GROUND-WATER STUDY 2

by

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1.0 ABSTRACT

Geology and the Occurrence of Coal

The Allegheny Plateau contains broadly folded sedimentary rocks of Devonian through Permian age. The general area, located in the southwest corner of Garrett County, contains part of one of the synclinal basins--the Upper Potomac basin. This area is underlain by sandstones, siltstones, shales, and coals of Pennsylvanian age, which lie disconformably above the Mauch Chunk Formation of Mississippian age. The coal beds of economic importance in the area are the Upper Freeport coal (Allegheny Group) and the less continuous, stratigraphically higher, Lower Bakerstown coal (Conemaugh Group). No significant faults are known in the area, but numerous photo-interpreted lineaments (fracture traces) are present. The rocks are jointed and fractured, resulting in secondary porosity and permeability.

Hydrology and Hydrologic Monitoring

Ground water in the area occurs in shallow, water-table aquifers and in deeper, artesian aquifers. Brackish water underlies the fresh ground-water system at depths of less than 1,000 feet. The deeper aquifers yield small quantities of water to wells; thus, pumping tests of long duration are difficult to perform. Hydraulic conductivity seems to decrease logarithmically with depth. Drawdown effects adjacent to dewatered mine excavations probably are localized. The ground-water flow patterns are complicated by fracturing, underclays, and the discontinuous nature of the rock units. Surface-water quality is affected by discharge from abandoned mines and from treated mine pumpage. The hydrologic monitoring network consists of sites with a cluster of wells equipped with water-level recorders, streamflow-gaging stations with stage and water-quality recorders, a precipitation gage, and miscellaneous observation wells, springs, and stream sites.

Mining Methods and Other Stresses on the Aquifer System

The area has abandoned surface and underground mines in the Upper Freeport coal and abandoned underground mines in the Lower Bakerstown coal. At present (1985), only one mine is operating in the area; it began underground extraction of the Upper Freeport coal in 1977. Other land uses in the area include agriculture and lumbering. Other than for mine dewatering, ground-water withdrawals are not significant.

Probable Hydrologic Impacts and Proposed Hydrologic Monitoring Network

Large quantities of water must be pumped to allow underground mining operations. Water levels in aquifers near the mine heading declined as much as 350 feet within a 1-month period. The magnitude of the decline diminished as the distance from the bottom of the well to the coal increased. Some springs and shallow wells may become dry as a result of mine dewatering. Impacts of mine dewatering include increases in streamflow due to discharge of treated pumpage into streams, decreases in streamflow due to reversal of ground-water gradients adjacent to streams, and alterations in water chemistry. Streamflow alterations are also caused by interbasin transfers of water. Treatment of mine pumpage and wastewaters decreases the acidity of stream water, but may increase concentrations of dissolved solids. A post-mining hydrologic monitoring network will include observation wells completed at various depths, streamflow-gaging stations, and water-quality sampling sites.

2.0 GEOLOGIC SETTING

2.1 PHYSIOGRAPHY

AREA LOCATED IN BROAD UPLAND WITH NORTHWEST TRENDING RIDGES AND VALLEYS

The general area is characterized by relief and steep slopes.

The general area is located within the Allegheny Plateau division of the Appalachian physiographic province and is a broad upland with northeast trending ridges and valleys. Land slopes are steep along parts of the streams and along Backbone Mountain. Swamps have formed in several locations where channels and land slopes are slight. Beaver dams have ponded some stream reaches.

The soils are chiefly gently sloping to steep, moderately deep, well drained to moderately well drained, and very stoney, having formed over acid, gray to yellowish sandstone and shale (20). Steep slopes and stoniness limit suitability for cultivation. Areas that have been surface mined for coal or have been covered with mine spoils from underground mining also may be unsuitable for cultivation. However, some of the abandoned mined areas, as shown in figure 2.1-1, have recently been regraded, seeded, and improved.

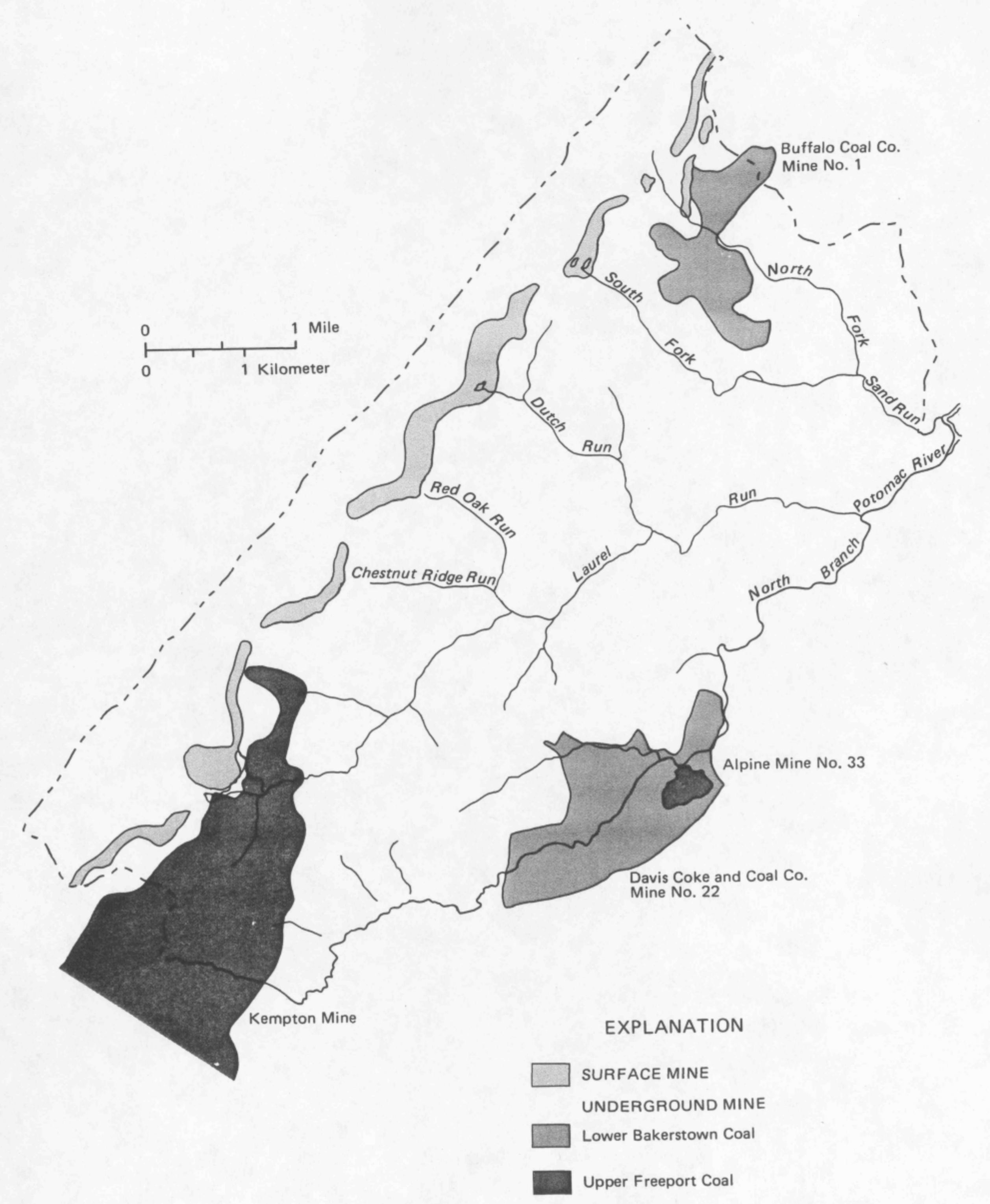


Figure 2.1-1— Abandoned coal mines in the general area.

2.0 GEOLOGIC SETTING

2.2 GEOLOGY

SEDIMENTARY BEDROCK IS OF LATE PENNSYLVANIAN AGE

Exposed rocks in general area consist of sandstones, siltstones, shales, limestones, and coals.

The sedimentary rocks exposed in the general area consist of sandstones, siltstones, shales, limestones, and coals and are of Late Pennsylvanian age. The formations and important coals are identified in the stratigraphic column shown in figure 2.2-1. Detailed lithologic descriptions of rock units composing the formations are shown in figure 2.2-2. These rocks represent a transition from an alluvial plain to a shallow marine environment (17).

The oldest exposed rocks, which belong to the Pottsville Group, and lie disconformably on the Mauch Chunk Formation of Mississippian age. The Pottsville Group consists primarily of sandstones and siltstones and includes some thin coals that are not economically important. This group was formed by sediments deposited in a braided fluvial environment. The well indurated basal conglomerate of the group forms the crest of Backbone Mountain.

The sedimentary rocks of the Allegheny Group are difficult to distinguish from the rocks of the Pottsville Group. The Allegheny Group includes several coal beds, but only the Upper Freeport coal is economically significant.

The Conemaugh Group underlies the rest of the general area, but erosion has removed much of the upper part. This group consists of siltstones, sandstones, shales, and coals deposited in a shallow marine environment. Red shales, which are characteristic of the Conemaugh, are absent in the older rocks. The Lower Bakerstown coal is the only coal in this group of economic importance, but a minable thickness is present in less than one-third of the area. Floodplain sediments along the streams and colluvial deposits at the toeslopes of hills are of limited extent and thickness.

The sedimentary rocks in the county have been folded to form five synclinal coal basins, as shown in figure 2.2-3. The broad folding produced general to moderate dips; the maximum dip in the general area is about 20˚. The geologic structure in the general area is shown in figure 2.2-4 by the contours on the base of the Upper Freeport coal. The axis of the Upper Potomac syncline plunges to the northeast.

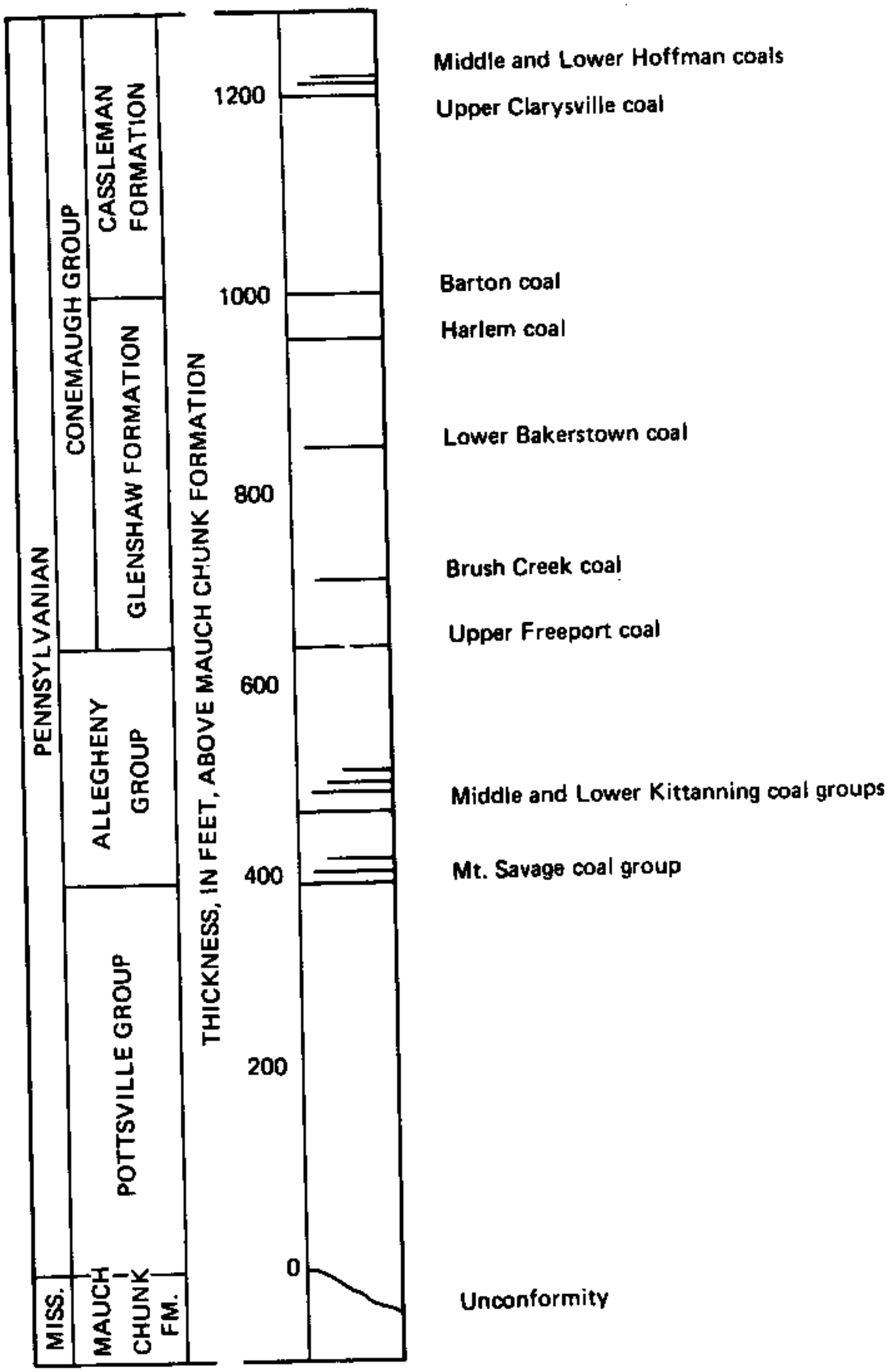


Figure 2.2-1. — General stratigraphic column for the Upper Potomac coal basin in the general area.

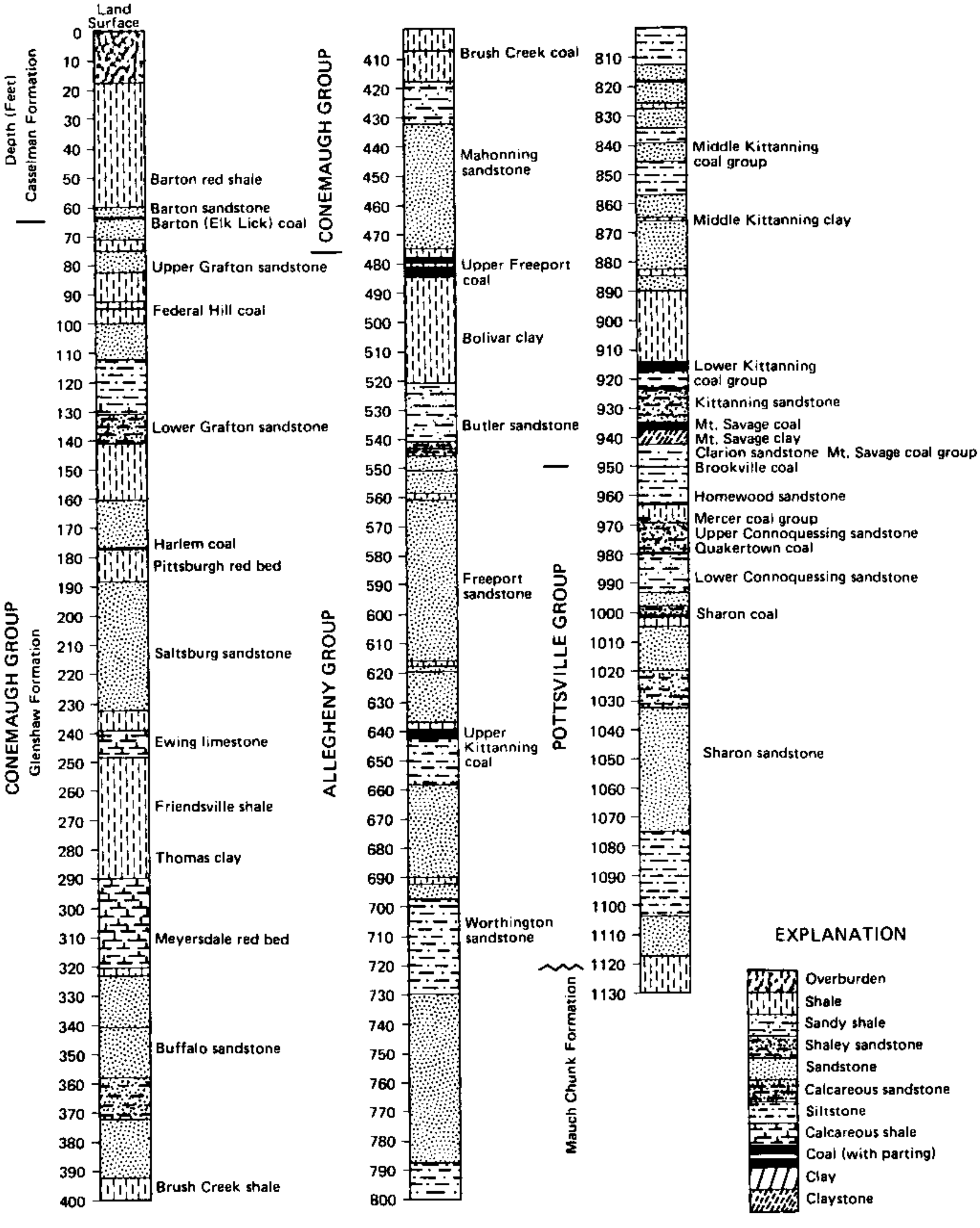


Figure 2.2-2.— Lithologic log of well FA 31. Depth below land surface is shown in feet.

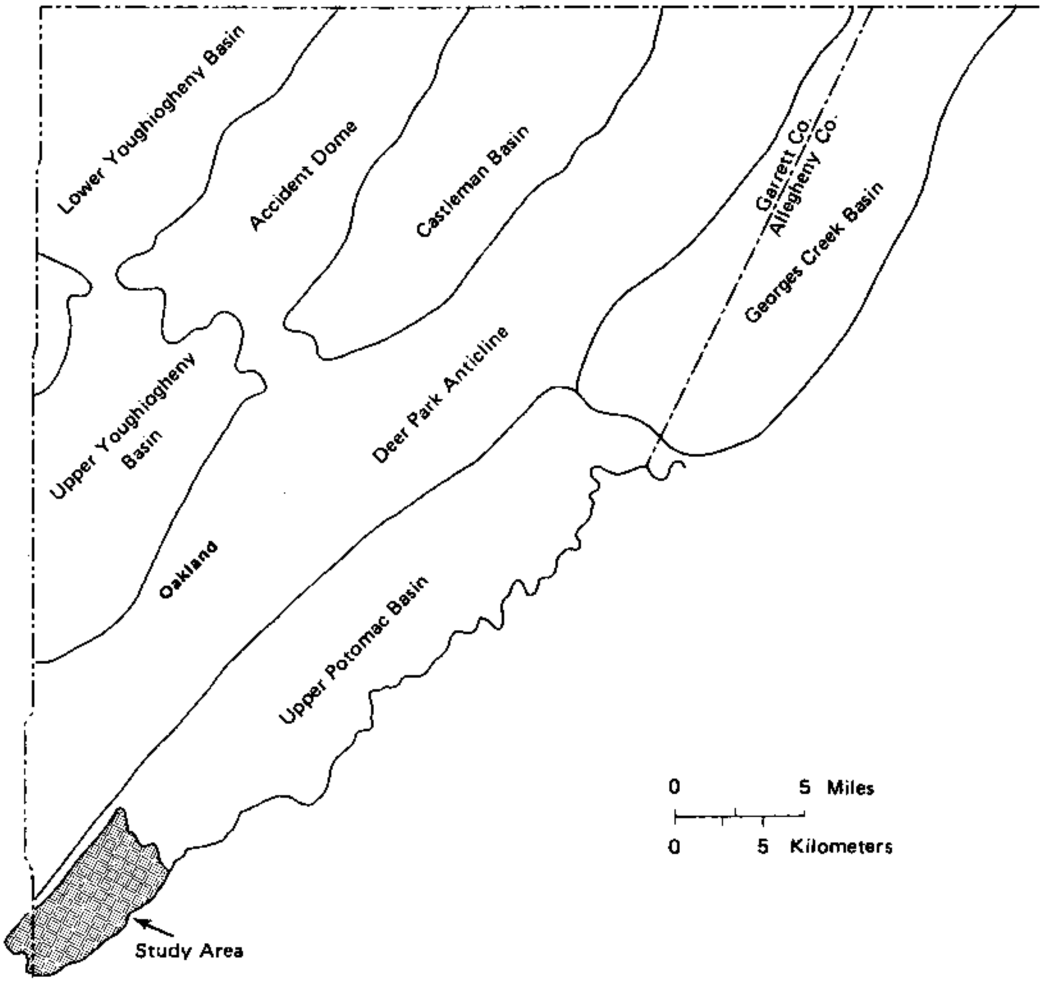


Figure 2.2-3.— Geologic structure in Garrett County.

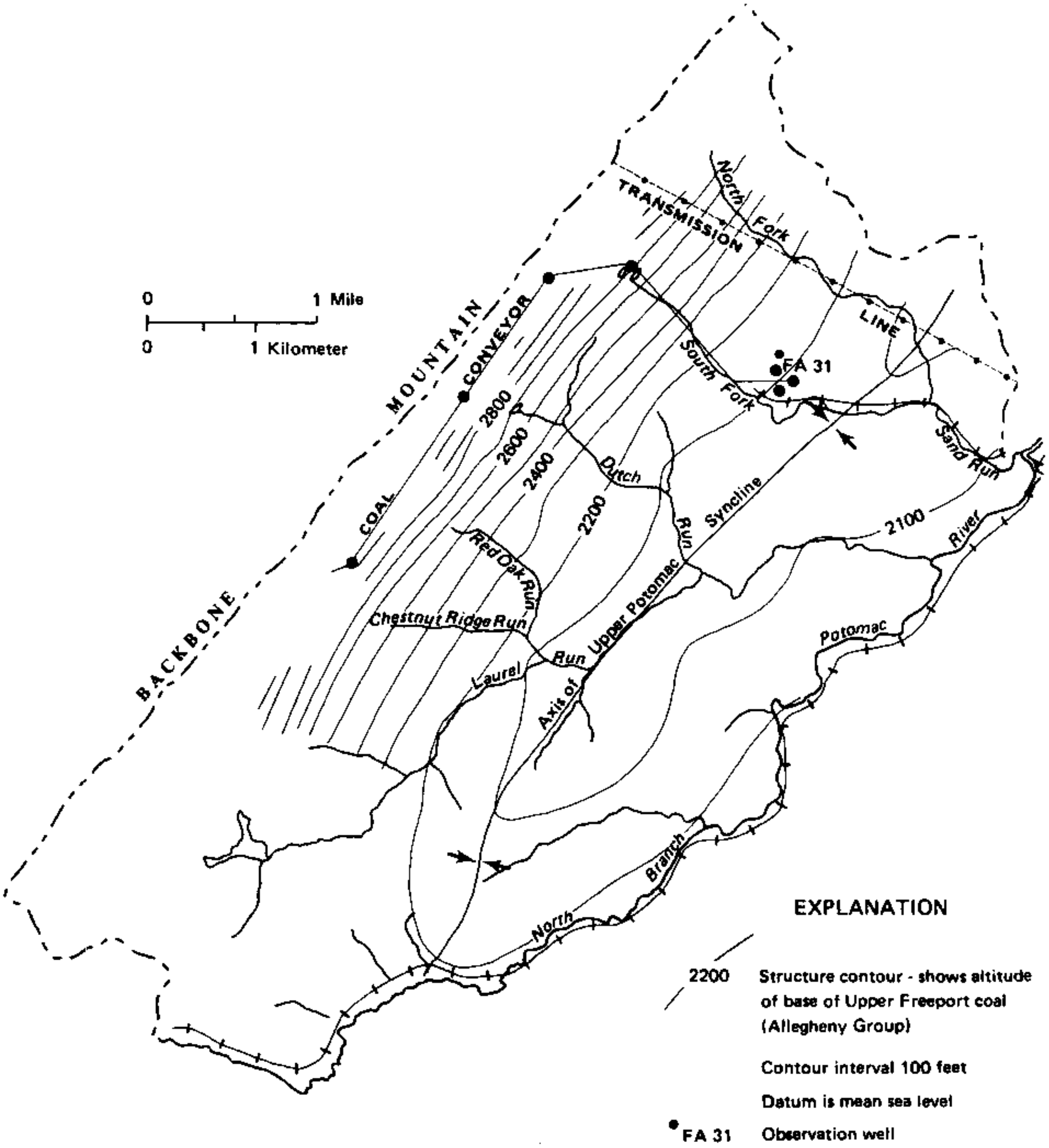


Figure 2.2-4.— Altitude of the base of the Upper Freeport coal of the Allegheny Group. (From Duigon and Smigaj, 1985, fig. 9.)

3.0 HYDROLOGIC SETTING

3.1 CLIMATE

HUMID CONTINENTAL CLIMATE CHARACTERISTIC OF AREA

The mean annual temperature is about 48˚F and the mean annual precipitation is about 47 inches.

Air masses from the interior of the continent provide the area with a humid continental climate. The prevailing winds are from the west and northwest but become more southerly in the summer. The mean annual precipitation, during 1941-70, is 47.11 inches at the nearest National Weather Service station, which is about 11 miles north-northeast of the area. The mean annual temperature at this station during the same period is 47.8˚F. Mean monthly temperatures exceed the mean annual from May through October, peaking in July at 67.4˚F. January is the coldest month, at 27.5˚F.

Mean monthly precipitation for March through August exceeds the average mean monthly (3.93 inches); mean monthly precipitation for the rest of the year, although less than average, is still abundant. Much of the annual precipitation occurs as snow, which may fall as early as September and as late as May. Snow cover may be as much as several feet in places.

3.0 HYDROLOGIC SETTING

3.2 OCCURRENCE AND FLOW OF GROUND WATER

OCCURRENCE OF GROUND WATER GOVERNED BY ROCK FRACTURES IN BEDROCK

Secondary porosity and permeability due to fracturing provide for storage and transmission of water.

Most of the water within the sedimentary rocks is related to the fractures within the rock mass. The secondary porosity and permeability provide storage and transmission of the ground water. The number of open fractures decreases with depth. Wells that are open at greater depths, with the shallow zones cased off, generally have smaller yields than shallow wells. Also, fractures are not evenly distributed among rock types. Plastic underclays provide very effective barriers to ground-water flow.

Zones of bedrock fracturing are interpreted from linear features observed on stereophotographs. These linear features are called fracture zones and are shown for the general area in figure 3.2-1. The orientation-frequency rosette shows some north-northwest south-southeast preference for the linear features.

The ground-water flow system in the general area consists of three major subsystems: shallow, intermediate, and deep. Associated with these subsystems are four interpreted open-hole water-bearing zones: zone 1 with the deep flow, zones 2 and 3 with the intermediate flow, and zone 4 with the shallow flow. The ground-water flow system, interpreted from water levels, is shown in figure 3.2-2.

The shallow flow system underlies the hills, discharges to the local streams, and, to some extent, leaks downward into the deeper, intermediate system, which discharges into higher order streams at lower altitudes. The shallow flow system also is perched above beds of lower permeability in places, and most of this ground water flows laterally to springs that discharge above stream levels.

The main water table probably is indicated by the water levels in the shallow wells. The source of most of the ground water in the flow system is precipitation, but some stream water also leaks into the shallow aquifers. At site 1 near the middle of South Fork Sand Run (fig. 3.2-2), the water table was generally several feet above the level of the stream. At site 2, near the downstream reach of South Fork Sand Run, the water table generally was near, or several feet below, the level of the stream. At site 3, on the hilltop, the water table was generally about 30 feet below the surface, where the water level in the next shallowest well (zone 4) is about 60 feet lower. These differences in water levels indicate perching of the shallow aquifer, with some leakage downward. The dissected terrain results in a number of local, independent shallow subsystems. In some parts of the area, very shallow systems perched above the main water table may be important contributors to streamflow following periods of precipitation. These localized, ephemeral systems may be perched on impervious soil zones, such as fragipans, or they may be zones of concentrated seepage developed by piping near the lower areas of the hillslopes.

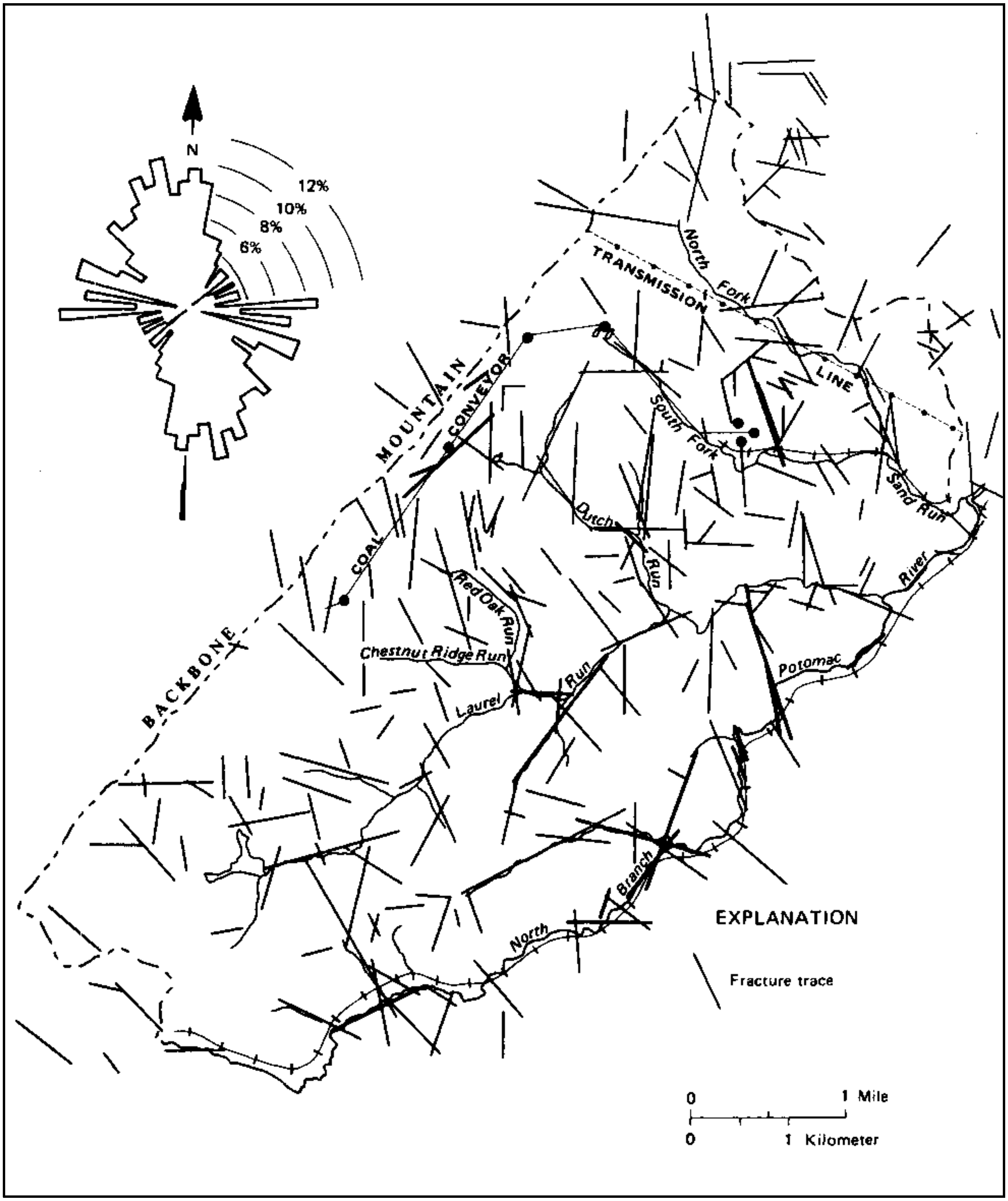


Figure 3.2-1.— Fracture traces and orientation rosette. (From Duigon and Smigaj, 1985, fig. 10.)

The intermediate flow system does not interact with the lower order streams within the area. Confining beds, such as the underclays of the Lower Bakerstown coal, separate some of the flow paths. These confining beds are not continuous throughout the area, and in some places may be hydraulically breached by fracturing. The bottom of the intermediate system may be at the underclay of the Upper Freeport coal. The water from this system may be discharged by upward leakage into stream valleys at lower altitudes outside of the area.

Water below the Upper Freeport coal may be part of a regional flow system extending from a high area southeast of the county and discharging to the Cheat River to the west. Although the regional system may receive some leakage from above, it is fairly well sealed by the underclay of the Upper Freeport coal.

The base of the fresh water in well FA 31 was at a depth of 940 feet. Figure 3.2-2 shows possible flow paths prior to April 1981. Flow into the plane of the figure is not shown, although such a component exists. The zone of salty water is below the lowest level shown in the illustration.

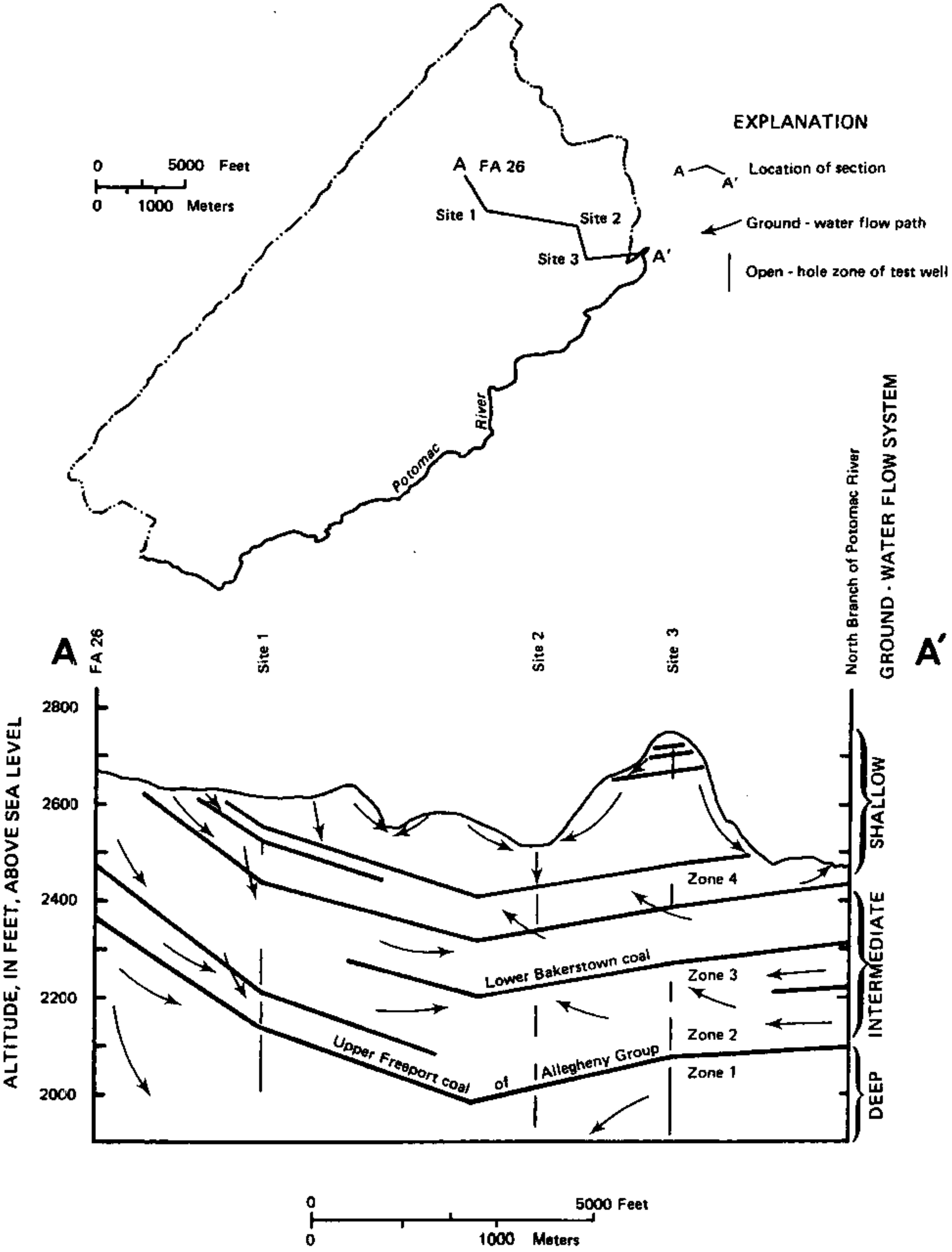


Figure 3.2-2.— Possible ground-water flow paths prior to April 1981.
(From Duigon and Smigaj, 1985, figs. 22 and 30.)

3.0 HYDROLOGIC SETTING

3.3 WELLS, SPRINGS, AND STREAMS

WATER QUANTITY AND QUALITY VARIATION DETERMINED FROM INVENTORIED AND INSTRUMENTED WELLS, SPRINGS, AND STREAMS

The location of water-bearing zones within the bedrock and the relevance to the hydrologic setting of the coal beds to be mined is determined from wells, springs, and streams.

The data-collection sites within the general area are shown in figure 3.3-1. Daily records of precipitation are provided by a rain gage in the area. Streamflow-gaging stations were constructed on the four main streams-Laurel Run, South Fork and North Fork Sand Run, and North Branch Potomac River. These stations were equipped to record stage, water temperature, and specific conductance. Onsite measurements of water-quality characteristics were made periodically at these sites, and samples were collected for laboratory analysis. Discharge measurements, onsite field determinations, and water samples were obtained at six additional sites. The streamflow-gaging stations and the precipitation gage are within the boundaries of the Beaver Run Mine. The location of the operational mine boundaries is shown in figure 3.3-2.

Thirteen wells drilled in three clusters were chosen to provide data across the syncline (fig. 3.2-2). This drilling had to accommodate property constraints and projected phases of mining. The three clusters are located within the boundaries of the Beaver Run Mine. At each cluster, wells are open to different zones, including the sandstone below the Upper Freeport coal. Four-inch casing was used in the construction of each well to provide room for the float and counterweight of the water-level recorder. This size also allows for the use of a small diameter submersible pump, which is used to pump test the wells and obtain samples for water-quality analyses. Water-level recorders were installed on all 13 wells. Additional water-level measurements were made in six other wells. Well FA 31 was drilled to a depth of 1,131 feet, as shown in figure 2.2-2, primarily to determine the depth to the Mississippian-Pennsylvanian contact and to the top of the salty-water zone that underlies the region. This well was subsequently grouted back to a depth of 606 feet.

At well site FA 35 is an abandoned underground coal mine in the Lower Bakerstown coal, where mine discharge was sampled and measured. Mine discharge was also measured at sites GA 3 and GA 6 from abandoned mines in the Upper Freeport coal. Discharge, pH, and specific conductance were measured at three springs. The records of wells, mine discharges, and springs are presented in table 3.3-1.

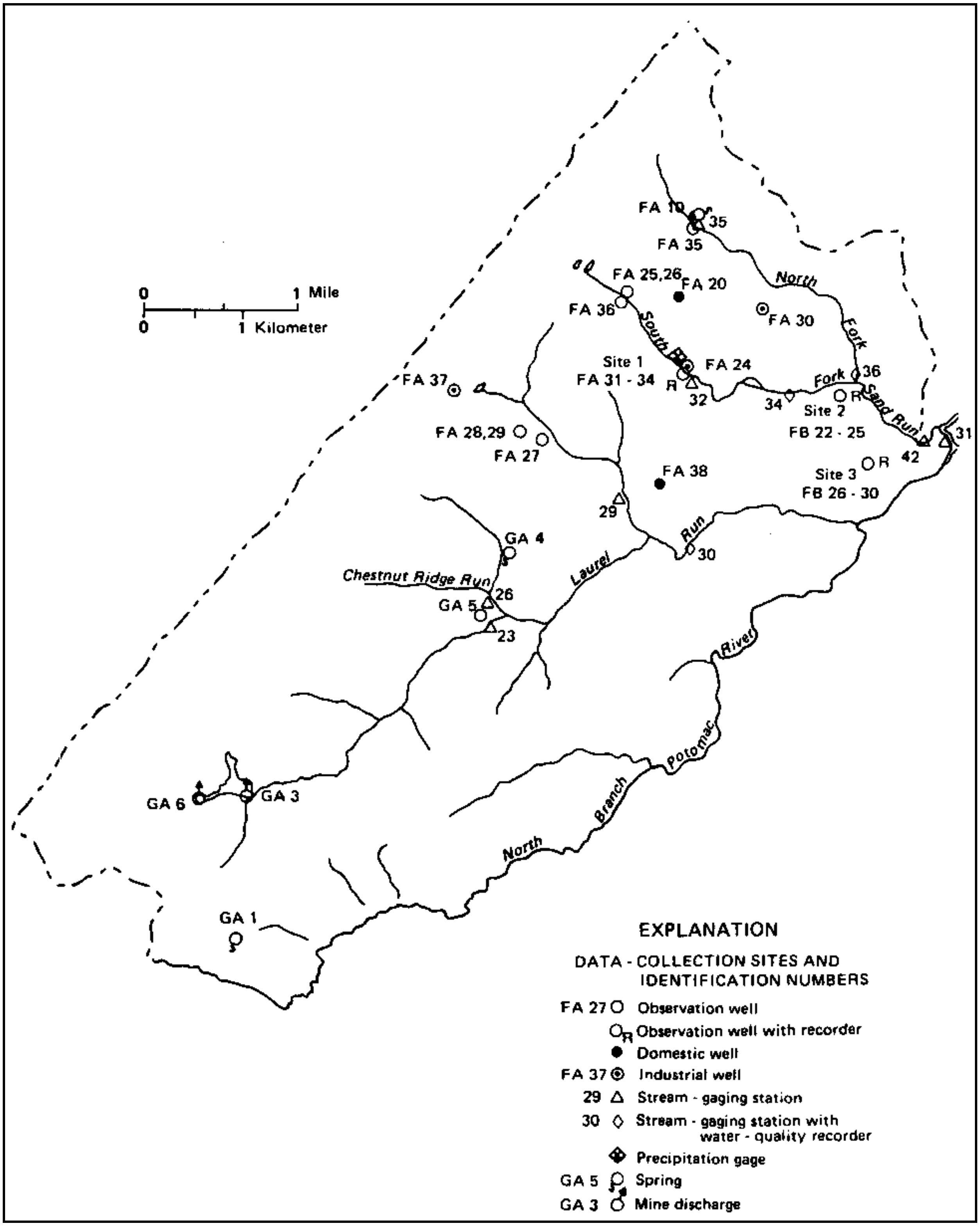


Figure 3.3-1.— Data-collection network.
(From Duigon and Smigaj, 1985, fig. 2.)

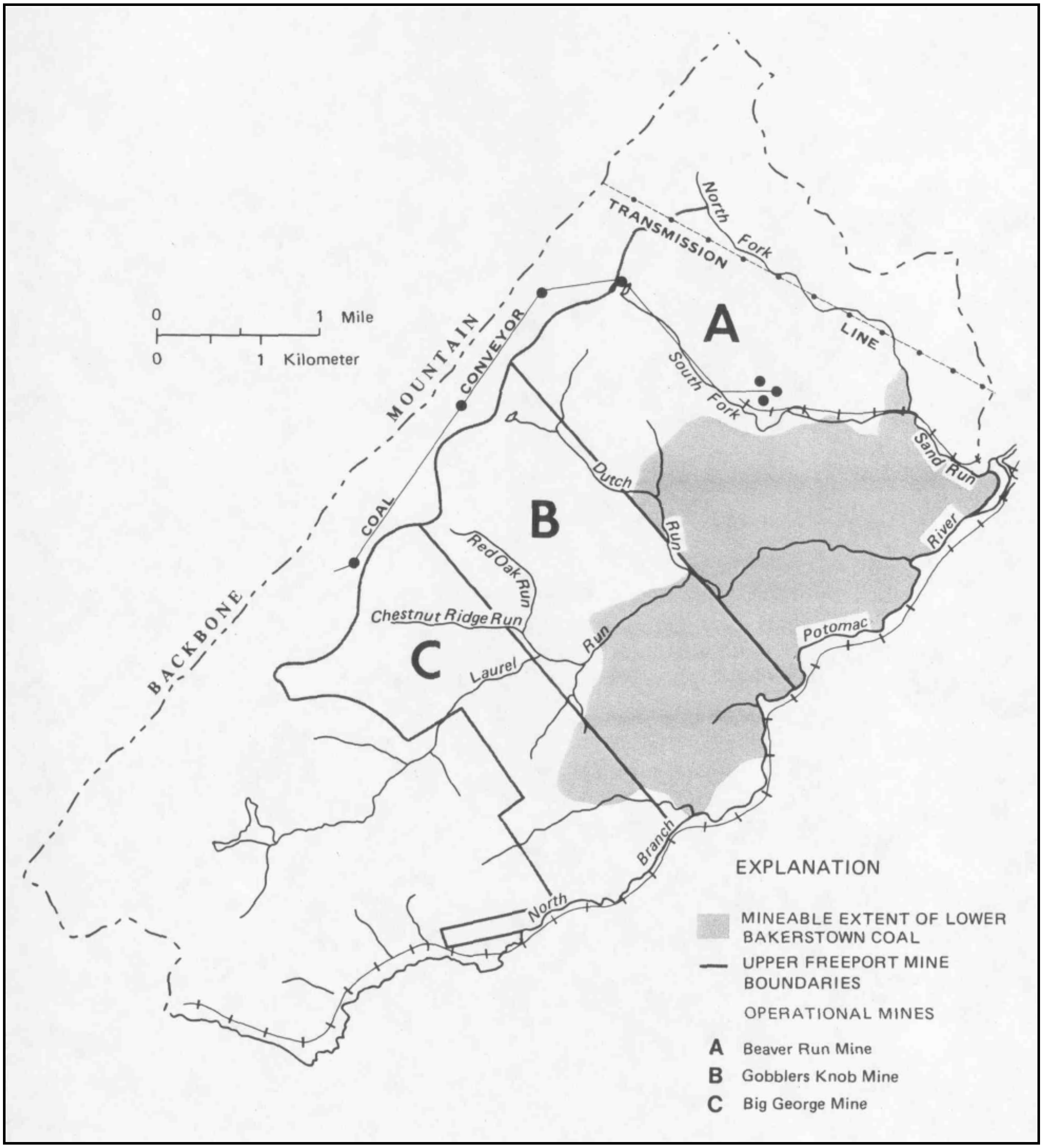


Figure 3.3-2.— Mine boundaries and approximate extent of mineable Lower Bakerstown coal.
(From Duigon and Smigaj, 1985, fig. 12.)

Table 3.3-1. – Records of wells, mine-discharge sites, and springs.

[ft, feet; in., inch; gal/min, gallons per minute; gal/min/ft, gallons per minute per foot of drawdown]
[U.S.G.S., U.S. Geological Survey; H, domestic use; N, industrial use; 0, observation; PS, public supply; U, unused]

WELLS

Site number	Owner	Altitude of land surface (ft)	Depth of well (ft)	Depth cased (ft)	Casing diameter (in.)	Aquifer	Water level		Draw-down (ft)	Discharge			Specific capacity (gal/min/ft)	Use of well
							(Depth ft)	Date measured		Rate (gal/min)	Date measured	Hours pumped		
FA 20	Cooper, Charles	2,750	78	22	5	Conemaugh	28	6/17/73	12	8.0	6/17/73	2.0	0.7	H
FA 24	Mettiki Coal Co.	2,610	229	30	8	Conemaugh	170	11/23/77	59	30	11/23/77	.5	.5	N
FA 25	do.	2,650	315	304	6	Conemaugh	301	6/23/78	-	-		-	-	O
FA 26	do.	2,650	170	150	6	Conemaugh	16	6/23/78	-	-		-	-	O
FA 27	do.	2,860	215	190	6	Conemaugh	169	6/23/78	-	-		-	-	O
FA 28	Mettiki Coal Co.	2,890	341	317	6	Conemaugh	105.50	6/23/78	-	-		-	-	O
FA 29	do.	2,890	226	203	6	Conemaugh	130.75	6/23/78	-	-		-	-	O
FA 30	do.	2,730	447	417	6	Conemaugh	440	5/20/78	7	50	5/20/78	-	7.1	N
FA 31	U.S.G.S.	2,618	606	470	4	Allegheny	11.54	10/09/80	107	2.0	3/11/81	.2	.02	O
FA 32	do.	2,618	473	430	4	Conemaugh	13.69	10/09/80	103	3.6	3/12/81	.4	-	
FA 33	U.S.G.S.	2,618	391	318	4	Conemaugh	17.94	10/09/80	93	2.0	5/22/81	1.5	-	O
FA 34	do.	2,618	115	96	4	Conemaugh	16.15	10/09/80	2	6.0	5/07/81	2.0	3.6	O
FA 36	Mettiki Coal Co.	2,650	210	46	8	Conemaugh	-2	6/20/78	-	200	6/20/78	.5	-	O
FA 37	do.	2,780	253	40	8	Conemaugh	50	1/17/79	203	100	1/17/79	.5	.5	N
FA 38	Glofelty, Curtis	2,680	118	39	6	Conemaugh	31	10/10/79	87	7.0	10/10/79	1.0	.1	H
FB 22	U.S.G.S.	2,530	640	517	4	Allegheny	78.18	10/09/80	65	3.0	4/21/81	.3	.05	O
FB 23	do.	2,530	495	460	4	Conemaugh	19.70	10/09/80	54	2.0	4/22/81	.5	.04	O
FB 24	do.	2,530	400	340	4	Conemaugh	20.05	10/09/80	117	4.0	4/23/81	.4	.03	O
FB 25	do.	2,530	180	120	4	Conemaugh	29.07	10/09/80	5	7.5	4/24/81	1.5	1.4	O
FB 26	do.	2,755	832	687	4	Allegheny	269.33	10/09/80	-	-		-	-	O
FB 27	U.S.G.S.	2,755	656	590	4	Conemaugh	4.60	10/09/80	167	4.0	5/04/81	.6	.02	O
FB 28	do.	2,755	556	517	4	Conemaugh	216.09	10/09/80	-	-		-	-	O
FB 29	do.	2,755	360	316	4	Conemaugh	252.69	10/09/80	-	-		-	-	O
FB 30	do.	2,755	85	82	4	Conemaugh	32.47	10/09/80	8	6.3	5/05/81	2.3	.8	O

MINE-DISCHARGE SITES

Site Number	Altitude of land surface above sea level (ft)	Discharge		Coal seam drained
		Rate (gal/min)	Date measured	
FA 35	2,630	58	6/30/81	Lower Bakerstown
GA 3	2,640	690	10/29/81	Upper Freeport
GA 6	2,650	1,659	8/25/70	Upper Freeport

SPRINGS
(Aquifer–Conemaugh Formation)

Site Number	Owner	Altitude of land surface above sea level (ft)	Discharge		Improvements	Use of water
			Rate (gal/min)	Date measured		
GA 1	Town of Kempton	2,860	750	7/ 50	Spring house	PS
GA 4	Radeheaver, Paul	2,660	40	10/29/81	Concrete basin	H
GA 5	-	2,660	5	10/29/81	Pipe	U

3.0 HYDROLOGIC SETTING

3.4 AQUIFER PROPERTIES

AQUIFER TEST METHODS USED TO DETERMINE TRANSMISSIVITY AND STORAGE COEFFICIENTS

Aquifer properties indicate most ground-water circulation occurs in the shallow flow system and hydraulic conductivity decreases logarithmically with depth.

Aquifer properties were determined for 10 wells using a submersible pump. However, slug or pressure tests would have been more efficient because of the small well yields, except for the shallow aquifer wells. Geophysical logs also gave some indication of aquifer properties. The base of the fresh ground-water system was determined, from fluid resistivity and electric logs, to be at a depth of about 940 feet at well FA 31. Neutron logs run in wells FA 31 and FB 26 indicated porosities less than about 6 percent in the sandstones. Porosity, calculated using a formation factor (13), was determined to be about 5 percent.

Table 3.4-1 lists values of hydraulic conductivity (K) and transmissivity (T) calculated by several methods: the slug test method (3), time-drawdown plot (5), and the one-drawdown estimation method (15). The procedures, assumptions, and requirements of these methods depend upon the hydraulic and physical conditions at a given site. As shown in table 3.4-1, the various methods can give results that differ by an order of magnitude. The Cooper-Jacob time-drawdown method probably gave the most reliable results for the shallower, larger yielding wells, but the Bouwer and Rice slug-test method probably gave better results for the deeper, smaller yielding wells.

Despite the ranges of the computed transmissivities, hydraulic conductivities determined for the shallow wells at each site are about an order of magnitude greater than the values determined for the deeper wells. Figure 3.4-1 shows the relationship of decreasing hydraulic conductivity with depth below land surface. This rapid decrease in hydraulic conductivity indicates that most of the ground-water circulation occurs within a few hundred feet of the land surface or in the shallow flow system.

Table 3.4-1. – Aquifer test results
[ft, feet; ft/d, feet per day; ft^2/d, square feet per day]

Site number	Well number	Aquifer	Well depth (ft)	Assumed aquifer thick-ness (b) (ft)	Assumed storage coeffi-cient[1] (S)	Hydraulic conduc-tivity[2] (K) (ft/d)	Transmissivity (T) (ft^2/d)		
							Kb	Time-drawdown[3]	Single drawdown[4]
1	FA 31	Allegheny	606	76	0.00008	0.3	22	2	25
	FA 32	Conemaugh	473	43	.00004	.5	22	.7	2
	FA 33	Conemaugh	391	66	.00007	.2	13	3	3
	FA 34	Conemaugh	115	64	.00006	9	580	570	1,100
2	FB 22	Allegheny	640	120	.0001	.05	6	3	6
	FB 23	Conemaugh	495	48	.00005	.3	14	8	10
	FB 24	Conemaugh	400	83	.00008	.2	16	11	12
	FB 25	Conemaugh	180	61	.00006	7	430	241	320
3	FB 27	Conemaugh	656	61	.00006	.05	3	9	6
	FB 30	Conemaugh	85	78	.00008	7	550	280	380

[1] S = assumed aquifer thickness (b) x 10^{-6} (from Lohman, 1972, p. 8)
[2] Bower and Rice, 1976
[3] Cooper and Jacob, 1946
[4] Ogden, 1965

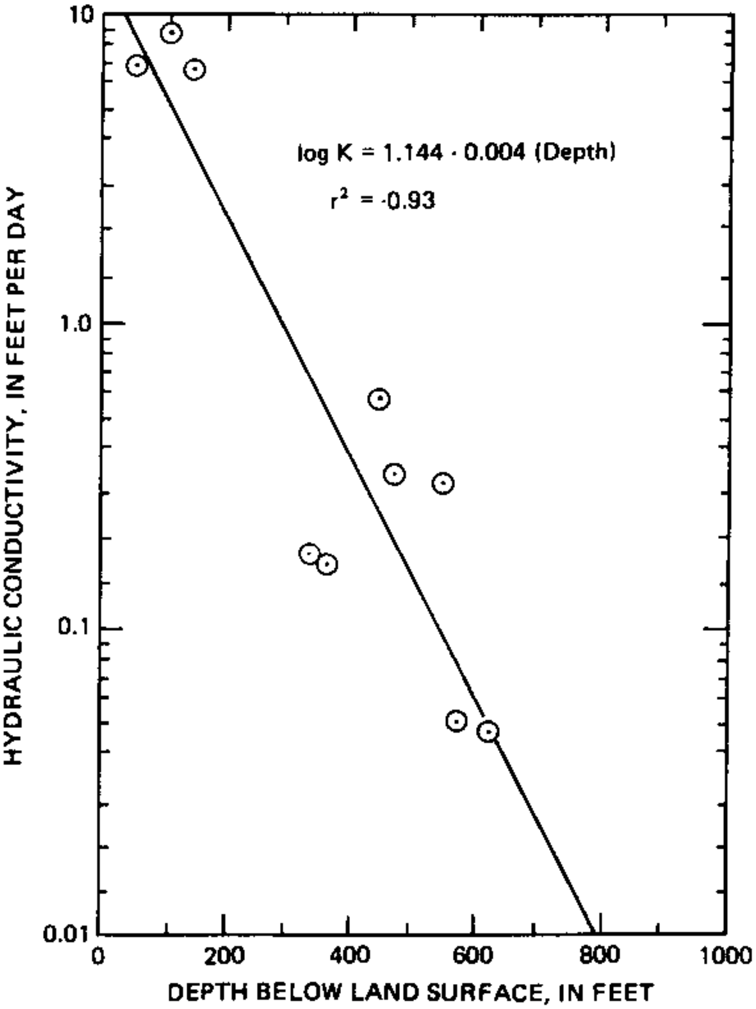


Figure 3.4-1. — Variation of hydraulic conductivity with depth.
Depth is plotted as the mid-point of the open-hole zone.
(From Duigon and Smigaj,1985, fig. 28.)

3.5 GROUND-WATER LEVELS

WATER LEVELS IN WELLS REFLECT VARIATIONS OF GROUND-WATER FLOW BELOW LAND SURFACE

Some wells flowed, while the water level in others was several hundred feet below land surface

Water levels in observation wells were measured periodically, beginning in 1978. At three sites, 13 test wells were equipped with instruments in 1980 to record hydraulic-head changes in different zones. Figure 3.5-1 shows the open-hole zones of each of these test wells in cross-section view; the zones are numbered from deepest to shallowest. Water levels, at every well, rose higher than the top of the zone to which the well was open.

In March 1980, water was observed seeping from a small terrace eroded into the hillside at site 3, at a rate of about 0.1 ft^3/s. The soil of this site is mapped as the Cookport loam (20). This soil has a fragipan, which impedes vertical drainage, and creates a perched water condition. Some other soils in the area are also characterized by perched water.

Figure 3.5-2 shows hydrographs for each of the wells of the three clusters for the period May 1980 through September 1981. At site 1, the heads, from highest to lowest, are in the order of zone 4-zone 3-zone 2, whereas at sites 2 and 3, the heads are in the order of zone 2-zone 3-zone 4. The head of zone 1, which is below the Upper Freeport coal, is out of order at each site, indicating that this zone is a part of a separate regional flow system. At all sites, before March 1981, the water level in zone 1 declined at a fairly constant rate. The sharp water-level declines at site 1 and in several zones after March 1981 to a lesser degree at site 3 were due to the approach of a side heading of the mine.

Ground water was discharged to the surface at three additional sites FA 35, GA 3, and GA 6 (fig. 3.3-1). The first site drains the abandoned mine in the Lower Bakerstown coal, and the other two sites drain the abandoned mine in the Upper Freeport coal.

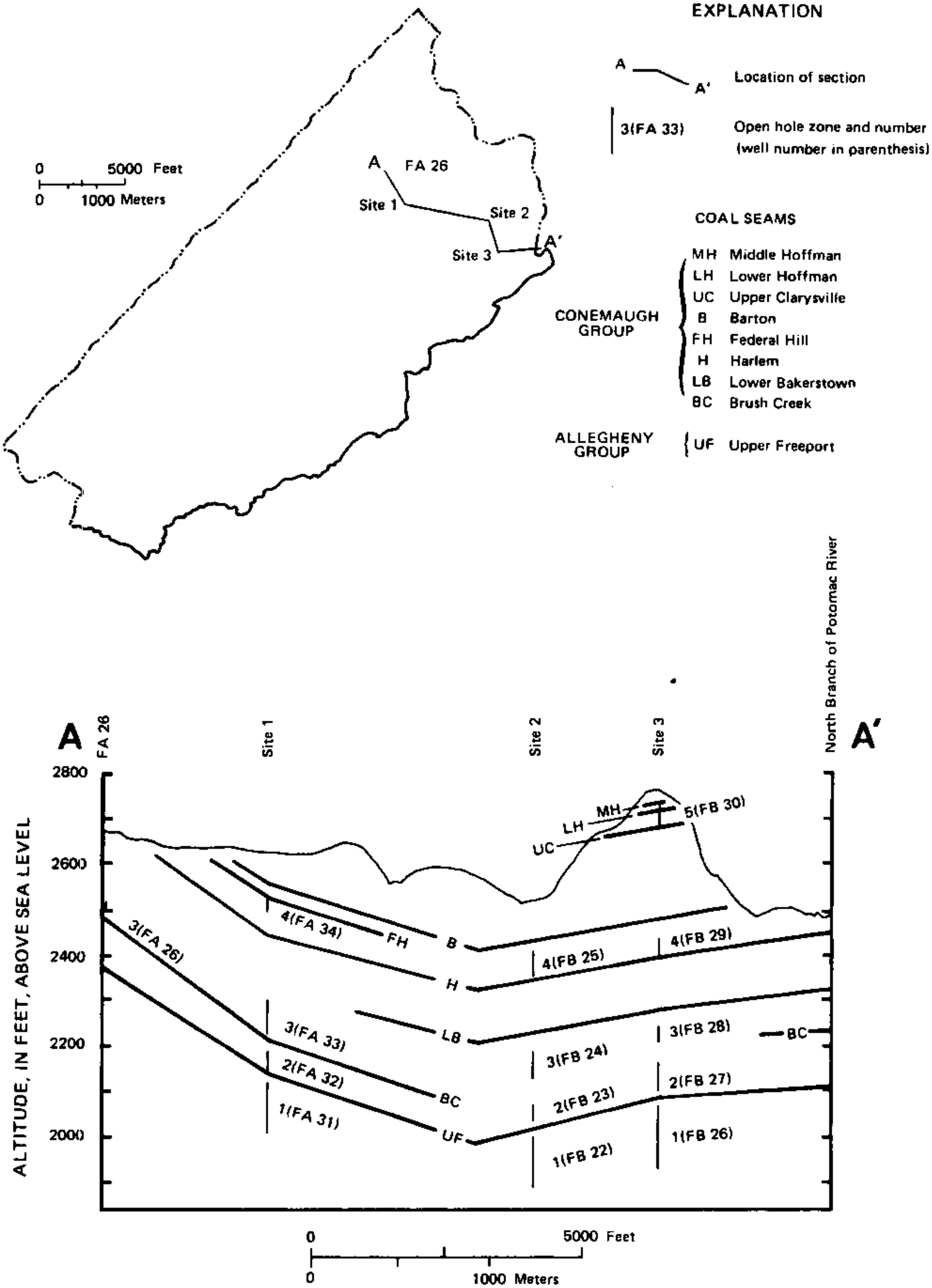


Figure 3.5-1.— Open-hole zones in relation to coal seams. (From Duigon and Smigaj, 1985, fig. 22.)

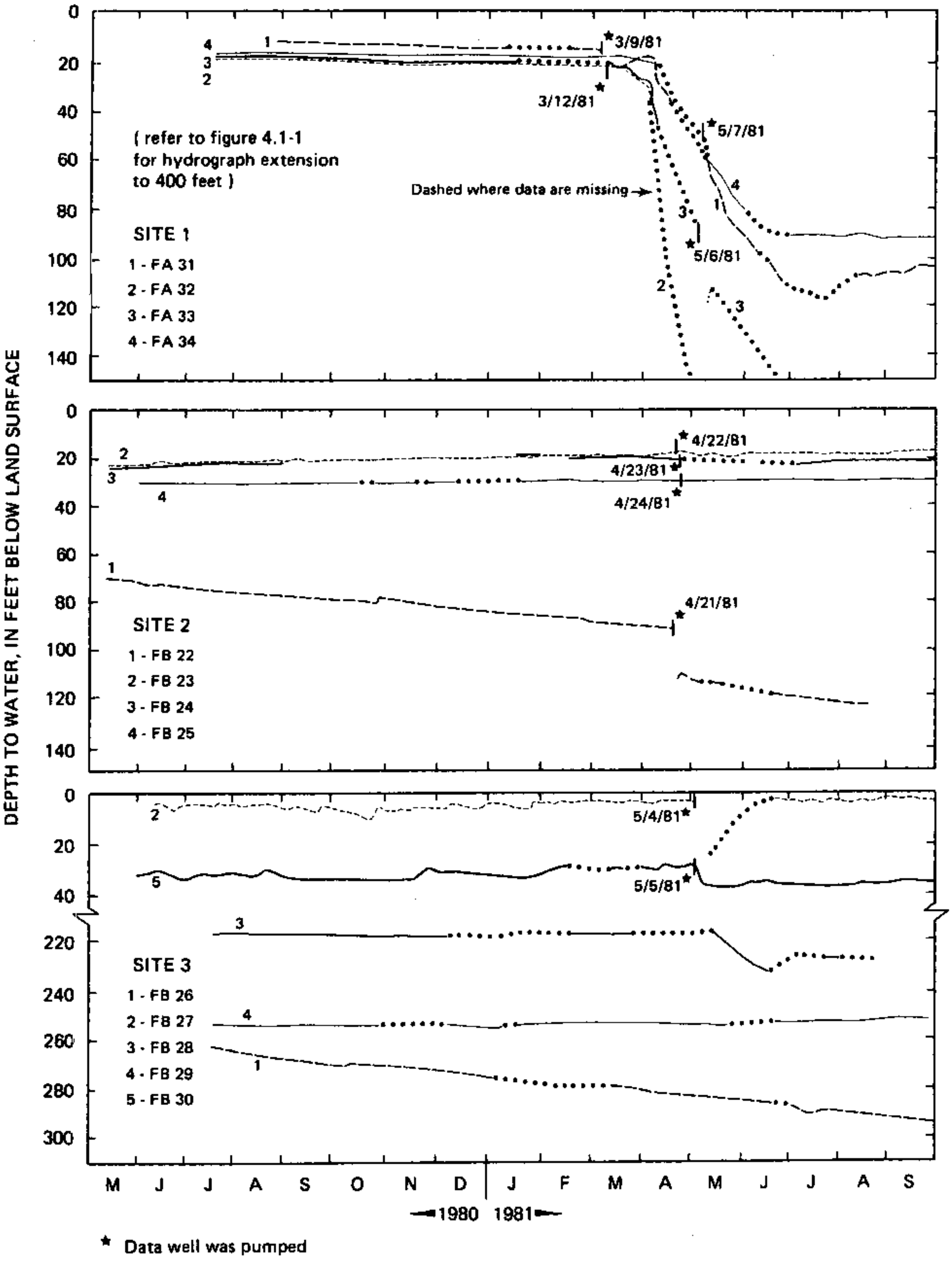


Figure 3.5-2.— Water-level variations at the observation wells at sites 1, 2, and 3. (From Duigon and Smigaj, 1985, fig. 24.)

3.6 GROUND-WATER QUALITY

SHALLOW FRESHWATER-FLOW SYSTEMS OVERLIE A DEEP, SALTY-WATER ZONE

Water-quality samples from streams, springs and wells indicates ground-water quality is different from surface-water quality.

The chemical quality of ground water, which was determined from laboratory analyses of samples collected from eight wells, three underground-mine discharge sites, three springs, and one site within the mine, is presented in table 3.6-1. The small yields of the deeper wells precluded pumping enough water to ensure that the samples represented formation water. Values of pH as large as 11.6, in some samples from deeper wells, are greater than the usual pH limits of near-surface environments (11) and indicate that the water may have reacted with the cement grout at the bottom of the casing. Consequently, some of the analyses in table 3.6-1 may not be representative of formation water. The pH of water in wells FA 31 and FA 32 was 10.4 and 11.6, respectively. However, a sample from a wall seep inside the mine near the wells and at about the same depth had a pH of 7.6, which seems reasonable for aquifers when compared with similar data from the area. The marked difference in pH of the well water and the mine-seep water further supports the conclusion that some of the well samples are not representative. Therefore, considerable care and judgment are needed in evaluating the chemical quality of ground water in relation to mining.

The potassium concentrations of several of the wells are nearly as large as, or larger than the sodium concentrations; this may be due to abundant potassium bearing minerals, such as potash-feldspar, muscovite, or illite in the rocks. Numerous stylolites in rock cores indicate that mineral solution has been extensive. Most of the sandstones are well cemented with silica, indicating that much precipitation has also taken place.

Well FA 31 was sampled from a depth of 1,131 feet, while it was flowing. The large sodium and chloride concentrations of 1,800 and 2,900 mg/L, respectively, show that the saltwater zone had been entered. Because the well was flowing, there must have been some mixing with water from other zones in the borehole.

The trilinear diagram (fig. 3.6-1) compares ground-water and surface-water samples according to relative concentrations of major ions. The well samples are distinct from the stream samples, although water from a shallow well, FB 25, appears to show mixing with water from the South Fork Sand Run. A sample collected inside the active mine resembles the sample from FB 25. The three abandoned-mine drainage samples (FA 35, draining the Buffalo Coal Company Mine in the Lower Bakerstown seam; GA 3 and GA 6, draining the Kempton Mine in the Upper Freeport seam) had much larger sulfate concentrations than the well samples and figure 3.6-1 indicates that the stream chemistry is strongly affected by these discharges.

Spring samples (GA 1, GA A, and GA 5) had smaller specific conductances than water from the wells (table 3.6-1), indicating the spring water is less mineralized. This condition may reflect shorter flow paths and residence times of water in these systems.

Table 3.6-1.– Chemical analyses of ground water.
[ft, feet; mg/L, milligrams per liter; ug/L, micrograms per liter; Site code: A-active mine wall; D-abandoned mine drainage; S- spring; W-well]

Site number	Type of site	Geologic group	Date of sample	Depth to top of sample interval (ft)	Depth to bottom of sample interval (ft)	Specific conductance, field (micromhos)	Specific conductance, lab (micromhos)	Field pH (units)	Laboratory pH (units)	Temperature, water (°C)	Hardness (mg/L as CaCO3)	Hardness noncarbonate (mg/L CaCO3)	Acidity total heated (mg/L as H)	Acidity (mg/L as CaCO3)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium dissolved (mg/L as Na)	Potassium dissolved (mg/L as K)
FA 20	W	Conemaugh	78-08-03	22	78	25	—	6.8	—	—	12	3	—	—	3.3	0.8	0.3	0.5
FA 31	W	Pottsville	80-02-11	488	2/1,131	—	9,470	—	8.0	—	300	99	—	—	90	18	1,800	4.7
		Allegheny	80-02-11	488	3/1,131	380	—	—	7.9	—	34	10	—	—	11	1.6	95	.7
		1/	81-03-10	470	606	420	286	10.4	11.0	9.8	64	0	—	—	24	1.0	10	7.9
FA 32	W	1/	81-03-12	430	473	2,600	2,910	11.6	11.8	10.0	710	—	—	—	280	1.7	13	41
FA 34	W	Conemaugh	81-05-07	96	115	141	161	7.0	7.6	14.8	82	8	—	—	24	5.4	.7	1.1
FA 35	D	Conemaugh	81-05-15	—	—	3,280	3,210	4.9	3.0	11.3	1,700	1,700	—	—	470	120	5.5	12
		do.	81-06-30	—	—	—	3,110	—	4.0	—	1,600	1,600	9.0	447	440	110	6.5	13
FB 22	W	1/	81-04-21	517	640	480	363	10.6	10.8	11.6	33	0	—	—	13	.2	.20	43
FB 23	W	Conemaugh	81-04-22	460	495	195	216	7.0	7.8	12.0	110	19	—	—	34	5.7	1.1	1.0
FB 25	W	do.	81-04-24	120	180	438	443	7.3	8.2	9.4	210	87	—	—	60	14	11	3.7
FB 30	W	do.	81-05-05	82	85	193	202	6.4	7.2	12.3	110	7	—	—	31	6.7	.4	1.6
GA 1	S	Conemaugh	81-10-29	—	—	86	—	6.9	—	11.0	—	—	—	--	--	--	--	—
GA 3	D	Allegheny	----	--	--	803	897	3.2	3.0	10.5	190	—	4.8	—	47	18	4.5	2.8
GA 4	S	Conemaugh	81-10-29	—	—	21	--	5.1	—	9.1	—	—	—	—	—	—	—	—
GA 5	S	do.	81-10-29	—	—	26	—	6.3	—	10.0	—	—	--	--	--	--	--	--
GA 6	D	Allegheny	70-08-25	—	—	1,020	1,690	3.4	2.6	10.3	—	599	—	—	90	32	56	3.5
Mine drip	A	do.	81-12-18	—	—	330	332	—	7.6	8.0	160	62	—	—	48	9.6	2.7	2.2

Site number	Alkalinity (mg/L as CaCO3)	Sulfate dissolved (mg/L as SO4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Nitrogen, NO2+NO3 total (mg/L as N)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	Phosphorus, total (mg/L as P)	Silica, dissolved (mg/L as SiO2)	Iron, suspended recoverable (ug/L as Fe)	Iron, total (ug/L as Fe)	Iron dissolved (ug/L as Fe)	Manganese, suspended recoverable (ug/L as Mn)	Manganese, total (ug/L as Mn)	Manganese, dissolved (ug/L as Mn)	Solids, residue at 180°C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Solids volatile, dissolved (mg/L)
FA 20	8	1.5	0.1	0.0	—	—	0.00	4.6	—	80	—	—	10	—	25	17	—
FA 31	200	.6	2,900	—	.03	—	.050	10	2,000	4,200	2,200	20	130	110	—	4,950	—
	24	.1	150	—	—	—	--	7.5	320	450	130	0	10	20	—	280	—
	79	8.4	2.1	.3	—	.11	—	8.4	—	—	780	--	—	5	106	111	—
FA 32	740	29	1.6	<.1	—	.01	—	9.5	—	—	170	—	—	10	1,360	821	—
FA 34	74	4.0	.5	.1	—	<.01	—	7.5	0	1,400	1,400	0	90	100	102	89	—
FA 35	0	2,100	2.5	.1	—	.04	—	31	60,000	290,000	230,000	0	5,700	6,000	3,360	2,980	—
	0	2,100	2.4	.2	—	.03	—	22	—	—	130,000	—	—	5,800	3,430	2,840	507
FB 22	98	12	1.3	.2	—	<.01	—	10	—	—	2,300	—	—	30	163	161	—
FB 23	89	14	1.0	.2	—	.01	—	6.3	—	—	40	—	—	120	120	117	—
FB 25	120	99	.6	.2	—	<.01	—	7.8	—	—	290	—	—	60	275	269	—
FB 30	98	7.2	1.1	.2	—	.02	—	7.8	0	3,600	3,800	0	260	290	121	119	
GA 1	--	—	—	—	--	--	--	--	—	—	--	--	—	—	—	—	--
GA 3	—	440	2.6	.4	—	<.01	—	33	2,000	52,000	50,000	100	1,800	1,700	—	—	—
GA 4	—	—	--	--	--	--	--	—	—	--	--	--	--	—	--	--	--
GA 5	--	—	--	--	--	--	--	--	--	--	--	--	--	--	--	—	--
GA 6	—	—	2.2	.8	—	—	—	43	—	85,000	—	—	2,500	—	1,000	—	—
Mine drip	97	68	0.9	.2	.41	—	<.01	6.8	1,600	2,300	750	0	120	120	222	198	—

1/ probably affected by grout and not representative of formation water. 2/ sampled at a depth of 1,100 feet. 3/ sampled at a depth of 870 feet.

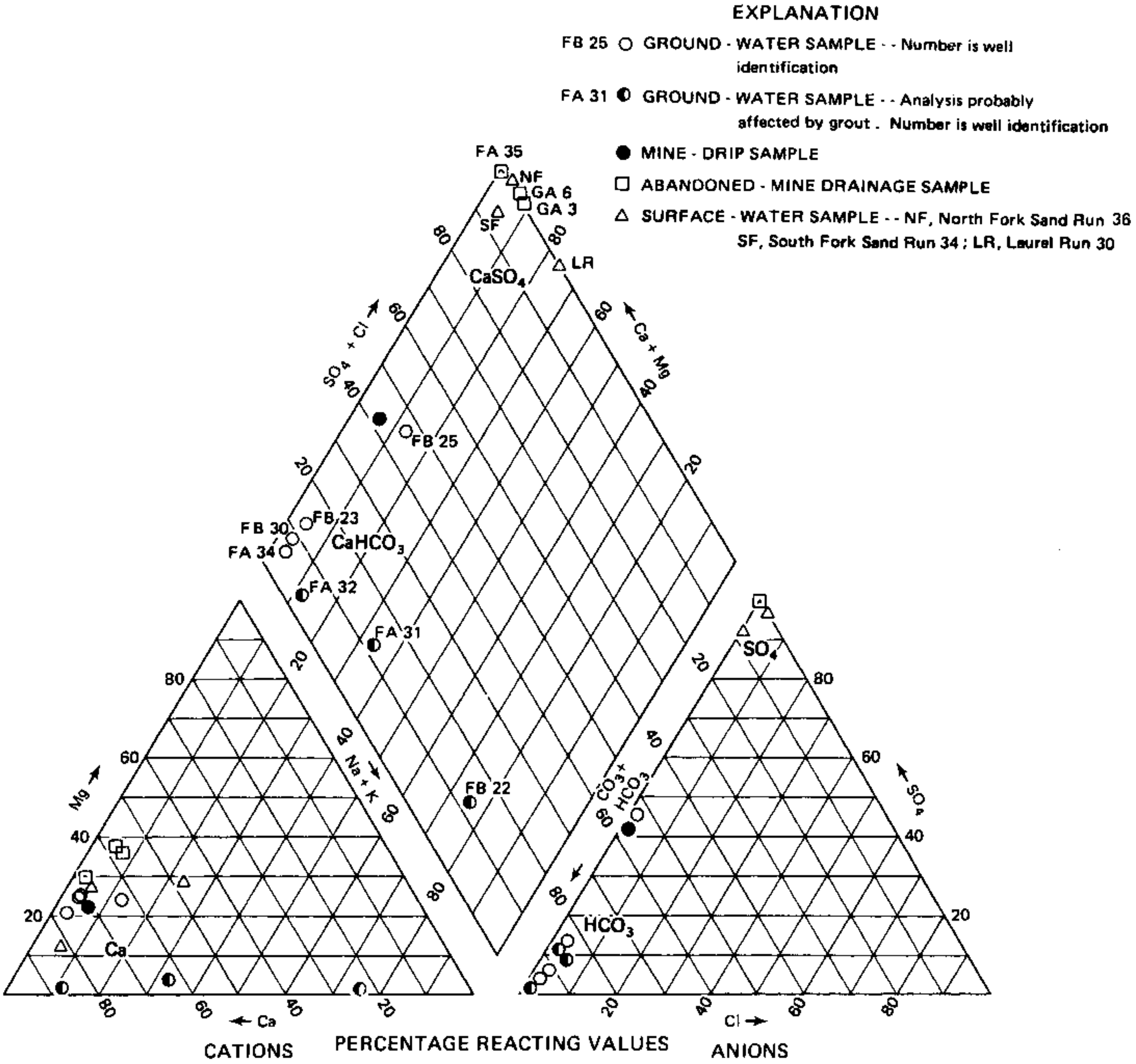


Figure 3.6-1.— Comparison of the chemical quality of ground and surface water in the general area..
(From Duigon and Smigaj, 1985, fig. 32.)

3.0 HYDROLOGIC SETTING

3.7 STREAMFLOW

QUANTITY OF STREAMFLOW IS AFFECTED BY PAST AND PRESENT MINING ACTIVITIES

Streamflows in the general area are from precipitation, abandoned and current mine drainage. Some streamflow is from treated mine pumpage and sewage from mine facilities.

Streamflows in Laurel Run, North Fork Sand Run, and South Fork Sand Run have been affected by abandoned mines and by current mining. Laurel Run, the largest of the streams, consistently receives drainage from the abandoned Kempton Mine (fig. 2.1-1). This drainage has been measured at sites GA 3 and GA 6. A tributary of Laurel Run, Chestnut Ridge Run, receives pumpage from the C mine (fig. 3.3-2), which is treated and discharged along with treated sewage from the mining facilities.

The North Fork Sand Run receives drainage from the abandoned Buffalo Coal Company mine in the Lower Bakerstown seam (fig. 2.1-1). This drainage has been measured at site FA 35. The flow at this site is much smaller than that from the Kempton Mine and ceases during dry periods.

The South Fork Sand Run receives treated pumpage from both the A and B mines (fig. 3.3-2), plus treated sewage from the mine facilities. Water is withdrawn for a coal-treatment facility from a pond about 1,200 feet downstream from this discharge point.

Figure 3.7-1 shows the hydrographs of daily flow, precipitation, and mine pumpage for May 1, 1980, to September 30, 1981. Table 3.7-1 summarizes steam-flow at the three gaging stations for the 1981 water year.

Table 3.7 1.– Summary of streamflow for water year 1981 (October 1, 1980 to September 30, 1981)
[ft^3/s, cubic feet per second; (ft3/s)/mi^2; cubic feet per second per square mile]

Station	Highest daily mean		Lowest daily mean		Annual mean		Annual runoff (inches)
	ft^3/s,	(ft^3/s)/mi^2	ft^3/s	(ft^3/s)/mi^2	ft^3/s	(ft^3/s)/mi^2	
North Fork Sand Run	47	24.6	0.32	0.168	4.79	2.51	33.7
South Fork Sand Run	52	33.5	.02	.013	3.7	2.4	[1]/ 33
Laurel Run	260	31.6	3.4	.413	26.4	3.21	43.1

[1]/ estimated—record incomplete

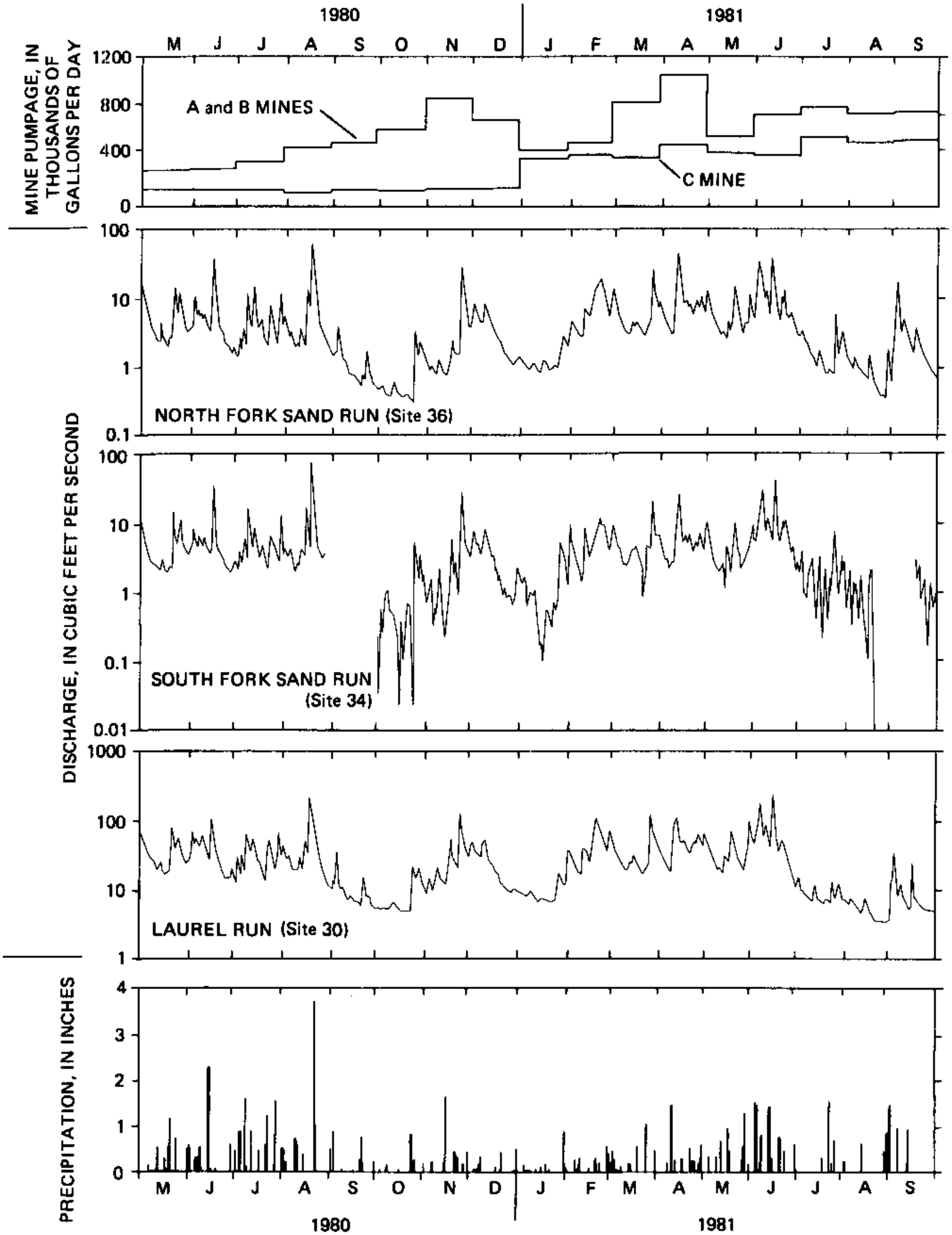


Figure 3.7-1— Mine pumpage, stream discharge, and precipitation for the period May 1, 1980, to September 30, 1981.
(From Duigon and Smigaj, 1985, fig. 14.)

3.0 HYDROLOGIC SETTING

3.8 SURFACE-WATER QUALITY

QUALITY OF STREAMFLOW IS AFFECTED BY PAST AND PRESENT MINING ACTIVITIES

Abandoned-mine drainage and effluent from mine-drainage treatment plants affect surface-water quality.

Field measurements were made and samples were collected periodically for a laboratory analysis at several stream sites (fig. 3.3-1). Ranges and median values for some of the physical and chemical characteristics are given in table 3.8-1. Temperature/specific conductance monitors provided hourly measurements at the three gaging stations. Specific conductance provides an approximation of the dissolved-solids concentration.

Figure 3.8-1 shows the variation of pH, specific conductance, and sulfate concentrations with discharge for three sites. The small pH (4.2) of the South Fork Sand Run was measured on a day that the acid mine-drainage treatment plant was not operating. The narrow ranges in pH of the South Fork Sand Run and Laurel Run may reflect the effects of the mine-drainage treatment plant and abandoned-mine drainage (site GA 3), respectively. These conditions also contribute to the large specific conductance of these two streams. The rate of change in specific conductance with discharge in the North Fork Sand Run is smaller than that of the other two streams, possibly because the mine-drainage contribution is relatively small. The sulfate-discharge relationships resemble the specific conductance-discharge relationships, for similar reasons.

Stream waters above points of abandoned mine discharges are less acidic than downstream and have small dissolved-solids concentrations. Some of them support fish.

Table 3.8-1. – Summary of chemical quality of selected surface-watersites (From Duigon and Smigaj, 1985, table 7) [mg/L, milligrams per liter; mg/L, micrograms per liter]

	pH (units)	Specific conductance (micromhos)	Alkalinity (mg/L as CO_3)	Acidity (mg/L as CO_3)	Solids sum of constituents dissolved (mg/L)	Turbidity (MTU)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Ca)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Iron, dissolved (mg/L as Fe)	Aluminum, dissolved (mg/L as Al)	Manganese, dissolved (mg/L as Mn)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Oxygen, dissolved (mg/L) (mg/L)	Silica, dissolved (mg/L as SiO_2)	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
Station	Laurel Run near Red Oak (Site 23)																	
Number of samples	6	6	0	5	6	1	6	6	6	6	6	0	6	6	6	3	6	6
Maxim an	3.1	915	–	159	397	6	41	17	5	2.6	12	–	1.6	290	2	23	25	1.1
Minimum	2.6	297	–	74	139	6	14	5.9	1.4	1.1	7.2	–	0.57	91	0.8	8.8	11	0.04
Median	3.1	200	–	104	285	6	29	11.5	3.1	1.9	10.5	–	1.2	200	1.8	10.3	19	0.22
Station	Chestnut Ridge Run near Red Oak (Site 26)																	
Number of samples	7	6	1	6	6	1	6	6	6	6	6	0	6	6	6	4	6	6
Maximum	6.9	540	8	10	364	8.1	73	15	7.3	3.6	0.22	–	1.4	250	3.5	12	6.9	1.3
Minimum	4.0	78	8	5	53	8.1	8.5	2.6	0.8	0.8	0.09	–	0.31	26	1.3	7.6	4.2	0.3
Median	5.7	163	8	5	101	8.1	18.5	4.5	2.2	1.3	0.16	–	0.48	56.5	2	10.6	4.9	0.6
Station	Dutch Run at Red Oak (Site 29)																	
Number of samples	6	5	0	4	4	0	5	5	5	5	5	0	5	5	5	5	5	5
Maximum	6.4	165	–	10	102	–	18	4.8	1.5	1.7	1.3		1.3	165	2.4	10.3	5.2	0.9
Minimum	4.5	98		5	67		9.4	2.9	0.7	0.8	0.26	–	0.89	98	1.4	5.4	4.5	0.1
Median	5.1	120	–	5	73	–	13	3.8	0.9	0.9	0.85	–	1.2	120	1.4	6	4.8	0.3
Station	Laurel Run at Dobbin Road near Wilson (Site 30)																	
Number of samples	21	20	9	18	16	11	18	18	18	18	19	5	20	20	17	16	18	14
Maximum	3.8	745	16	149	357	19	42	14	14	2.5	11	6.9	1.4	250	3.8	12.3	20	1.1
Minimum	2.4	143	0	10	69	0.4	9.8	3	0.8	0.8	1.6	1.7	0.47	42	0.9	4.9	5.3	0.16
Median	3	433	1	70	208.5	4.9	24	8.4	2.2	1.6	5	5.1	0.97	195	1.6	9.9	13	0.32
Station	North Branch Potomac River at Wilson (Site 31)																	
Number of samples	7	7	5	6	1	0	1	1	1	1	7	0	7	7	1	7	1	1
Maximum	4.8	2,000	2	41	110	–	28	3	1.1	.9	2	–	0.86	800	.9	12.5	4.1	.47
Minimum	3.5	189	0	5	110	–	28	3	1.1	.9	0.18	–	.24	68	0.9	7.7	4.1	.47
Median	4.4	588	0	23.1	110	–	28	3	1.1	.9	0.87	–	.50	240	.9	9.1	4.1	0.47
Station	South Fork Sand Run at Moon Ridge (Site 32)																	
Number of samples	5	4	0	2	4	0	4	4	4	4	4	0	4	4	4	3	4	4
Maximum	7	678	–	5	457	–	71	14	48	3	.18	–	1.7	300	2.2	9.7	7.4	.59
Minimum	6.3	183	–	0	111	–	21	4	3.1	1.1	0.06	–	0.12	56	1.1	8.4	3.7	.34
Median	6.8	261	–	2.5	158	–	28.5	4.9	17.1	1.7	.11	–	0.16	82.5	1.7	9.5	4.4	.47
Station	South Fork Sand Run near Wilson (Site 34)																	
Number of samples	17	6	8	12	15	10	15	15	15	15	17	5	17	17	5	13	15	11
Maximum	7.1	959	28	20	683	45	170	20	25	4.2	0.70	1.0	2.4	470	4.9	12.7	7.5	.92
Minimum	4.2	125	0	0	65	0.6	13	2.1	0.5	0.9	0	0	0.04	40	1.2	7.9	3.1	.20
Median	6.5	452.5	170	5	373	2	81	9.5	4.6	2.4	0.03	0.05	0.62	250	2.6	9.5	4.5	.39
Station	North Fork Sand Run at Moon Ridge (Site 35)																	
Number of samples	5	5	0	3	4	0	4	4	4	4	5	0	5	6	5	3	4	5
Maximum	6.8	122	–	25	72	–	9.4	3.1	.9	1.4	.16	–	1.3	280	2.6	11	5.6	.98
Minimum	3.4	46	–	15	39	–	6.4	1.9	.4	0.5	0	–	0.48	21	0.7	7	4.1	.11
Median	3.9	83	–	15	55	–	7	2.3	.5	0.8	.53	–	0.64	34.5	1	9.2	4.7	.31
Station	North Fork Sand Run near Wilson (Site 36)																	
Number of samples	18	7	3	4	15	10	5	5	5	5	17	5	7	7	5	12	15	13
5Maximum	6.9	547	31	60	332	8.6	68	15	1.4	2.1	12	.75	1.6	220	3.7	12.6	7.9	.97
Minimum	3.8	53	1	0	37	0.8	5.4	0.8	0.6	0.6	0.11	0.03	0.28	20	0.7	7.9	3.6	.2
Median	5.1	139	21	5	83	3.1	17	3.8	0.9	0.9	0.36	0.05	0.46	54	1.3	9.5	4.7	.45
Station	Sand Run at Wilson (Site 42)																	
Number of samples	7	7	3	4	7	0	7	7	7	7	7	0	7	7	7	6	7	6
Maximum	7.8	535	6	30	372	–	89	12	17	2.7	.49	–	.59	240	2.8	11.6	5.7	.58
Minimum	4.2	140	0	5	74	–	13	2.6	.6	0.8	0.01	–	0.32	45	1.2	7.3	3.7	.23
Median	6.3	345	1	10	213	–	46	7.3	4.5	1.7	.14	–	.46	130	1.5	9.3	4.6	.45

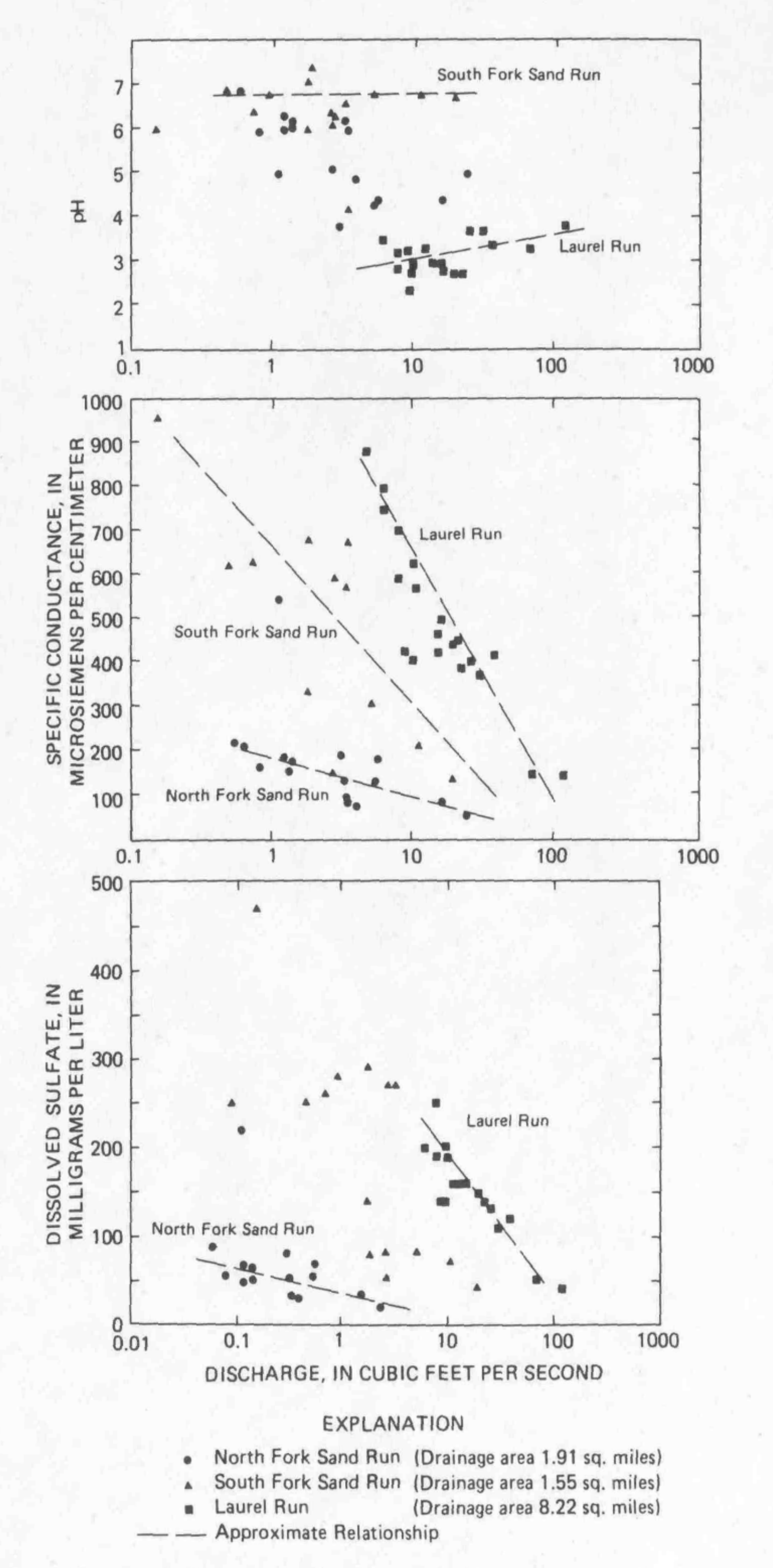


Figure 3.8-1.— Relationship of discharge to Ph, specific conductance, and sulfate.

4.0 HYDROLOGIC CONSEQUENCES DURING AND AFTER MINING

4.1 HYDROLOGIC BUDGET

BUDGET ANALYSES FOR BASINS REVEALED STORAGE LOSSES RESTRICTED TO AREAS IN THE VICINITY OF MINE WORKINGS

The change in storage for the three-basin area is related to the mine dewatering after a hydrologic budget analysis.

Large quantities of water must be pumped to allow underground-mining operations. The hydrologic properties of the overlying rocks are such that, although ground-water levels may be lowered significantly by the pumping, the entire overlying mass is not dewatered. In dewatered areas, flow may divert toward the mine. Aquifers may be recharged by leakage of water through streambeds where the water levels have dropped. Some springs and shallow wells may become dry as a result of lowered water tables.

As an example of how mining can affect water levels, a side heading in a northerly direction in the A mine extending from the main heading was begun in January 1981 (fig. 4.1-1), to provide drainage sumps for the mine. At the end of March 1981, water levels in all four wells at site 1 declined substantially (fig. 4.1-1). By July 1, when the side heading had approached to within about 300 feet of site 1, progress had been suspended. The water levels ceased to decline steeply by the end of July, and the water levels in two wells even rose.

The water level of the well completed in the zone above the Upper Freeport coal (FA 32) was most affected. The well completed in the zone below the coal (FA 31) was much less affected, owing to the effectiveness of the underclay as a confining bed. Excluding this zone, the declines appear to be inversely proportional to the logarithm of the distance of the zone above the coal (fig. 4.1-2).

Mining impacts on streams include changes in flow rates by discharge into or withdrawal from surface waters, and alterations of water chemistry. The South Fork Sand Run receives treated mine pumpage from the A and B mines. Pumpage from the C mine is discharged into Chestnut Ridge Run, a tributary of Laurel Run. Interbasin transfers may have decreased the flow of Laurel Run and increased the flow of the South Fork.

The withdrawal of water from South Fork Sand Run for use in the coal-treatment facility causes periods of very low flow. The withdrawals from, and discharges into, the South Fork greatly affect its streamflow. Discharge of treated water into Laurel Run represents a small fraction of that stream's flow, and withdrawals from it are not significant, so its pattern of flow is less affected by current mining. North Fork Sand Run has no significant additions or withdrawals, so its flow regimen may be representative of nonmining conditions.

Flooding of underground mine workings is prevented by pumping the water out of the mine, which lowers ground-water levels; this lowering, in turn, results in leakage of water through streambeds where the streams cross at or near undermined areas and, consequently, lowers stream flows. The streams are not likely to become completely dry, however, because the abundant precipitation maintains saturated zones, perched near land surface, that maintain streamflow. Average annual flows, however, may be expected to decline as longer stream reaches are undermined and leakage through streambeds increases.

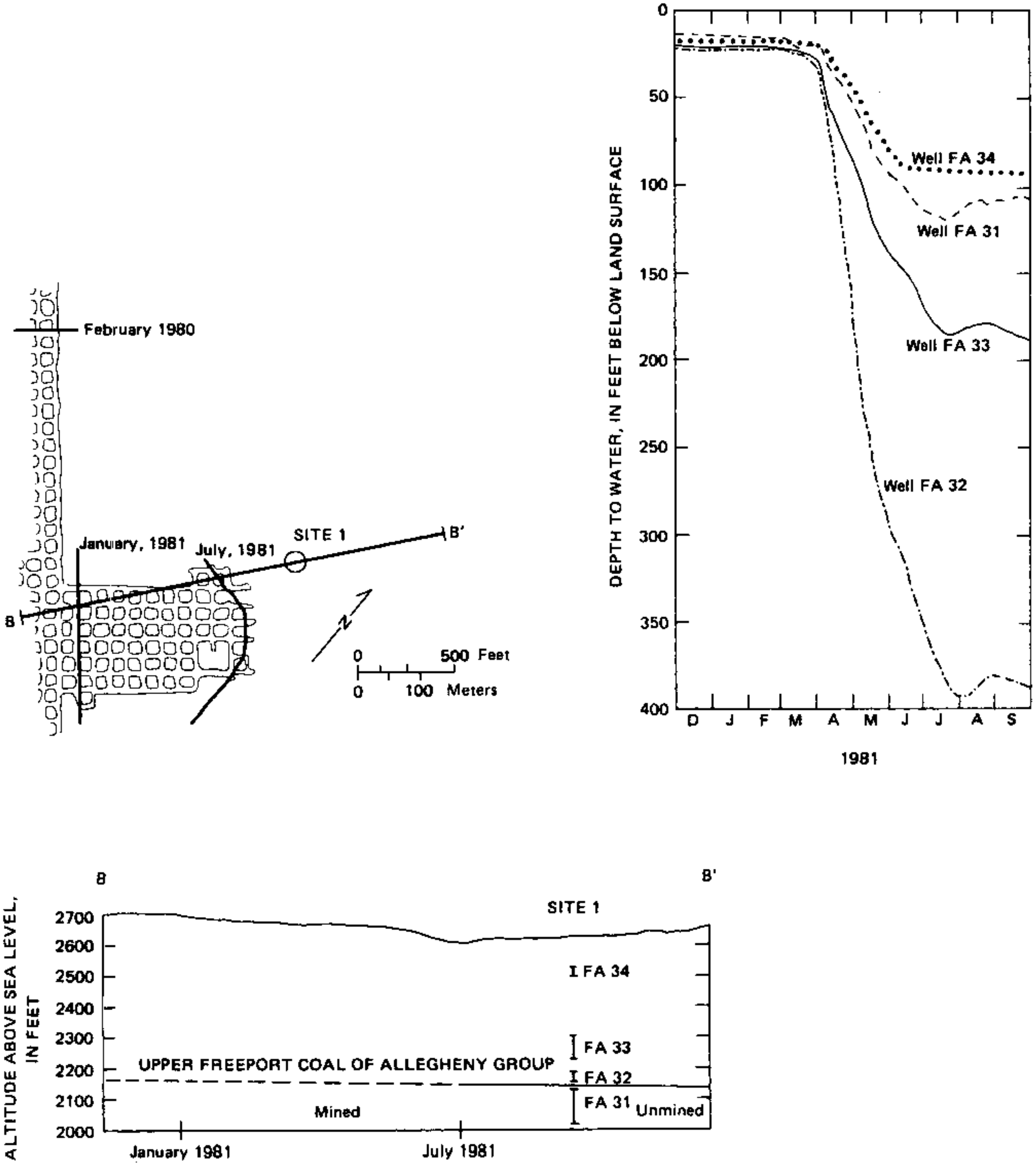


Figure 4.1-1.— Mine-map and cross section for site 1 with mining progress and associated water-level declines, as a consequence of mine dewatering. (Modified from Duigon and Smigaj, 1985, fig. 25.)

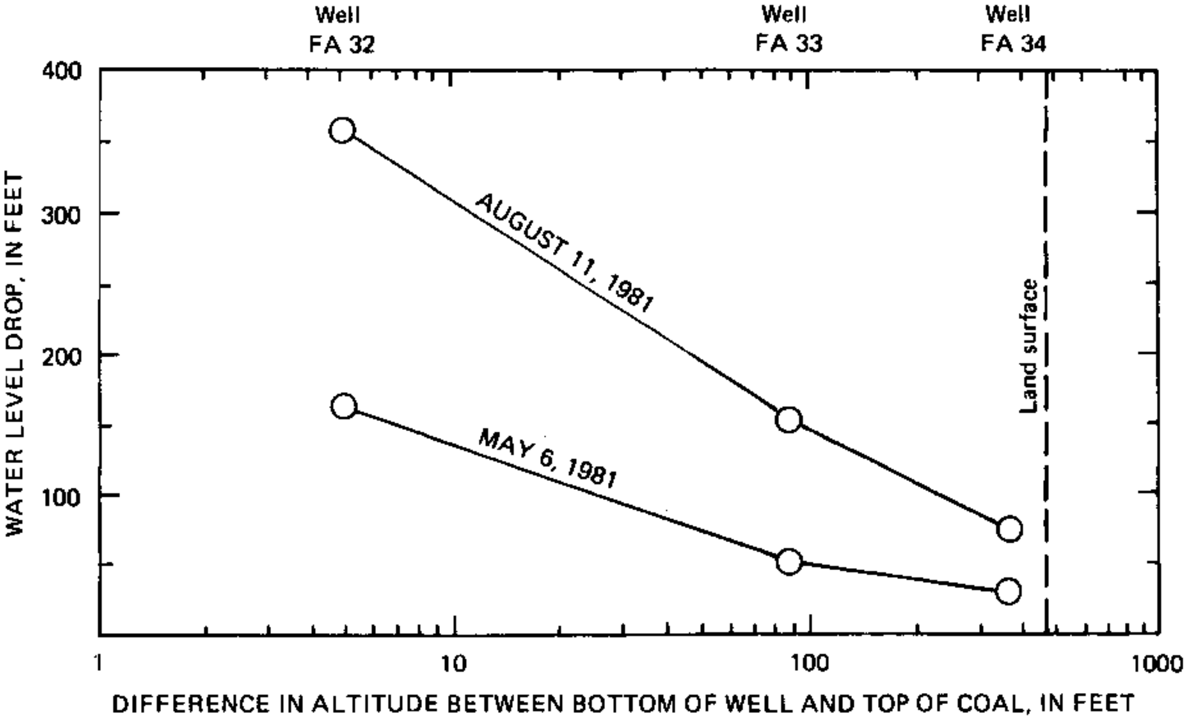


Figure 4.1-2. — Relationship between the water-level decline at site 1 and the difference in altitude between the well bottom and the Upper Freeport coal of the Allegheny Group.
(From Duigon and Smigaj, 1985, fig. 26.)

The general equation of the water balance, in simple terms, is:

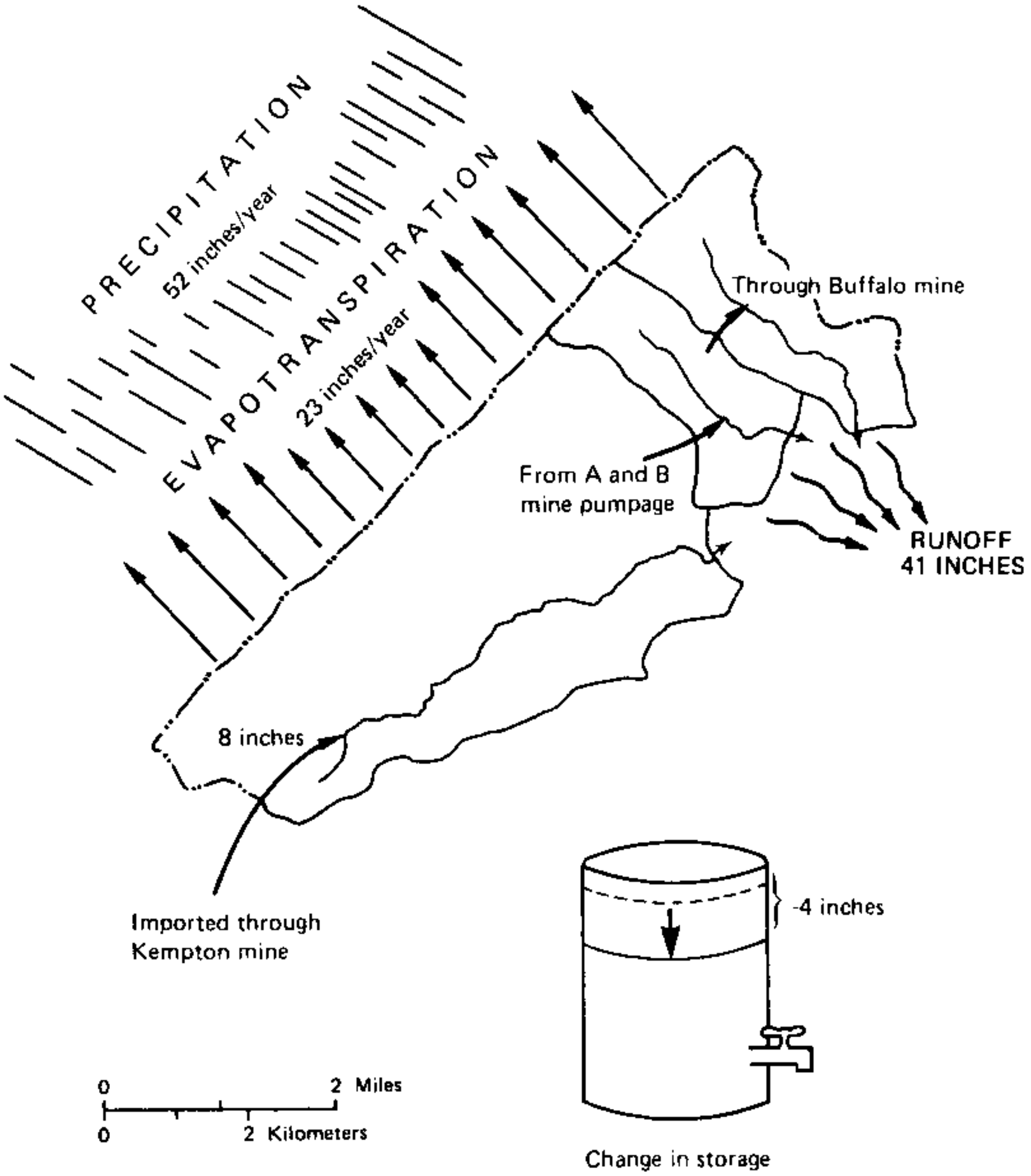
$$\text{INPUT} = \text{OUTPUT}, \quad \text{or} \quad P + I = R + ET + E + \Delta S$$

where P = precipitation,
I = water imported into the basin,
R = total runoff (discharge past the gage),
ET = evapotranspiration,
E = water exported outside the basin, and
ΔS = change in basin storage.

For the three basins, an estimation of the hydrologic budget is (all units in inches):

$$52 \text{ in.} + 8 \text{ in.} = 41 \text{ in.} + 23 \text{ in.} + 0 \text{ in.} - 4 \text{ in.}$$

Precipitation and total runoff were measured for water year 1981. Water imported by way of the abandoned Kempton Mine was measured at site GA 3 and was estimated for site GA 6. Other interbasin transfers were not quantified. Evapotranspiration was estimated by the method described in (21). Change in basin storage can be calculated as the residual term in the equation. Because the change was due to mine dewatering, it can also be estimated from the mine-pumpage data, and, in fact, the results are in agreement. For the area as a whole, the import term is important because of the contribution coming from the Kempton Mine. At present (1982), no water is exported from the area. If the individual basins are considered separately, then both imports and exports need to be evaluated because of the amount of interbasin transfers of mine pumpage and the extent of underground mines.

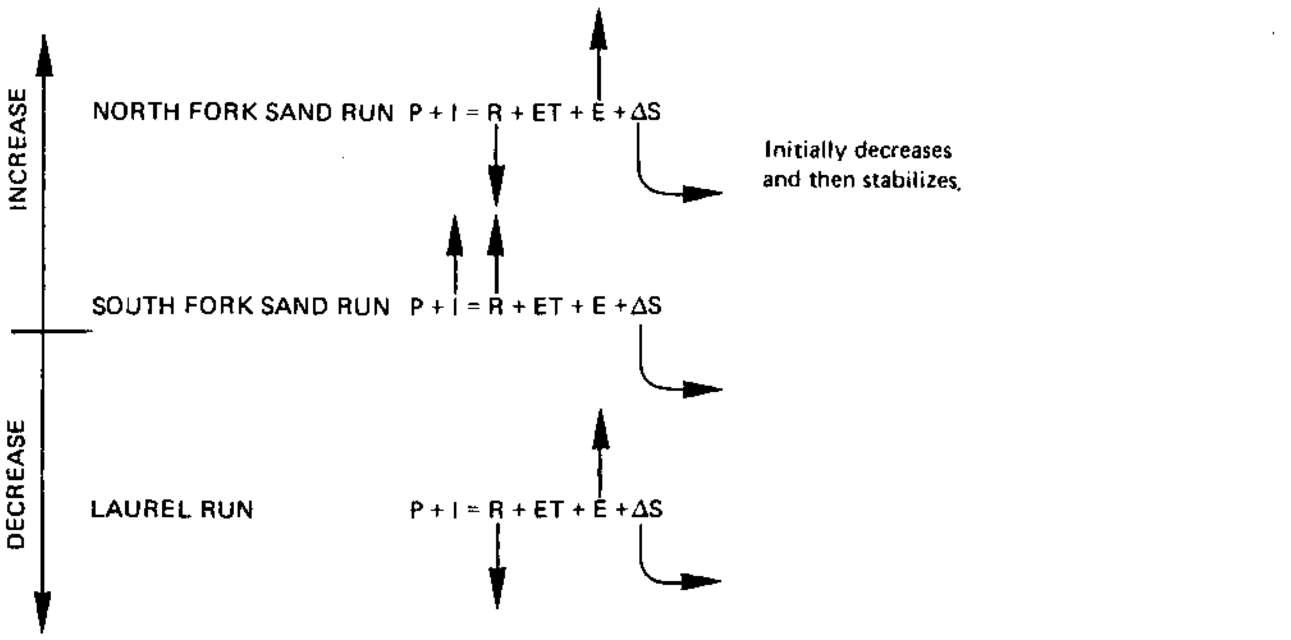


$P + I = R + ET + E\ \underline{1}/ + \Delta S$; $\underline{1}/\ E = 0$; no water is exported from the basin.

Figure 4.1-3.— Approximate hydrologic budget for water year 1981. (October 1980-September 1981). Dashed arrows indicate inter-basin transfers through abandoned mines or active mining operations. (From Duigon and Smigaj, 1985, fig. 33.)

Figure 4.1-3 shows the relationships of the terms of the budget. Precipitation and evapotranspiration are assumed to be uniform throughout the area. For the three-basin area, about 4 inches has been lost from storage for the 1-year period. This loss represents water pumped out of active mines. Water-level declines did not spread very far from the undermined area; storage losses were concentrated near mine workings. Ground-water storage will decline as dewatering continues. Figure 4.1-4 indicates the type of changes that might occur in the hydrologic budget.

The most immediately noticeable impact on water quality is the discharge of treated mine pumpage and wastewaters. The wastewater consists primarily of conventionally treated sewage—about 4,000 to 5,000 gal/d from each mine. In addition, dewatering of each mine produces about 670,000 gal/d. One facility treats water from the A and B mines and discharges into the South Fork Sand Run. Another facility treats water from the C mine, and discharges into Chestnut Ridge Run. Mine waters are neutralized by reaction with lime, a process which decreases the acidity but increases the dissolved-solids content. This has had a greater impact on South Fork Sand Run than on Laurel Run, because South Fork Sand Run receives more treated mine drainage, which constitutes a greater fraction of the stream's total flow.



where P = Precipitation
I = Water imported into the basin
R = Total runoff (discharge past the gage)
ET = Evapotransporation
E = Water exported outside the basin
ΔS = Change in basin storage

Figure 4.1-4.— Relationship of hydrologic budgets during mining to hydrologic conditions before current mining began.

POST-MINING SUBSIDENCE FRACTURES AFFECT GROUND WATER AND SURFACE WATER

> Post-mining subsidence fractures may cause increased base flows and some acid input to streams. Collapse into mine voids will allow greater rates of vertical movement of ground water.

After cessation of mine dewatering, water levels will rise, and recharge from streams may diminish, although infiltration may generally be increased throughout the area. Fracturing, caused by mining and post-mining subsidence, will change the hydrologic properties of the rocks, resulting in new equilibria which may be characterized by a hydraulic-head distribution different from the pre-mining distribution. As a possible consequence, water levels may not recover fully under hilltops, and gradients will flatten.

Fractures created by subsidence into mine voids may cause hydraulic conductivity to increase. The rocks in the area may have very small initial permeability, and increases in secondary permeability, due to subsidence, will probably be significant. Because sections of the rock mass will become hydraulically linked, transmissivity over the area will increase. The rock mass will be able to store greater quantities of water as a result of the increase in fracture volume.

Flow paths may be altered as a result of fracturing. As flow-impeding layers are breached, perched zones may leak downward more readily. This condition may diminish lateral flow components, at least locally, and affect the flow of springs emanating from outcrops of perched zones. The mined coal seam will be a very permeable zone, despite collapse of overburden, and its configuration will exert a significant control on flow directions; this condition may increase the movement of ground water between surface-water basins. Because flow velocities may increase as a result of increased secondary permeability, ground water may move more rapidly to discharge zones along streams. The flow systems above the coal seam will be affected the most. The deeper flow system will be much less affected, owing to less fracturing and the sealing effect of the underclay.

Alteration of ground-water flow paths can effect changes in water quality, owing to the mixing of waters with different chemistries, exposure of zones of different mineralogies to increased solution, and changes resulting from the water's contact with atmospheric oxygen and carbon dioxide. One consequence of coal mining has been the discharge of acid waters from mines no longer in operation. Two such mines in the study area have been described in previous sections. These confirm that acid mine drainage is a potential problem in this environment. Much emphasis in the literature has been given to minimizing contact of water seeping into mines with air because of the acid-producing oxidation of pyrite and other sulfide minerals. However, pyrite can oxidize in mine waters essentially devoid of oxygen (1,2). The sealing of mine entrances and dewatering wells upon completion of mining will decrease the input of oxygenated water to the mine voids and the number of concentrated discharge points. Subsidence fractures, if sufficiently developed, could allow upward movement of mineralized water from the mined seam. Barrier pillars between the mines may retard the flow along the direction of synclinal plunge. The water filling the mine voids will become mineralized and acidic, and some of it will emerge at the surface.

Figure 4.2-1 indicates the types of consequences on streamflow that may be expected after the cessation of mining. The post-mining hydrologic budget of the three basins will show some differences from pre-mining conditions, primarily in response to the creation of numerous fractures. Near-surface fractures will allow greater amounts of ground-water recharge.

Base flows may increase (8) and the magnitudes of high flows may decrease because of increased infiltration. Total runoff may increase or decrease, depending on the amounts of water transferred into or out of the individual basin by way of the mined coal seam. Figure 4.2-2 summarizes the expected alterations in the hydrologic budget of the three sub-basins after mining ceases.

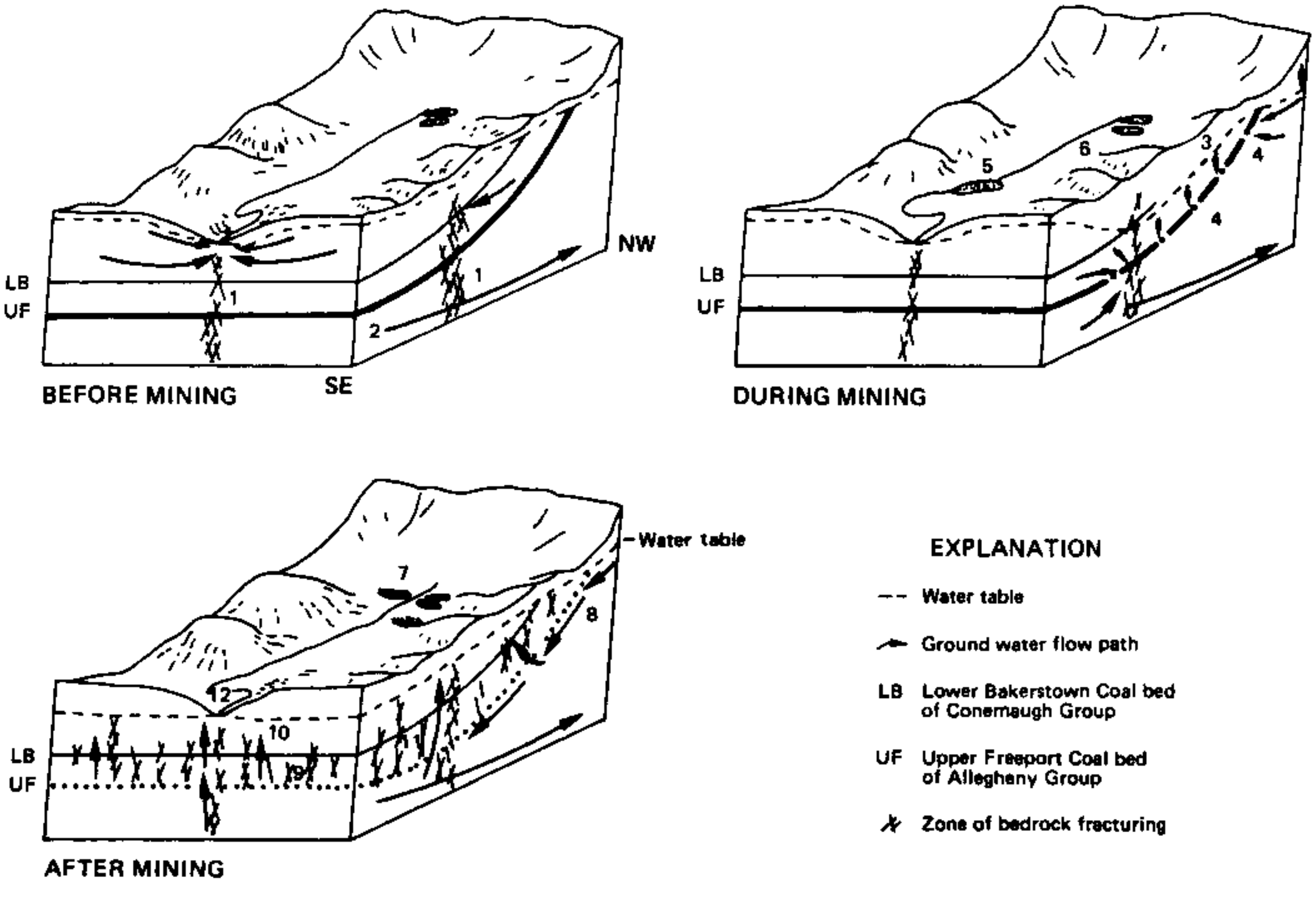
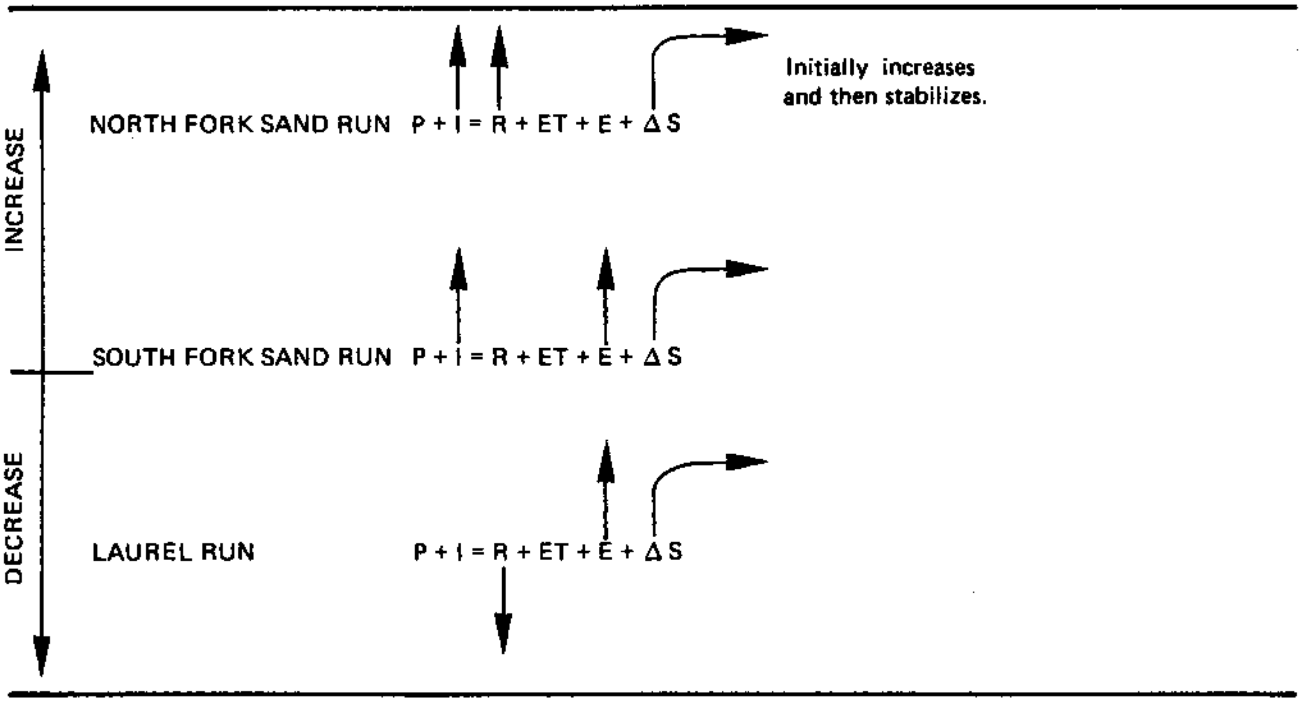


Figure 4.2-1.— Possible consequences of underground mining on the hydrologic system. The block corresponds approximately to the basin of the South Fork of Sand Run.
(From Duigon and Smigaj, 1985, fig. 34.)



where P	=	Precipitation
I	=	Water imported into the basin
R	=	Total runoff (discharge past the gage)
ET	=	Evapotransporation
E	=	Water exported outside the basin
ΔS	=	Change in basin storage

Figure 4.2-2.— Postulated relationship of post-mining hydrologic budgets to hydrologic conditions before current mining began.

5.0 POST-MINING HYDROLOGIC MONITORING

POST-MINING HYDROLOGIC MONITORING DETERMINES LONG-TERM HYDROLOGIC IMPACTS

Most of existing hydrologic monitoring plan can be included in the post-mining plan, although fewer recording instruments need to be maintained.

Post-mining hydrologic monitoring will be needed to determine lasting impacts. Most of the existing data-collection network can be utilized. The streamflow-gaging stations would continue to record stream stage, temperature, and specific conductance. Flows at the non-instrumented stations may also be measured, and the relationship compared to earlier relationships.

Although wells deeper than the Upper Freeport coal will be destroyed as mining passes through them, measurement can be made in the others. The integrity of the wells will need to be checked after the area is mined out to determine if casing or grout seals become damaged by subsidence.

At this time, field measurements of temperature, pH, specific conductance, dissolved oxygen, alkalinity, and acidity can be made periodically at the same sites previously measured, including wells. It would also be desirable to collect samples at the three gaging stations and the wells for laboratory analyses of major ions, aluminum, iron, manganese, and residue on evaporation; selected samples would also be analyzed for dissolved trace metals.

The frequency of measurements and sample collection and the duration of post-mining monitoring can be determined as the post-mining data are analyzed. An evaluation of climatic conditions is needed to determine whether stream flows and water levels are representative of average conditions.

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