream of a specified point. The area of a drainage basin or watershed, expressed in square miles, acres, or other unit of area.

Drainage basin--A part of the surface of the Earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drawdown in a well--The vertical drop in water level in a well caused by pumping.

Drift mine--A horizontal or nearly horizontal mine passage underground that is entered from the surface outcrop of a coal bed.

Drift mine, above drainage--Mine workings are above the elevation of area drainage features (streams), and mine entrances are above stream elevation and at coal seam outcrops.

Drift mine, below drainage--Mine workings pass beneath streams, but mine entrances are above stream elevation and at coal seam outcrops.

Duncans Multiple Range Test--A statistical procedure which compares the means of different groups to determine if they are significantly different from each other at a specified significance level.

Ephemeral stream--A stream which flows only in direct response to precipitation, and whose channel is at all times above the water table.

Evapotranspiration--Water loss from a land area by evaporation from water surfaces and moist soil, and by plant transpiration, the loss of water from leaf and stem tissues of growing vegetation.

Fault--A fracture in the Earth's crust accompanied by displacement of one side of the fracture with respect to the other.

Fracture--A break in rock that may be caused by compressional or tensional forces.

Gaging station--A particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained. When used in connection with a discharge record, the term is applied only to those gaging stations where a continuous record of discharge is computed.

Gain-and-loss measurements--Flow measurements made at various points along a stream to determine if the stream is losing or gaining water.

Gaining stream--A stream, or segment of a stream that receives water from an aquifer. (See losing stream.)

Gob or spoil--The refuse or waste rock material displaced by mining.

Gradient, hydraulic--The change of pressure head per unit distance from one point to another in an aquifer.

Ground water--Water contained in the zone of saturation in the rock. (See surface water.)

Head--Pressure, expressed as the height of a column of water that can be supported by the pressure.

High wall--The exposed vertical or near-vertical rock wall associated with a strip mine or other surface mine.

Hydrograph--A graph showing discharge, water level, or other property of water with respect to time.

Ion--An atom, group of atoms, or molecule that has acquired a net electrical charge.

Joints--System of fractures in rocks along which there has been no movement parallel to the fracture surface. In coal, joints and fractures may be termed "cleats."

Kruskal-Wallis Test--The nonparametric equivalent of the parametric analysis of variance test, which is performed on ranked data. The test provides an estimate of the probability that the data originate from the same or from different population distributions.

Lineaments--Linear features on aerial photographs or imagery formed by the alignment of stream channels or tonal features in soil, vegetation, or topography.

Lithology--The physical character of a rock, expressed in terms of its color, structure, composition and texture, determined by observation with the unaided eye or with the aid of a low-power magnifier.

Load--The amount of material, whether dissolved, suspended, or on the bed, which is moved and transported by a flowing stream past a point in a given period of time such as a day, month, or year.

Losing stream--A stream, or segment of a stream that is contributing water to an underlying aquifer. (See gaining stream.)

Median--The value X such that it falls in the middle of the array of N values when they have been ordered from the least numerical value to the greatest value.

Micrograms per liter (µg/L)--A unit expressing the concentration of chemical constituents in solution as mass (micrograms) of solute per unit volume (liter) of solution. One thousand micrograms per liter is equivalent to one milligram per liter (mg/L).

Micromho (µmho)--One-millionth of a mho, which is the practical unit of specific conductance equal to the reciprocal of the ohm.

Milligrams per liter (mg/L)--A unit for expressing the concentration of chemical constituents in solution. Milligrams per liter represent the mass of solute per unit volume (liter) of solution. Concentration of suspended sediment also is expressed in mg/L, and is based on the mass of sediment per liter of water-sediment mixture.

Orogeny--The process of mountain formation.

Overburden--Rock and soil overlying a minable coal bed.

Oxidation--The removal of one or more electrons from an element or ion, thus, increasing its positive charge or decreasing its negative charge.

Perched water table--A saturated zone of rock separated from an underlying body of ground water by unsaturated, relatively impermeable rock.

Permeability, primary--Permeability due to interstices that were created at the time the rocks were formed.

Permeability, secondary--Permeability due to cracks, fractures, joints, faults, solution openings or other fractures that formed after the rock consolidated.

Permeability, intrinsic--A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Perennial stream--A stream which flows continuously.

pH--A measure of the hydrogen ion (H^+) activity in water and is expressed as the negative base 10 logarithm of the hydrogen ion activity in moles (M) per liter. The pH can have any value from 0 to 14. Values less than 7 are acidic and values greater than 7 are alkaline. A solution with a pH of 7 is considered neutral.

Potentiometric surface--An imaginary surface that everywhere coincides with the static level of water in the aquifer.

Precipitation, atmospheric--Water in the form of hail, mist, rain, sleet, or snow that falls to the Earth's surface.

Recovery of pumped well--The rise of the water level in a well when pumping from the aquifer that is tapped by the well ceases.

Recharge--The process by which water is added to an aquifer. Recharge is also the quantity of water that is added to the aquifer.

Recurrence interval--(1) The average time interval between actual occurrences of a hydrologic event of a given or greater magnitude, (2) in an annual flood series, the average interval in which a flood of a given size recurs as an annual maximum, and (3) in partial duration series, the average interval between floods of a given size, regardless of their relation to the year or any other part of time.

Reduction--The addition of one or more electrons to an element or ion, thus, reducing its positive charge or increasing its negative charge.

Runoff--That part of the precipitation that appears in surface streams.

Sediment--Solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water. It includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity and characteristics of sediment in streams are influenced by factors such as degree of land slope, length of slope, soil characteristics, land use, and quantity and intensity of precipitation.

Sedimentary rock--Rock formed by the accumulation of sediment in water or from the air. The sediment may consist of rock fragments of various sizes, of the remains or products of animals and plants, of the product of chemical action or evaporation, or a mixture of these materials.

Shaft mine--Relatively deep mine workings that are connected to the land surface by vertical or inclined shafts. Inclined shaft mines are often referred to as slope mines. Generally, shaft mines are deep and below stream drainage.

Solute--Any substance derived from the atmosphere, vegetation, soil, or rocks and dissolved in water.

Specific capacity--The rate of discharge of a well in gallons per minute, divided by the drawdown of the water level in the well in feet. Reported as gallons per minute per foot of drawdown (gal/min/ft) after pumping for a specified period of time.

Specific conductance--A measure of the ability of water to conduct an electrical current. It is expressed in micromhos per centimeter at 25 degrees Celcius. Specific conductance is related to the number and specific chemical types of ions in solution and can be used for approximating the dissolved-solids content in the water.

Standard error of estimate--In linear regression, the standard deviation of the residuals. A residual is the difference between the actual value and the value predicted from the regression equation. Standard error of estimate has the same units as the dependent variable and indicates how reliably it may be estimated from a given value of the independent variable. It may also be expressed as a percentage of the mean expression of the dependent variable.

Stiff diagram--Plot of major cation and anion concentrations in milliequivalents per liter using one vertical axis and four parallel horizontal axes. Connecting the points representing anions and cations gives a closed figure whose shape is approximately characteristic of a given type of water.

Storage coefficient--The volume of water an aquifer releases or takes into storage per unit surface area of the aquifer, per unit change in head.

Strike of rock strata--The direction of a line formed by the intersection of the bedding and a horizontal plane. (See dip of rock strata.)

Streamflow--The discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Subsidence--A sinking of part of the Earth's surface, such as may result from soil compaction, collapse of underground mines, or removal of ground water, oil, or gas.

Subsidence crack--A crack or joint in the rock formed or widened as a result of subsidence.

Surface water--Water on the surface of the Earth, including snow and ice. (See ground water.)

Surface mine, contour strip--Removal of overburden and mining the coal beneath that overburden on a mountainside. A strip bench and high-wall that follow the coal seam may be mined in this fashion on the same hillside, creating a steplike series of strip benches that follow the coal-seam outcrops.

Surface mine, mountaintop-removal--Removal of the entire mountaintop above a hillside coal seam, creating a flat plain at the elevation of the base of the coal seam.

Surface mine, auger--Removal of coal by an auger working on the strip bench. The auger drills horizontally into the coal seam, possibly several hundred feet, beneath the strip-bench highwall.

Suspended sediment--The sediment that at any given time is maintained in suspension by the upward components of turbulent currents, or that exists in suspension as a colloid.

Suspended-sediment concentration--The concentration of suspended sediment in the sampled zone (from the water surface to a point of approximately 0.3 ft above the streambed) expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/L).

Syncline--A fold that is convex downward, with younger rocks exposed toward the axis of the fold.

Tectonic activity (tectonism)--Any form of movement in or deformation of the Earth's crust.

Taxon--Any classification category of organism, such as phylum, class, order, or species.

Total recoverable--The amount of a given constituent that is in solution after a representative water-suspended sediment sample has been digested by a method that results in dissolution of only readily soluble substances. Complete dissolution of all particulate matter is not achieved by the digestion treatment, and thus the determination represents something less than the "total" amount (that is, less than 95 percent) of the constituent present in the dissolved and suspended phases of the sample.

Trace elements--Elements, such as iron, which generally occur in concentrations of less than one milligram per liter. Trace elements are often required in microgram per liter concentrations for both floral and faunal growth. Higher concentrations of some trace elements can be toxic to fish, plants, and humans.

Transmissivity--The rate at which water of a prevailing viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

Volatile--Readily evaporated or vaporized.

Water table--That surface in an unconfined water body at which pressure is atmospheric, generally the top of the saturated zone.

Appendix 1.--Location and site identification for water-quality sites

Site number	Latitude	Longitude	Station number	Site name or description[1]
1	37°35'16"	81°31'12"	03202310	Bearhole Fork at Pineville, W. Va.
2	37°35'16"	81°31'12"		Precipitation site.
3	37°35'23"	81°31'02"		Bird Branch at mouth.
4	37°35'24"	81°31'03"		Private well.
5	37°35'36"	81°30'28"		Bearhole Fork below Lefthand Fork.
6	37°35'39"	81°30'24"		Private well.
7	37°35'42"	81°30'24"		Do.
8	37°35'48"	81°30'25"		Do.
9	37°36'04"	81°30'29"		Do.
10	37°36'06"	81°30'27"		Do.
11	37°36'27"	81°30'22"		Do.
12	37°35'27"	81°30'27"		Bearhole Fork above Lefthand Fork.
13	37°35'46"	81°29'31"		Private well.
14	37°35'47"	81°29'29"		Bearhole Fork below unnamed tributary 2.
15	37°36'00"	81°29'44"		Private well.
16	37°36'09"	81°29'34"		Do.
17	37°36'16"	81°29'24"		Goode Branch at mouth.
18	37°36'15"	81°29'28"		Bearhole Fork above Goode Branch.
19	37°36'35"	81°29'27"		Private well.
20	37°36'36"	81°29'44"		Do.
21	37°36'53"	81°29'21"		Unnamed tributary 1 to Bearhole Fork at mouth.
22	37°36'49"	81°29'21"		Bearhole Fork above unnamed tributary 1.
23	37°36'51"	81°29'07"		Private well.
24	37°37'19"	81°28'54"		Do.
25	37°37'40"	81°28'50"		Do.
26	37°37'51"	81°28'46"		Bearhole Fork at headwaters.
27	37°37'19"	81°28'54"		Private well.
28	37°40'32"	81°29'56"		Mine discharge.
29	37°40'32"	81°29'55"		Do.
30	37°40'52"	81°28'32"		Private well.
31	37°40'48"	81°28'27"	03202695	Milam Fork at McGraws, W. Va.
32	37°40'48"	81°28'27"		Precipitation site.
33	37°40'57"	81°28'20"		Private well.
34	37°40'52"	81°28'19"		Do.
35	37°40'58"	81°28'19"		Do.
36	37°40'57"	81°28'14"		Mine shaft.
37	37°40'42"	81°28'13"		Private well.
38	37°40'41"	81°28'04"		Do.
39	37°40'41"	81°28'02"		Do.
40	37°40'42"	81°28'00"		Do.

Appendix 1.--Location and site identification for water-quality sites--Continued

Site number	Latitude	Longitude	Station number	Site name or description[1]
41	37°40'16"	81°27'45"		Private well.
42	37°40'11"	81°27'47"		Unnamed tributary 3 to Milam Fork at mouth.
43	37°39'49"	81°28'05"		Private well.
44	37°39'35"	81°27'58"		Do.
45	37°40'14"	81°27'47"		Milam Fork above unnamed tributary 3.
46	37°40'20"	81°27'29"		Private well.
47	37°40'21"	81°27'28"		Do.
48	37°40'22"	81°27'26"		Do.
49	37°40'40"	81°27'11"		Do.
50	37°40'52"	81°27'08"		Do.
51	37°40'55"	81°27'08"		Do.
52	37°40'57"	81°27'06"		Do.
53	37°41'00"	81°27'03"		Unnamed tributary 2 to Milam Fork at mouth.
54	37°41'12"	81°27'06"		Mine shaft.
55	37°40'52"	81°27'00"		Milam Fork above unnamed tributary 2.
56	37°41'02"	81°26'37"		Private well.
57	37°40'57"	81°26'22"		Do.
58	37°41'09"	81°26'10"		Unnamed tributary 1 to Milam Fork at mouth.
59	37°41'10"	81°26'10"		Milam Fork above unnamed tributary 1.
60	37°38'19"	81°23'38"	03202245	Marsh Fork at Maben, W. Va.
61	37°38'19"	81°23'38"		Precipitation gage.
62	37°38'20"	81°23'38"		Private well.
63	37°38'18"	81°23'43"		Do.
64	37°38'40"	81°24'13"		Marsh Fork 0.75 mile above mouth.
65	37°38'53"	81°24'51"		Private well.
66	37°39'09"	81°24'34"		Marsh Fork below unnamed tributary 1.
67	37°39'12"	81°24'37"		Unnamed tributary 1 to Marsh Fork at mouth.
68	37°39'15"	81°25'03"		Private well.
69	37°39'31"	81°26'07"		South Branch headwaters of unnamed tributary 1 to Marsh Fork.
70	37°39'35"	81°26'03"		North Branch headwaters of unnamed tributary to Marsh Fork.
71	37°39'16"	81°24'39"		Marsh Fork above unnamed tributary 1.
72	37°40'00"	81°25'10"		Mouse Fork at mouth.
73	37°40'10"	81°25'06"		Marsh Fork above Mouse Fork.
74	37°40'21"	81°29'10"		Marsh Fork near Polk Gap.
75	37°34'49"	81°26'02"		Still Run at mouth.
76	37°34'50"	81°25'59"		Still Run 0.25 miles above mouth.

Appendix 1.--Location and site identification for water-quality sites--Continued

Site number	Latitude	Longitude	Station number	Site name or description[1]
77	37°34'51"	81°25'42"	03202255	Still Run at Itmann, W. Va.
78	37°34'51"	81°25'42"		Precipitation site.
79	37°34'52"	81°25'43"		Private well.
80	37°34'52"	81°25'43"		Mine discharge.
81	37°34'53"	81°25'38"		Workman Branch at mouth.
82	37°34'50"	81°25'47"		Holding pond drainage at Still Run gage.
83	37°34'46"	81°25'41"		Mine drain.
84	37°34'55"	81°25'40"		Still Run above Workman Branch.
85	37°35'00"	81°25'32"		Mine drain.
86	37°35'18"	81°25'21"		Mine interior.
87	37°35'17"	81°25'24"		York Branch at mouth.
88	37°35'14"	81°25'22"		Mine drain.
89	37°35'19"	81°25'21"		Mine discharge.
90	37°35'17"	81°25'20"		Private well.
91	37°35'16"	81°25'17"		Mine drain.
92	37°35'22"	81°24'59"		Mine interior.
93	37°35'21"	81°24'55"		Do.
94	37°35'32"	81°24'48"		Do.
95	37°35'32"	81°24'35"		Mine drain.
96	37°35'47"	81°24'35"		Mine discharge.
97	37°35'19"	81°25'24"		Still Run above York Branch.
98	37°35'26"	81°25'33"		Mine drain.
99	37°35'27"	81°25'37"		Mine discharge.
100	37°35'33"	81°25'30"		Still Run 1.3 miles above mouth.
101	37°35'53"	81°25'30"		Still Run 1.6 miles above mouth.
102	37°36'10"	81°25'02"		Mouth of unnamed tributary 1 to Still Run.
103	37°36'09"	81°25'06"		Still Run below unnamed tributary 1.
104	37°36'14"	81°25'02"		Private well.
105	37°36'17"	81°25'03"		Still Run above unnamed tributary 1.
106	37°36'17"	81°25'05"		Private well.
107	37°36'18"	81°25'05"		Mine drain.
108	37°36'21"	81°24'58"		Mine discharge.
109	37°35'57"	81°24'40"		Mine interior.
110	37°36'21"	81°25'02"		Still Run below Zack Fork.
111	37°36'38"	81°24'47"		Zack Fork at mouth.
112	37°36'36"	81°24'52"		Still Run above Zack Fork.
113	37°37'13"	81°24'50"		Still Run above Horsecamp Branch.
114	37°35'22"	81°20'57"		Allen Creek at mouth, W. Va.
115	37°35'27"	81°20'54"		Allen Creek 0.2 mile above mouth.
116	37°35'25"	81°20'54"		Mine discharge.
117	37°35'33"	81°20'48"	03203210	Allen Creek at Allen Junction, W. Va.

Appendix 1.--Location and site identification for water-quality sites--Continued

Site number	Latitude	Longitude	Station number	Site name or description[1]
118	37°35'33"	81°20'48"		Precipitation site.
119	37°35'52"	81°20'29"		Unnamed tributary 2 at mouth.
120	37°35'53"	81°20'30"		Allen Creek above unnamed tributary 2, W. Va.
121	37°35'56"	81°20'33"		Private well.
122	37°36'02"	81°20'39"		Do.
123	37°36'11"	81°20'35"		Do.
124	37°36'13"	81°20'36"		Do.
125	37°36'07"	81°20'39"		Mine discharge.
126	37°36'12"	81°20'45"		Allen Creek above Wyco, W. Va.
127	37°36'29"	81°21'08"		Allen Creek below unnamed tributary 1.
128	37°36'29"	81°21'11"		Mine discharge.
129	37°36'32"	81°21'10"		Unnamed tributary 1 at mouth.
130	37°36'36"	81°21'22"		Mine discharge.
131	37°36'37"	81°21'24"		Do.
132	37°36'41"	81°21'24"		Do.
133	37°36'32"	81°21'09"		Allen Creek above unnamed tributary 1.
134	37°36'45"	81°21'01"		Mine discharge.
135	37°36'50"	81°20'54"		Left Fork Allen Creek at mouth.
136	37°38'05"	81°21'09"		Mine discharge.
137	37°38'07"	81°20'54"		Left Fork Allen Creek 2 miles above mouth.
138	37°36'49"	81°20'49"		Allen Creek above Left Fork.
139	37°36'50"	81°20'46"		Mine discharge.
140	37°36'49"	81°20'43"		Do.
141	37°36'50"	81°20'43"		Do.
142	37°36'45"	81°20'12"		Do.
143	37°38'27"	81°20'03"		Allen Creek 2.8 miles above mouth Left Fork.
144	37°34'59"	81°32'15"		Bearhole Fork at mouth.
145	37°35'08"	81°31'54"		Bearhole Fork 0.5 mile above mouth.
146	37°35'09"	81°31'55"		Rockcastle Creek at Highway 10 bridge at Pineville, W. Va.
147	37°35'09"	81°31'48"		Bearhole Fork above Rockcastle Creek
148	37°40'58"	81°28'39"		Private well.
149	37°41'21"	81°29'03"		Do.
150	37°41'22"	81°29'03"		Laurel Fork at Highway 5 Bridge at Ravencliff, W. Va.
151	37°42'16"	81°28'31"		Private well.
152	37°34'23"	81°27'44"		Cabin Creek at Joe Branch.

Appendix 1.--Location and site identification for water-quality sites--Continued

Site number	Latitude	Longitude	Station number	Site name or description[1]
153	37°37'50"	81°20'28"		Private well.
154	37°38'08"	81°26'09"		Do.
155	37°38'09"	81°26'05"		Do.
156	37°38'38"	81°25'53"		Do.
157	37°38'38"	81°25'51"		Do.
158	37°38'39"	81°25'52"		Do.
159	37°38'06"	81°27'18"		Do.
160	37°39'26"	81°27'59"		Do.
161	37°34'32"	81°25'05"		Do.
162	37°34'55"	81°22'55"		Slab Fork at Mullens, W. Va.
163	37°35'03"	81°22'52"		Private well
164	37°36'01"	81°22'45"		Slab Fork at Highway 54 bridge at Nuriva, W. Va.
165	37°36'41"	81°22'34"		Private well
166	37°37'42"	81°23'23"		Do.
167	37°40'27"	81°22'07"		Do.
168	37°41'12"	81°21'02"		Do.
169	37°35'49"	81°19'14"		Devils Fork at Amigo, W. Va.
170	37°36'09"	81°19'18"		Stonecoal Creek at Amigo, W. Va.
171	37°38'09"	81°18'51"		Winding Gulf Creek at Helen, W. Va.

[1] All sites are in Wyoming or Raleigh Counties, West Virginia.

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