GROUND-WATER STUDY 7

by

Hugh E. Bevans

TABLE OF CONTENTS

Page

1.0 Abstract 227
2.0 Geologic setting 229
  2.1 Surface geology. 229
  2.2 Stratigraphy of coal beds 232
3.0 Hydrologic setting 234
  3.1 Physiography and climate 234
  3.2 Hydrologic monitoring network. 235
  3.3 Ground-water occurrence and availability at pre-mining 237
  3.4 Pre-mining ground-water-quality conditions 239
  3.5 Pre-mining base flow 241
  3.6 Base-flow quality 243
4.0 Hydrologic impacts of coal mining.. 245
  4.1 Ground-water occurrence and availability 245
  4.2 Ground-water quality 247
  4.3 Base-flow quantity. 248
  4.4 Base-flow quality 251
5.0 References 255

LIST OF ILLUSTRATIONS

Figure Page

2.1-1. — Map showing surface geology and coal outcrops 230
2.2-1. — Generalized stratigraphic column of the Krebs and Cabaniss formations 233
3.2-1. — Map showing the hydrologic monitoring network 236
3.3-1. — Geologic log for well 15 of the hydrologic-monitoring network 238
3.5-1. — Graph showing flow-duration curves for selected streams draining unmined areas 242
4.1-1. — Diagrams showing typical examples of coal mining creating or impairing aquifers in the study area 246
4.3-1. — Graph showing modified flow-duration curves for selected streams draining coal-mined areas. 249
4.3-2. — Diagram showing surface-mine aquifer discharging into an adjacent stream 250

4.4-1. — Relationship of percentage of drainage area surface mined to (1) mean specific conductance, (2) mean concentration sulfate ion, and (3) mean concentration of dissolved solids during base-flow periods 253

LIST OF TABLES

Table — Page

2.1-1. — Description of the surface rocks 231
3.4-1. — Water-quality data from wells in unmined areas 240
3.6-1. — Water-quality data from streams draining unmined areas during base-flow periods 244
4.2-1. — Water-quality data from wells in coal-mined areas 247
4.4-1. — Mean values of selected water-quality parameters and constituents sampled in streams draining coal-mined areas during base-flow periods, 1976-80 251
4.4-2 . — Results of correlation and regression analyses relating the percentage of drainage area strip mined to (1) mean specific conductance, (2) mean concentration of sulfate ion, and (3) mean concentration of dissolved solids during base-flow conditions 254

1.0 ABSTRACT

Geology and Occurrence of Coal

The mine area is in the Osage Plains division of the Central Lowlands physiographic province. The bedrock is of Pennsylvanian age and consists of alternating beds of shale, siltstone, limestone, sandstone, coal, and underclay. These rocks dip to the northwest at about 20 feet per mile. Unconsolidated deposits of silt, clay, sand, and gravel of Quaternary age occur in stream valleys incised into the older Pennsylvanian bedrock.

Hydrogeology

The area has a humid-continental climate and receives average annual precipitation of about 40 inches, almost all in the form of rain. Topographic relief is low, but the predominantly shale bedrock and soils having slow infiltration rates cause most of the precipitation to move as runoff into streams. Base streamflow is poorly sustained because few aquifers are capable of providing sufficient water to maintain it.

Unconsolidated valley-fill deposits and shallow bedrock aquifers sometimes yield water of adequate quantity and quality to meet domestic needs. The quality of ground water usually depends on the geochemistry of the rock unit that yields it. Limestone rocks yield calcium bicarbonate type water, shales yield water with large concentrations of sulfate, and sandstones yield water with relatively small concentrations of dissolved solids. Wells completed in alluvial terrace deposits yield water that reflects the geochemistry of upstream and adjacent rock outcrops. Shallow aquifers are susceptible to contamination, mining disturbance, and drought. Deeper aquifers near the base of the Pennsylvanian System and in the Mississippian System yield water that is too mineralized to meet any water-use requirement.

Mining Method

The area has yielded about 300 million tons of bituminous coal, primarily from underground mines in the Weir-Pittsburg coal bed. An estimated 640 million tons of coal reserves remain for surface mining, primarily in the Mineral, Bevier, Weir-Pittsburg, Rowe, and Croweburg coal beds. Surface mining has been the only method used to recover coal in the area since 1964 and will continue to be the predominant method of mining. Great thicknesses of overburden (as much as 100 feet) must be removed to mine the relatively thin coal seams (less than 4 feet) and large areas are disturbed during surface mining.

Probable Hydrogeologic Impacts

The probable hydrogeologic impacts of coal mining differ with hydrogeologic conditions and the method of mining. Few aquifers in this area that are used for water supply could be impaired by coal mining. Occasionally, valley-fill or shallow bedrock aquifers are used for domestic or stock-watering supplies. If these shallow aquifers or their recharge areas are disturbed by surface mining, both the quantity and quality of water yielded will probably decrease. Underground mining could dewater shallow aquifers or contribute acid mine discharge to them.

In this area mine spoils function as recharge areas and as aquifers that discharge to the

adjacent streams. The principal impact of coal mining here would be increased base flow and impaired quality of streamflow as a result of recharge received from the spoils.

Hydrologic Monitoring

Wells, seeps, and base streamflow were sampled in both mined and unmined areas for water-quality and -quantity analyses. Low-flow data were collected because discharges from abandoned coal mines may be a significant part of low flow in streams. Relationships were developed between the percentage of a drainage basin surface mined and concentrations of sulfate and dissolved solids in base streamflow. These relationships are adequate for estimating the effects of surface mining on the quality of base streamflow. Potentiometric surfaces were developed using lake, stream, and well water-level altitudes in combination with topographic maps.

2.0 GEOLOGIC SETTING

2.1 SURFACE GEOLOGY

Bedrock that crops out in the study area is of Pennsylvanian age and contains the commercially important coal beds. Unconsolidated Quaternary deposits overlie bedrock along stream valleys.

The surficial geology of the study area (fig. 2.1-1) consists mostly of shale, limestone, and sandstone beds of Pennsylvanian age and unconsolidated deposits of silt, clay, sand, and gravel of Quaternary age. The consolidated Pennsylvanian rocks dip to the northwest at about 20 ft/mi, exposing progressively older rocks from northwest to southeast. Pennsylvanian rock units exposed in the study area are, from oldest to youngest: Krebs Formation, Cabaniss Formation, Fort Scott Limestone, Labette Shale, and Pawnee Limestone. Generalized lithologic description of these bedrock units is presented in table 2.1-1. The Krebs and Cabaniss Formations contain coal beds. However, the commercially important coal beds, including the Weir-Pittsburg, Mineral, and Bevier coals, are in the Cabaniss Formation. The coal outcrop lines shown in figure 2.1-1 represent only the major coal beds at the surface in the study area. The outcrop lines do not represent the limit of good quality coal, as erosion has removed some coal and weathering has rendered some unusable.

Unconsolidated deposits of silt, clay, sand, and gravel of Quaternary age occur in stream valleys. The valleys are incised into the older Pennsylvanian bedrock.

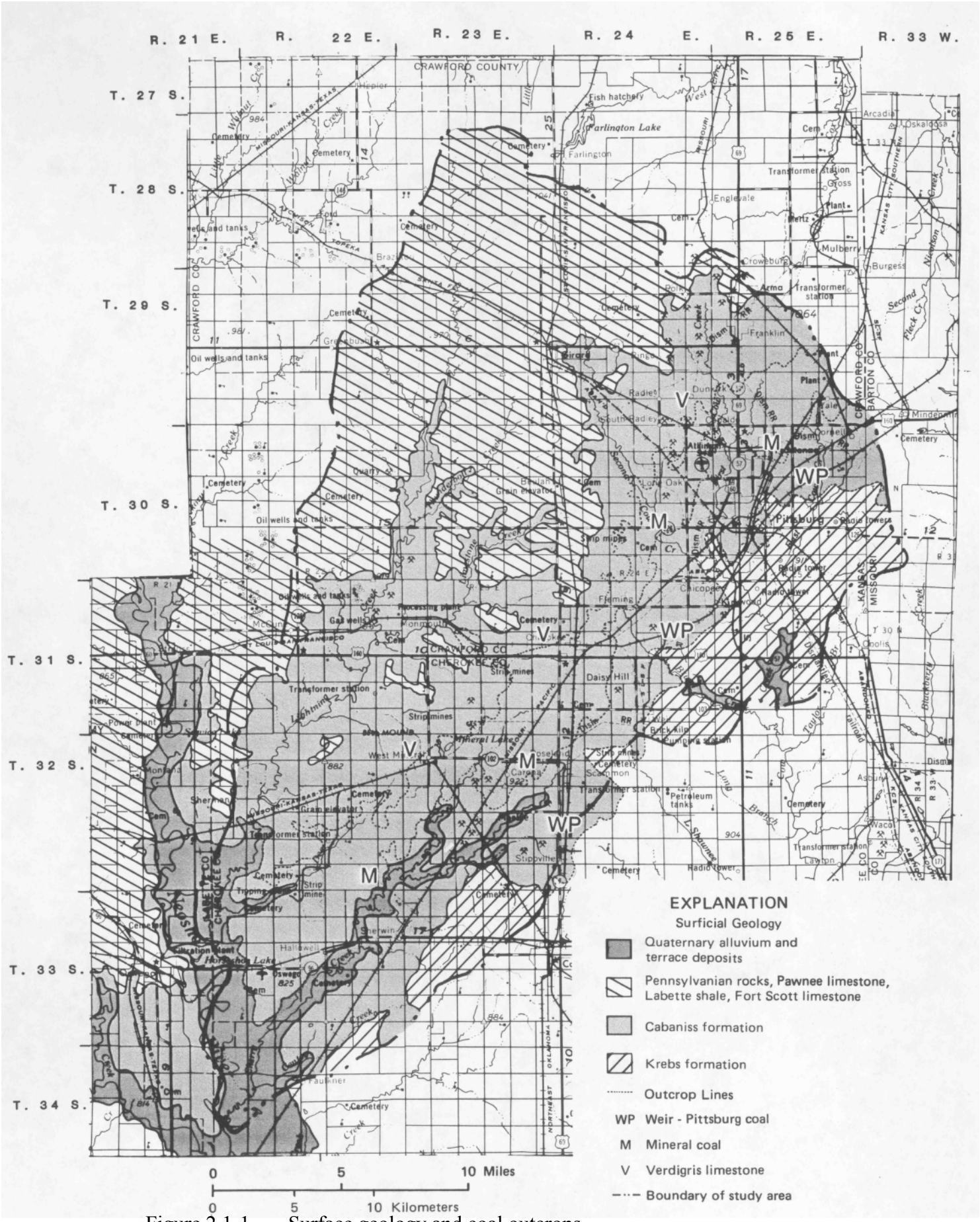

R. 21 E.
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 33 W.
T. 27 S.
T. 28 S.
T. 29 S.
T. 30 S.
T. 31 S.
T. 32 S.
T. 33 S.
T. 34 S.
CRAWFORD COUNTY
CRAWFORD CO
CHEROKEE CO
BARTON CO
KANSAS
MISSOURI
Farlington Lake
Hartshorn Lake
Mineral Lake
Pittsburg
Frontenac
Franklin
Arma
Crowebury
Mulberry
Burgess
Radley
Fleming
Chicopee
Daisy Hill
Stippville
Scammon
Weir
Mineral
Petroleum tanks
Radio tower
Transformer station
Strip mines
Cemetery
Oil wells and tanks
Gas wells
Processing plant
Grain elevator
Quarry
Power plant
Fish hatchery
Brick kiln
Pumping station
Dismantled railroad
Missouri-Kansas-Texas railroad
Kansas City Southern railroad
Atchison Topeka and Santa Fe railroad
Chicago Rock Island and Pacific railroad
Kansas City Southern railroad
Northeast Oklahoma railroad
Kansas City Southern railroad
Missouri-Kansas-Texas railroad
Wacoo
Lawton
Asbury
Oswego
Hallowell
Sherwin
Sherman
Tripping
Faulkner
Mineral
Carpenter
Scammon
Stippville
Weir
Pittsburg
Frontenac
Franklin
Arma
Crowebury
Mulberry
Burgess
Radley
Fleming
Chicopee
Daisy Hill

Table 2.1-1– Description of the surface rocks.
(From Seevers. 1975, and Howe, 1956.)

System	Geologic unit	Average thickness (feet)	Description
Quaternary	Alluvium	30	Silt, and silty sand, gray to grayish-brown, limonite stained in part; contains some sand and median to coarse gravel at base.
	Terrace deposits	25	
	Pawnee Limestone	20	Limestone, light-gray to white, fine crystalline, cherty, massive.
	Labette Shale	60	Shale, gray to greenish-gray to black; contains fine-grained sandstone and thin local limestone and coal bed.
Pennsylvanian	Fort Scott Limestone	20	Limestone, light-gray to brownish-gray, and black to light-gray shale, light-gray shale.
	Cabaniss Formation	225	Shale, light- to dark-gray; contains siltstone, limestone, sandstone, and coal. Commercially most important coal beds occur in this formation.
	Krebs Formation	225	Shale, light- to dark-gray, and fine-to median-grained sandstone; contains coal, under clay, siltstone, and some limestone locally.

2.0 GEOLOGIC SETTING

2.2 STRATIGRAPHY OF BEDROCK CONTAINING COAL BEDS

Coal beds of economic importance in the coal field occur as part of cyclothems.

The stratigraphy of the commercially important coal-containing Krebs and Cabaniss Formations is shown in figure 2.2-1. The Krebs and Cabaniss Formations exhibit typical cyclic successions (cyclothems) from the top of a given coal bed to the top of the next higher coal bed. These successions are commonly composed of five lithologic units occurring from the base upward:

(1) Dark shale or dark irregular limestone. The Krebs Formation commonly has clay-ironstone, with iron-sulfide minerals such as pyrite and marcasite associated with the dark shale; whereas, the Cabaniss Formation has phosphatic nodules in platy black fissile shale associated with the limestone.

(2) Unfossiliferous, evenly bedded gray shale. This is commonly the thickest unit in the lithologic succession.

(3) Either sandstone or impure nodular limestone. Sandstone ranges from massive to shaley or thin-bedded; most of it is fine grained, lenticular, and grades laterally into impure sandy limestone, called underlimestone.

(4) Underclay. This unit is least variable in lithology, is relatively uniform in thickness, and is commonly silty and slightly calcareous.

(5) Coal. This is the most economically important rock in the succession. Lateral extent, thickness, and quality are variable; however, many beds in the area are remarkably persistent.

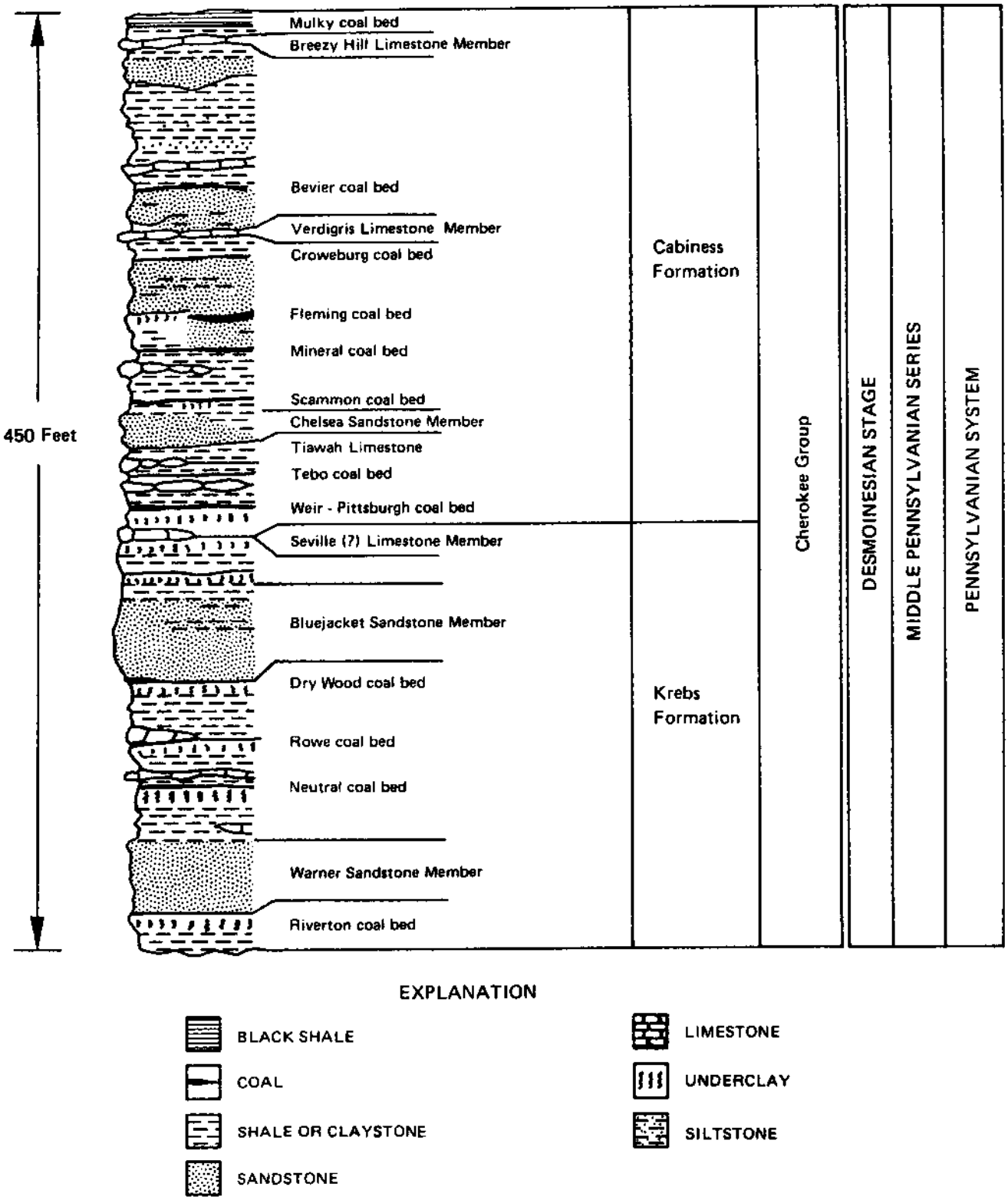


Figure 2.2-1.— Generalized stratigraphic column of the Krebs and Cabaniss Formations. (From Zeller, 1968.)

3.0 HYDROLOGIC SETTING

3.1 PHYSIOGRAPHY AND CLIMATE

The mine site is in a humid-continental climate and within flat rolling plains. Annual precipitation exceeds 40 inches, most occurring as rainfall from spring through summer.

The climate is humid-continental and is characterized by abundant precipitation, warm to hot summers, mild winters, moderate to high humidity, light to moderate winds, and little annual snowfall. The average annual precipitation exceeds 40 inches; about 75 percent of this occurs as rain from April through October. However, gentle rains of longer duration occur during the spring and fall.

The permit area is in the Osage Plains division of the Central Lowlands physiographic province. The natural topography is gently undulating with maximum relief less than 200 feet. In areas where shales crop out, the terrain is nearly flat and the stream valleys have broad flood plains. Areas where limestones crop out have more relief and narrower stream valleys.

3.0 HYDROLOGIC SETTING

3.2 HYDROLOGIC-MONITORING NETWORK

The hydrologic-monitoring network consists of 20 stream data-collection stations and 25 well and seep data-collection stations.

Hydrologic data were obtained at data-collection stations and sites shown in figure 3.2-1. Stream data were collected from April 1976 through March 1980. Most well data were collected from 1963 through 1965. Well 4 was sampled in 1947 and 1954. Wells 15, 21, and 22 were drilled and sampled in 1972. Wells 24 and 25, which are actually discharges from air shafts of abandoned underground mines, were sampled in March 1980.

Stream stations were used primarily to monitor base flow during periods of no overland runoff. This discharge is from shallow aquifers, which are providing the base flow. Sampling the base flow provides information on the water quality of shallow aquifers in the area drained.

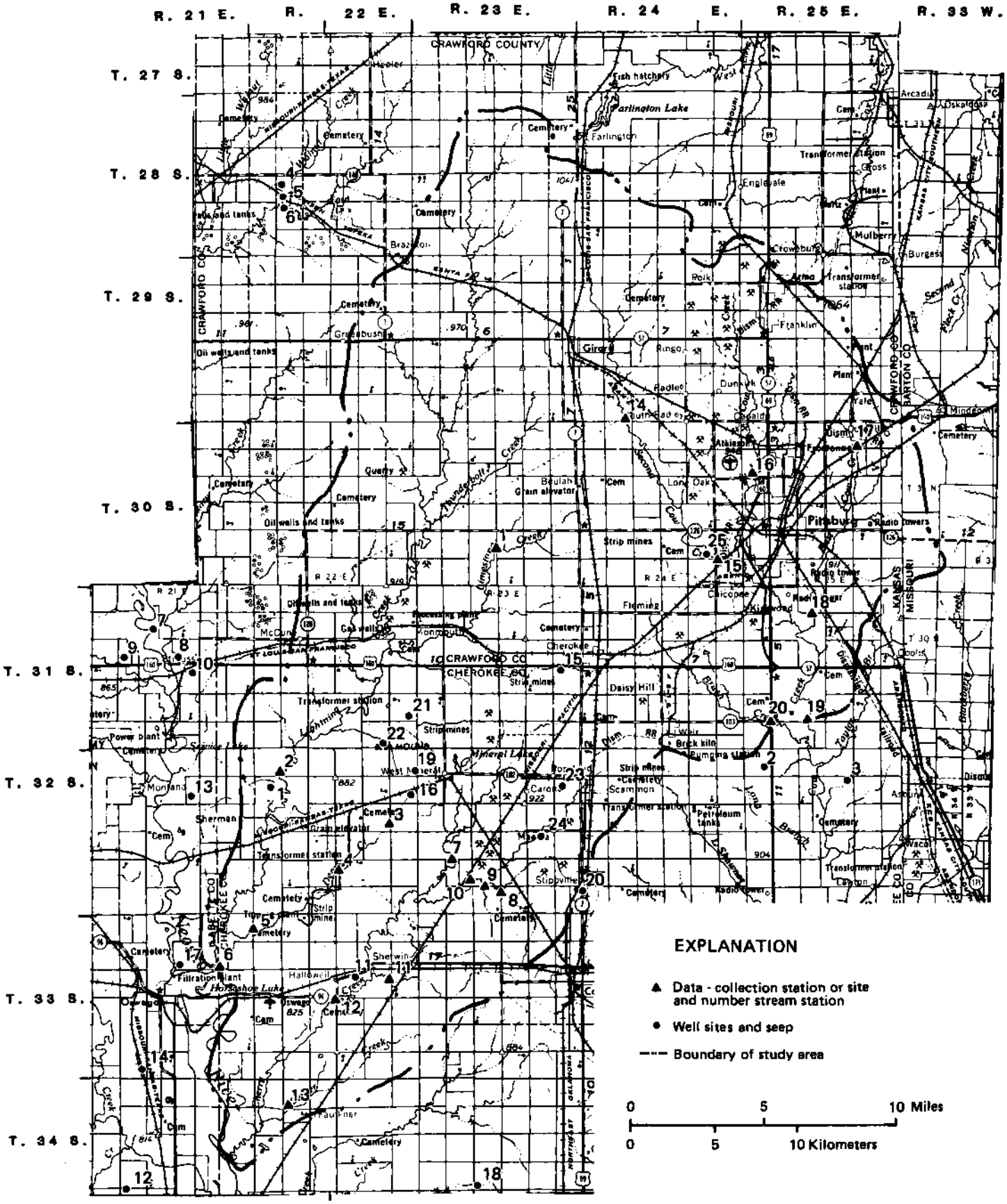


Figure 3.2-1.— Hydrologic-monitoring network.

3.3 GROUND-WATER OCCURRENCE AND AVAILABILITY AT PRE-MINING

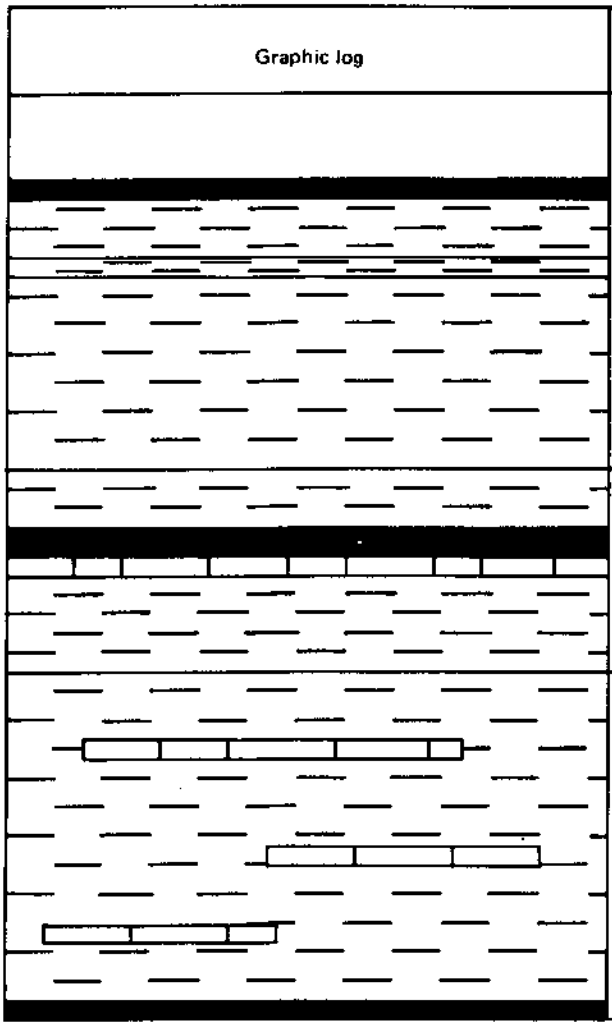
Aquifers capable of yielding quantities of water sufficient to satisfy water-use requirements are generally absent in the area.

The Krebs and Cabannis Formations of Pennsylvanian age have combined thicknesses ranging from about 200 feet in the south to 500 feet in the northwest. These formations contain relatively few aquifers capable of satisfying any water-use requirements. The rocks are mostly fine-grained marine shales and siltstones, which are poor aquifers. Continuous underclay beneath many of the coal beds impedes the vertical movement of ground water. Well 15 (T. 31 S., R. 23 E., sec. 24 on fig. 3.2-1) in the hydrologic-monitoring network, is 43-feet deep, is completed in the Cabaniss Formation, and yields only about 2 gal/min. The geologic log for this well is presented in figure 3.3-1. The well is open throughout its depth, but the principal water-producing zone is the sandy shale at 8.5 to 17.5 feet below land surface. Limestones and thin discontinuous sandstones can also produce small quantities of water. Typically, shallow bedrock wells yield less than 5 gal/min. Bedrock wells completed in the Warner Sandstone Member or Blue Jacket Sandstone Member of the Krebs Formation may yield as much as 50 gal/min, but the quality of the water is suitable for domestic use only near their outcrops.

Except during periods of drought, quantities of water suitable for domestic uses are yielded by wells completed in unconsolidated terrace and alluvial deposits of Quaternary age. Wells tapping these deposits can yield as much as 100 gal/min.

Ground-water recharge in the area varies with climate, topography, and rock and soil textures. Recharge occurs mainly during the spring when rainfall is plentiful and evapotranspiration loss is small. Recharge is greatest on alluvium developed on valley fill and terrace deposits where slopes are gentle and the soils are most permeable. Gently sloping surfaces developed on northeast- to southwest-trending outcrops of thick limestone units collect moderate amounts of recharge water. Very little recharge takes place on steep slopes or where the land surface is underlain by claypan or impermeable shale.

Water movement in alluvial and terrace deposits is towards the streams. Water in confined and unconfined bedrock aquifers moves downgradient. Water movement in unconfined bedrock aquifers is affected by the topography. Ground-water movement in perched aquifers is lateral toward the outcrop of the underlying impermeable bed. Estimates of the rate of ground-water movement in this general area range from 0.34 ft/d in unconsolidated alluvial and terrace deposits to 0.03 ft/d in upland bedrock aquifers (12).



Graphic log	Depth (feet)	Thickness (feet)	Lithologic description
	0.0 - 4.0	4.0	Silty clay loam
	4.0 - 4.5	0.5	Weathered Fleming coal bed
	4.5 - 7.5	3.0	Gray, mottled - brown shale
	7.5 - 8.5	1.0	Brown clayey shale
	8.5 - 17.5	9.0	Gray shale, sandy and clayey (principal aquifer)
	17.5 - 20.0	2.5	Dark - gray shale
	20.0 - 21.0	1.0	Mineral coal bed
	21.0 - 22.0	1.0	Hard, gray limestone
	22.0 - 27.0	5.0	Gray shale
	27.0 - 42.5	15.5	Dark - gray shale with 2 to 6 inch limestone streaks
	42.5 - 43.0	0.5	Scammon coal bed

Figure 3.3-1.— Geologic log for well 15 of the hydrologic monitoring network.

3.0 HYDROLOGIC SETTING

3.4 PRE-MINING GROUND-WATER-QUALITY CONDITIONS

The quality of ground water in the study area is variable; calcium, magnesium, bicarbonate, and sulfate are the major ions in solution.

The chemical composition of ground water in the area depends on the geochemical composition of the aquifer that is the source of the ground water. Water quality in alluvial aquifers commonly reflects the chemical composition of upstream adjacent rock outcrops. Wells 1, 2, and 3, are completed in alluvium adjacent to outcrop areas of coal and black shale containing iron sulfides. Water from these wells has large concentrations of sulfate ion relative to bicarbonate ion (table 3.4-1).Wells 4,5, and 6, are completed in alluvium adjacent to limestone outcrop areas. Water from these wells has large concentrations of bicarbonate relative to sulfate.

Wells completed in terrace deposits also reflect the geochemistry of the adjacent bedrock. Wells 10, 11, and 12 are completed in terrace deposits adjacent to outcrops of coal and black shale and also in areas of mines. Water from these wells has relatively large sulfate concentrations. Wells 7, 8, and 9 are completed in terrace deposits adjacent to limestone outcrop areas. Water from these wells has relatively large bicarbonate concentrations.

Wells 13-17, completed in the Cabaniss Formation, and wells 18-20, in the Krebs Formation, contain waters whose chemical types are dependent on the geochemistry of the aquifers. However, in most wells the particular rock unit that yields water is not known. Wells 14, 15, and 20 probably produce water from shale units based on the relatively large concentrations of sulfate ion. Wells 13, 16, and 19 probably produce water from limestone based on the relatively large concentrations of bicarbonate ion. Well 17 probably produces water from both shale and limestone units because the concentrations of sulfate ion and bicarbonate ion are roughly equal. Water from well 18, which is finished in the Bluejacket Sandstone Member of the Krebs Formation, has very small concentrations of both sulfate ion and bicarbonate ion.

Examination of dissolved-solids data indicates that large concentrations of dissolved solids are commonly associated with large concentrations of sulfate ion. However, large concentrations of dissolved solids may also be associated with large concentrations of bicarbonate ions. The pH values in table 3.4-1 are all in the neutral range. This condition indicates that sufficient amounts of carbonate rocks are present to buffer the acidity resulting from dissolution of iron-sulfide minerals associated with black shales and coal beds. Iron and manganese concentrations cannot be related to geologic source, perhaps because pH values are not low enough to keep the iron and manganese in solution.

Table 3.4-1.— Water-quality data fran wells in unmined areas
[ft, feet; mg/L, milligrams per liter; ug/L, micrograms per liter; < less than]

Well number	Land-line location (township-range-section)	Depth (ft)	Geologic source	Specific conductance (micromhos per centimeter at 25˚C)	PH (units)	Bicar-bonate (mg/L)	Sulfate (mg/L)	Dissolved solids (mg/L)	Total iron (ug/L)	Dissolved mangan-ese (ug/L)
1	32S-22E- 7	12	Alluvium	2,170	—	224	1,050	1,660	—	—
2	32S-25E- 6	25	do.	1,650	—	59	816	1,250	—	8,600
3	32S-25E-10	29	do.	2,500	—	212	898	2,020	40	600
4	28S-22E-20	35	do.	—	7.1	454	26	451	—	220
	28S-22E-20	35	do.	—	7.1	446	37	470	800	210
5	28S-22E-20	50	do.	—	7.2	454	40	496	600	260
6	28S-22E-20	23	do.	—	7.2	588	51	630	2,200	<10
7	31S-21E- 9	28	Terrace deposits	680	—	478	20	439	9,200	1,000
8	31S-21E-15	18	do.	620	—	256	116	406	7,200	200
9	31S-21E-17	30	do.	970	7.4	226	118	650	70	<10
10	31S-21E-22	33	do	2,210	—	393	922	1,710	30	220
11	32S-21E-10	23	do.	1,420	7.0	528	201	905	30	1,100
12	33S-22E-16	64	do.	1,480	7.9	146	715	1,160	590	<10
13	32S-21E-10	52	Cabaniss Formation	850	7.7	422	.0	504	490	<10
14	33S-21E-32	35	do.	1,090	—	105	458	835	2,000	<10
15	31S-23E-24	43	do.	1,750	8.0	256	872	1,470	2,700	330
16	32S-22E-12	100	do	1,440	—	791	80	874	320	<10
17	34S-21E-29	102	do.	2,490	7.9	608	665	1,670	3,400	150
18	34S-23E-24	26	Krebs Formation	85	—	27	.0	68	70	<10
19	32S-22E- 1	400	do.	2,130	—	939	9.8	1,220	7,100	150
20	32S-23E-36	201	do.	3,470	7.2	861	1,020	2,350	<10	<10

3.0 HYDROLOGIC SETTING

3.5 PRE-MINING BASE FLOW

Base flow is poorly sustained in the area.

The interaction of surface water and ground water can be interpreted by examining the base-flow parts of the flow-duration curves, which indicate the percentage of time streamflow was equaled or exceeded. The flow-duration curves shown in figure 3.5-1 represent low- and base-flow duration at three nearby continuous-record streamflow stations: (a) Big Hill Creek near Cherryvale, 40 miles west of the general area with a drainage area of 37 mi^2 ; (b) Little Osage River at Fulton, 55 miles to the north with a drainage area of 295 mi^2; and (c) Marmaton River near Marmaton, 40 miles to the north with a drainage area of 292 mi^2. The period of record covered by the flow-duration curves is October 1976 through September 1980. The three stations are considered close to the general area and are representative of undisturbed streams within the area.

To compensate for differences in drainage-area size, unit discharge was calculated for each station. Unit discharge is the streamflow divided by the drainage area. Even though the drainage area ranged from 37 mi^2 to 295 mi^2, the flow-duration curves are similar for the three stations. Base flow at 90-percent flow duration is 0.0005 $(ft^3/s)/mi^2$ for the Marmaton River near Marmaton, and 0.00056 $(ft^3/s)/mi^2$ for the Little Osage River at Fulton. The steep slopes of the curves indicate little base flow and the streams mainly respond to storm runoff. Flow-duration curves for the two larger streams indicate higher unit discharge base flows, which are related to the greater percentage of alluvial deposits within their drainage areas.

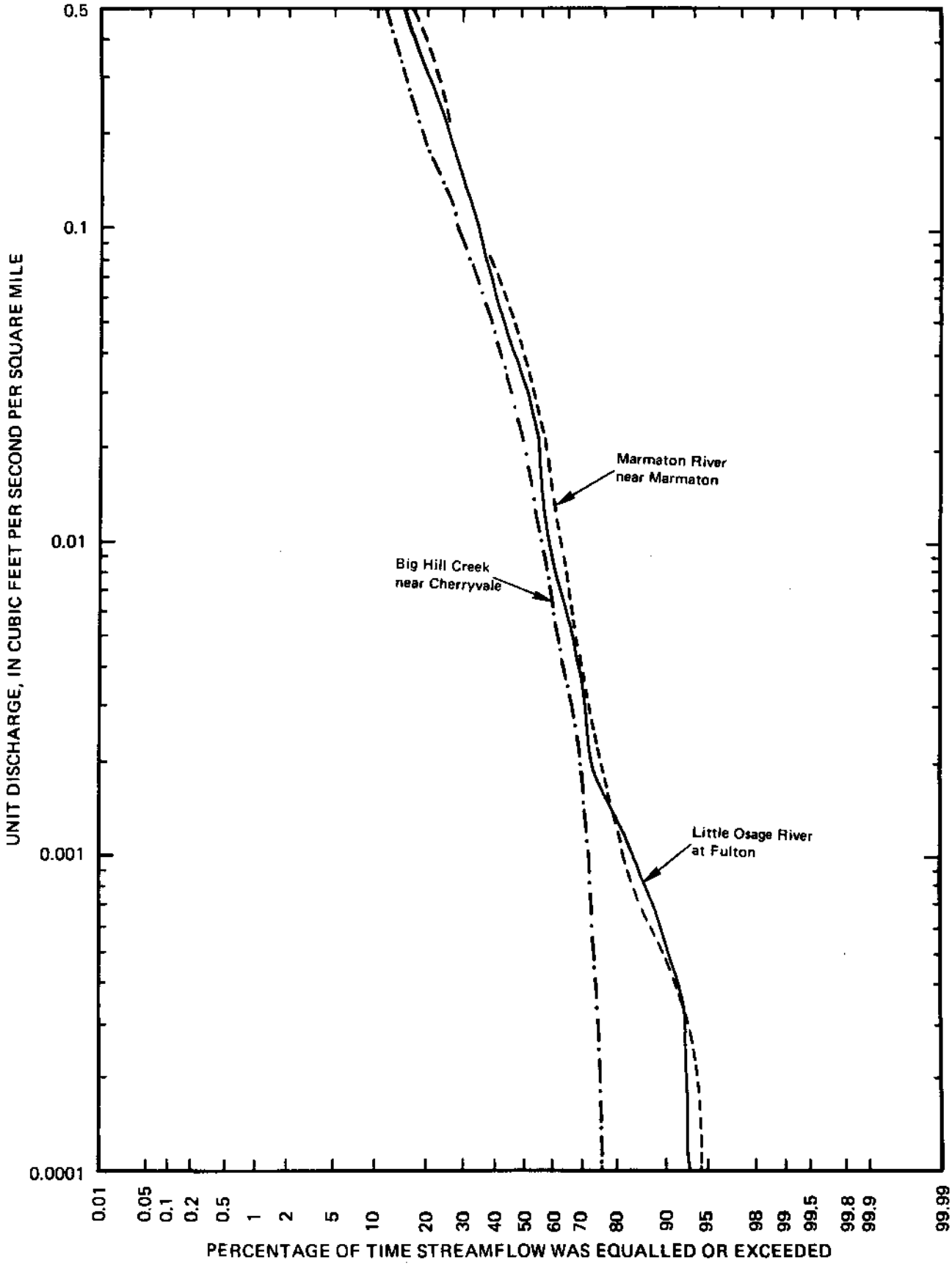


Figure 3.5-1.— Flow-duration curves for selected streams draining unmined areas.

3.0 HYDROLOGIC SETTING

3.6 BASE-FLOW QUALITY

Quality of base flow of streams draining unmined areas indicates the pre-mining water quality of the shallow aquifers.

Streams draining unmined areas where limestone crops out contain water with large concentrations of bicarbonate relative to sulfate during base-flow periods. Base-flow water-quality data presented in table 4.6-1 show that station 1 (Limestone Creek near Beulah) and station 14 (Second Cow Creek near Girard) contain water with large concentrations of bicarbonate ion relative to sulfate ion. These two streams are examples of streams that drain areas of limestone outcrops.

Streams that drain unmined areas where black shales, coal beds, and associated iron sulfide minerals crop out contain water with large concentrations of sulfate relative to bicarbonate during base-flow periods. Water-quality data in table 3.6-1 show that station 8 (Little Cherry Creek tributary 1), station 9 (Little Cherry Creek tributary 2), station 11 (Denny Branch Creek near Hallowell), and station 13 (Center Creek near Faulkner), contain water with large concentrations of sulfate ion relative to bicarbonate ion during base-flow periods. These streams are examples of streams that drain areas of black shale and coal outcrops.

Table 3.6-1.– Water-quality data from streams draining unmined areas during base-flow periods [ft^3/s, cubic feet per second; mg/L, milligrams per liter; ug/L, micrograms per liter]

Station Number	Station name	Stream -flow (ft^3/s)	Specific conductance (micromhos per centimeter at 25˚C)	pH (units)	Bicar-bonate (mg/L)	Sul-fate (mg/L)	Dis-solved solids (mg/L)	Total iron (ug/L)	Total mangan-ese (ug/L)
1	Limestone Creek near Beaulah	0.11	519	7.5	230	97	335	290	130
8	Little Cherry Creek tributary 1	.08	428	7.7	73	130	245	480	170
9	Little Cherry Creek tributary 2	.02	403	7.1	66	120	232	1,100	700
11	Denny Branch Creek near Hallowell	.12	542	7.4	90	170	318	960	700
13	Center Creek near Faulkner	.09	330	6.8	61	95	205	2,700	320
14	Second Cow Creek near Girard	.13	580	7.3	220	110	380	230	160

4.0 HYDROLOGIC IMPACTS OF COAL MINING

4.1 GROUND-WATER OCCURRENCE AND AVAILABILITY

Coal-mining activities in the area may increase or decrease the occurrence and availability of ground water.

Usable ground water is naturally scarce in most of the area. However, there are some reasonably good aquifers, principally alluvial aquifers and the Warner and Bluejacket Sandstone Members of the Krebs Formation. If these aquifers are disturbed during mining operations by (1) disrupting their continuity, (2) decreasing their recharge capabilities, or (3) dewatering them, the occurrence and availability of ground water may diminish locally.

In most of the area, the shallow shale aquifers yield little water. The fracturing of the bedrock that may occur during mining operations can increase the permeability and transmissivity, and consequently can increase the local occurrence and availability of ground water.

Wells 15, 21, and 22 of the hydrologic-monitoring network were drilled in an attempt to determine the differences in yields from undisturbed bedrock aquifers and unreclaimed strip-mined land. Well 15 was drilled into the undisturbed geologic interval between the Verdigris Limestone Member of the Cabanis Formation and the Mineral coal bed. This well had an estimated yield of about 2 gal/min. Wells 21 and 22 were drilled into unreclaimed spoils. The estimated yield of these wells was 10 to 50 gal/min.

Some of the effects of surface-mined areas on the aquifer systems are illustrated in figure 4.1-1. Illustrated in cross section A-A' are (1) the mine spoils with the 'ridge and furrow' topography, (2) the surface-mine pit lakes which provide increased surface-water storage, and (3) the disturbance of the sandstone aquifer. Illustrated in cross section B-B' are (1) the coal mine aquifers formed by the voids after abandoning of underground mining activities, and (2) the draining of the sandstone aquifers into the underground mine workings by the collapse of abandoned shaft openings, and coal-test drill holes. Illustrated in cross section C-C ' are (1) the disturbed spoils area and surface-mine pit lakes which recharge the sandstone, and (2) the disturbance of the sand and gravel alluvial aquifer, and stream base flow.

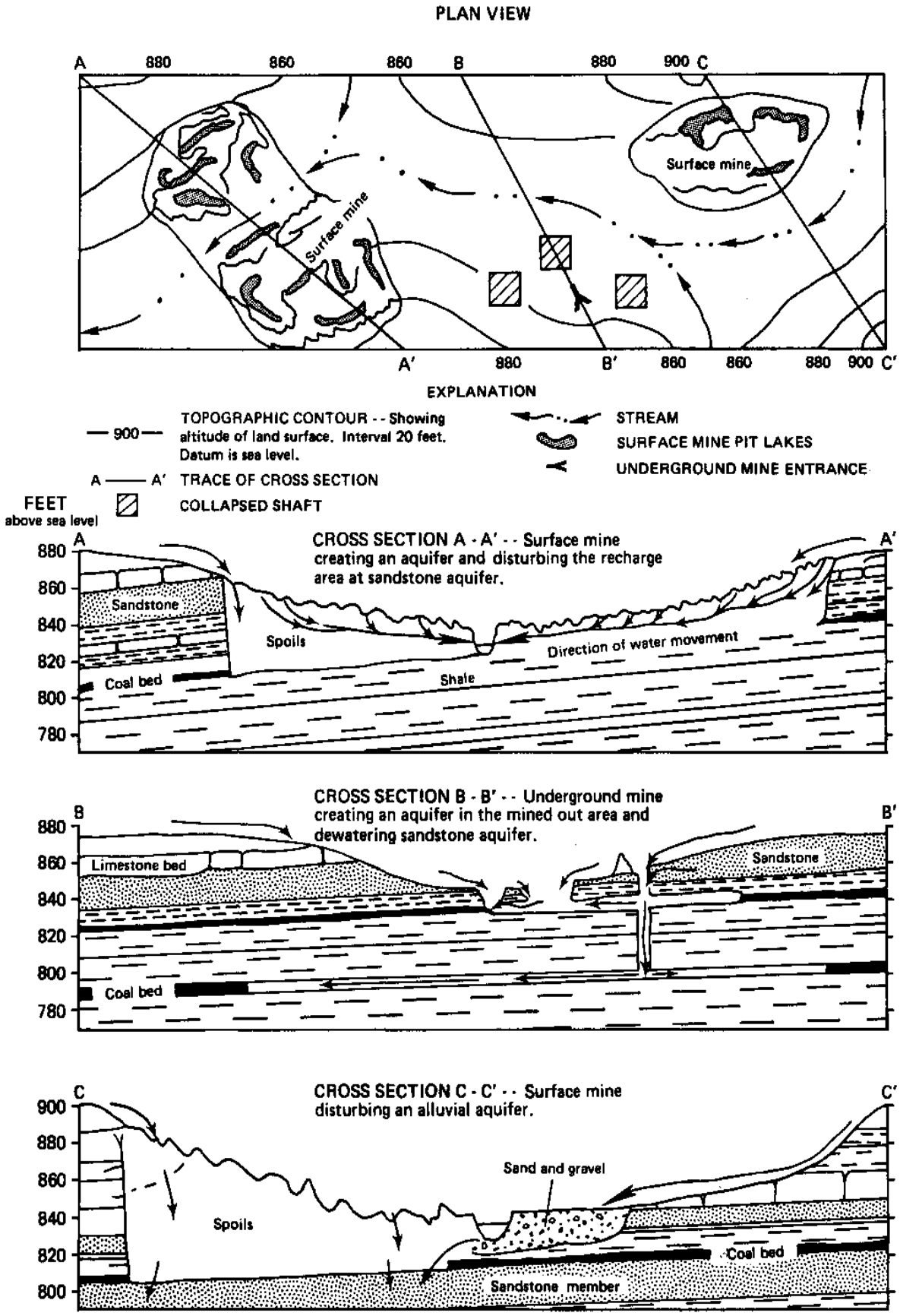


Figure 4.1-1.— Typical examples of coal mining creating or impairing aquifers in the area.

4.0 HYDROLOGIC IMPACTS OF COAL MINING

4.2 GROUND-WATER QUALITY

Ground water in coal-mined areas generally has large concentrations of sulfate ion and consequently large concentrations of dissolved solids.

The quality of ground water in coal-mined areas is illustrated by data presented in table 4.2-1. Wells 21 and 22 are completed in unreclaimed mine spoils. These wells yield water with large sulfate concentrations, and large concentrations of dissolved solids. The pH values of 7.4 and 8.1 and the concentrations of bicarbonate ion of 590 and 634 mg/L repsectively, for waters from the two wells indicate the presence of enough limestone fragments in the spoils to neutralize the acid produced by the weathering of iron-sulfide minerals.

Well 23 is completed in strata that have been both underground mined for Weir-Pittsburg coal and surface mined for Mineral coal. Water from this well has large concentrations of sulfate and dissolved solids. The relatively small bicarbonate concentration indicates that the pH, which was not recorded, was probably acidic and that the well could be receiving underground-mine discharge.

Samples 24 and 25 are ground water seeping from underground mines. Waters from these underground mines have large concentrations of sulfate and dissolved solids. The pH values are acidic, allowing more iron to be in solution and indicating, along with the smaller bicarbonate concentrations, that underground-mine discharge usually does not come into contact with enough limestone to neutralize the acid formed by weathering of iron-sulfide minerals.

Table 4.2-1.— Water-quality data from wells in coal-mined areas
[ft, feet; mg/L, milligrams per liter; ug/L, micrograms per liter]

Well number	Land-line location (township-range-section)	Depth (ft)	Source	Specific conductance micromhos per centimeter at 25˚C	pH (units)	Bicar-bonate (mg/L)	Sulfate (mg/L)	Dis-solved solids (mg/L)	Total iron (ug/L)	Dis-solved manga-nese (ug/L)
21	31S-22E-25	33	Surface -mined area	3,400	7.4	590	1,760	2,930	1,700	5,200
22	31S-22B-35	33	Surface -mined area	5,030	8.1	634	2,740	4,340	460	4,100
3	32S-23E-14	40	Shaft- and surface- mined area	3,470	—	71	1,950	2,960	620	540
24	32S-23E-23	Sur-face	Shaft-mine seep	1,640	4.0	0	970	1,370	6,900	7,500
25	30S-24E-26	Sur-face	Shaft-mine seep	—	6.1	320	1,200	2,100	49,000	1,800

4.0 HYDROLOGIC IMPACTS OF COAL MINING

4.3 BASE-FLOW QUANTITY

Base flow may be increased by coal mining.

Abandoned coal mines in the area usually function as aquifers that discharge to adjacent streams. The flow-duration curves (fig. 4.3-1) present streamflow, for the period October 1976 through September 1980, of drainage basins that have been affected by surface or underground mining. Lightning Creek near McCune (station 2 in the hydrologic monitoring network) has been slightly affected by surface mining; only 2.5 percent of its drainage area is disturbed. Cherry Creek near Hallowell (station 12 in the network) and Cow Creek near Weir (station 19 in the network) have been more affected by coal mining; 11 and 12 percent of their respective drainage areas are disturbed by surface mining. Cherry Creek and Cow Creek are also affected by abandoned underground mines.

The flow-duration curve for Lightning Creek is similar to those of undisturbed streams presented in figure 3.5-1, indicating that the small amount of surface mining has had little effect on the quantity of base-flow. The 90-percent flow-duration value for Cherry Creek is 0.003 $(ft^3/s)/mi^2$, and for Cow Creek is 0.006 $(ft^3/s)/mi^2$, which are an order of magnitude greater than the unit discharge values of the undisturbed basins. Curves representing Cherry Creek and Cow Creek also indicate longer duration base-flow periods. The increased base flow probably results from coal mining creating new recharge areas and aquifers that discharge water into adjacent streams. An example of a surface-mine aquifer discharging into an adjacent stream is presented in figure 4.3-2.

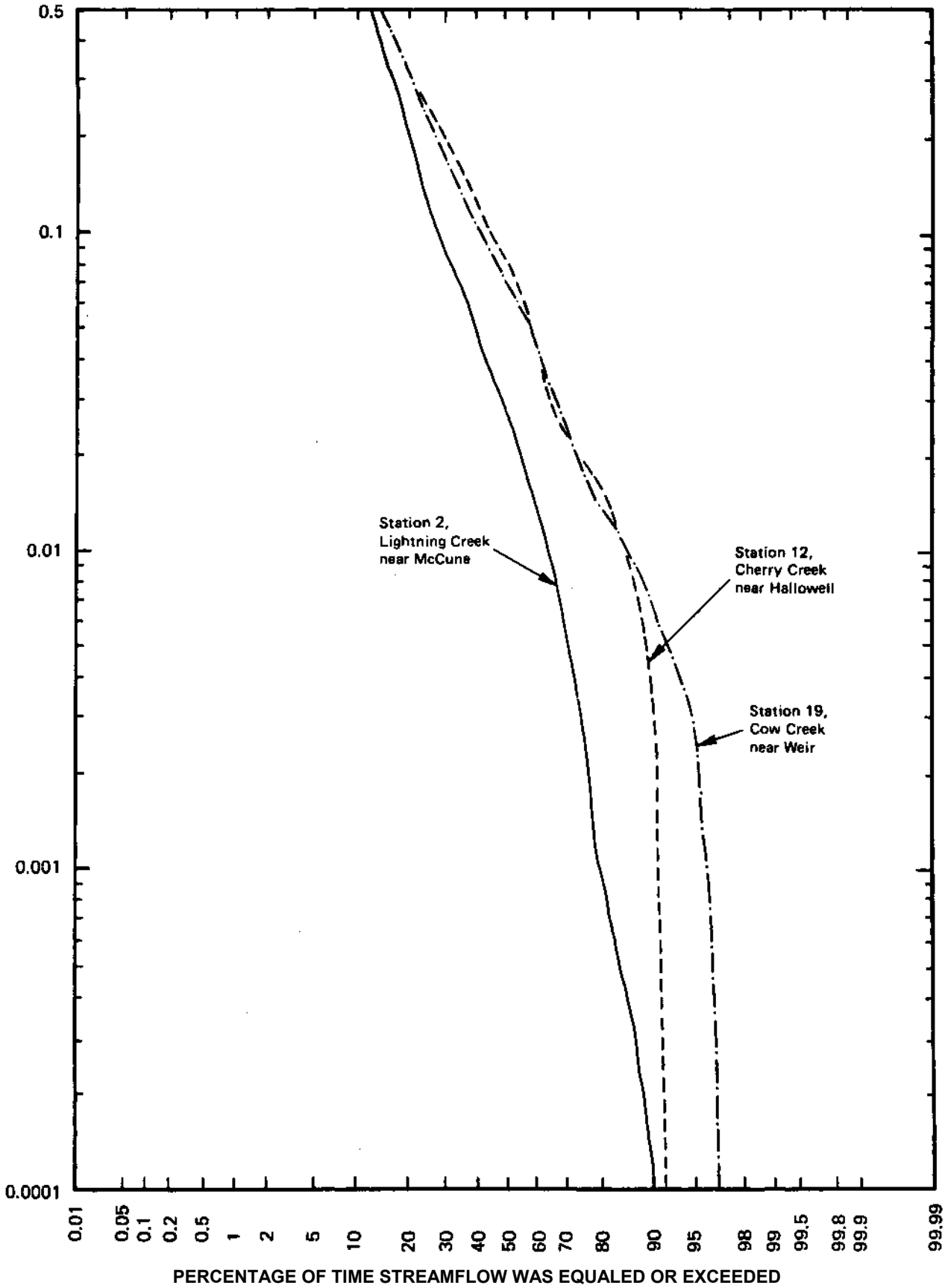


Figure 4.3-1.— Modified flow-duration curves for selected streams draining coal-mined area.

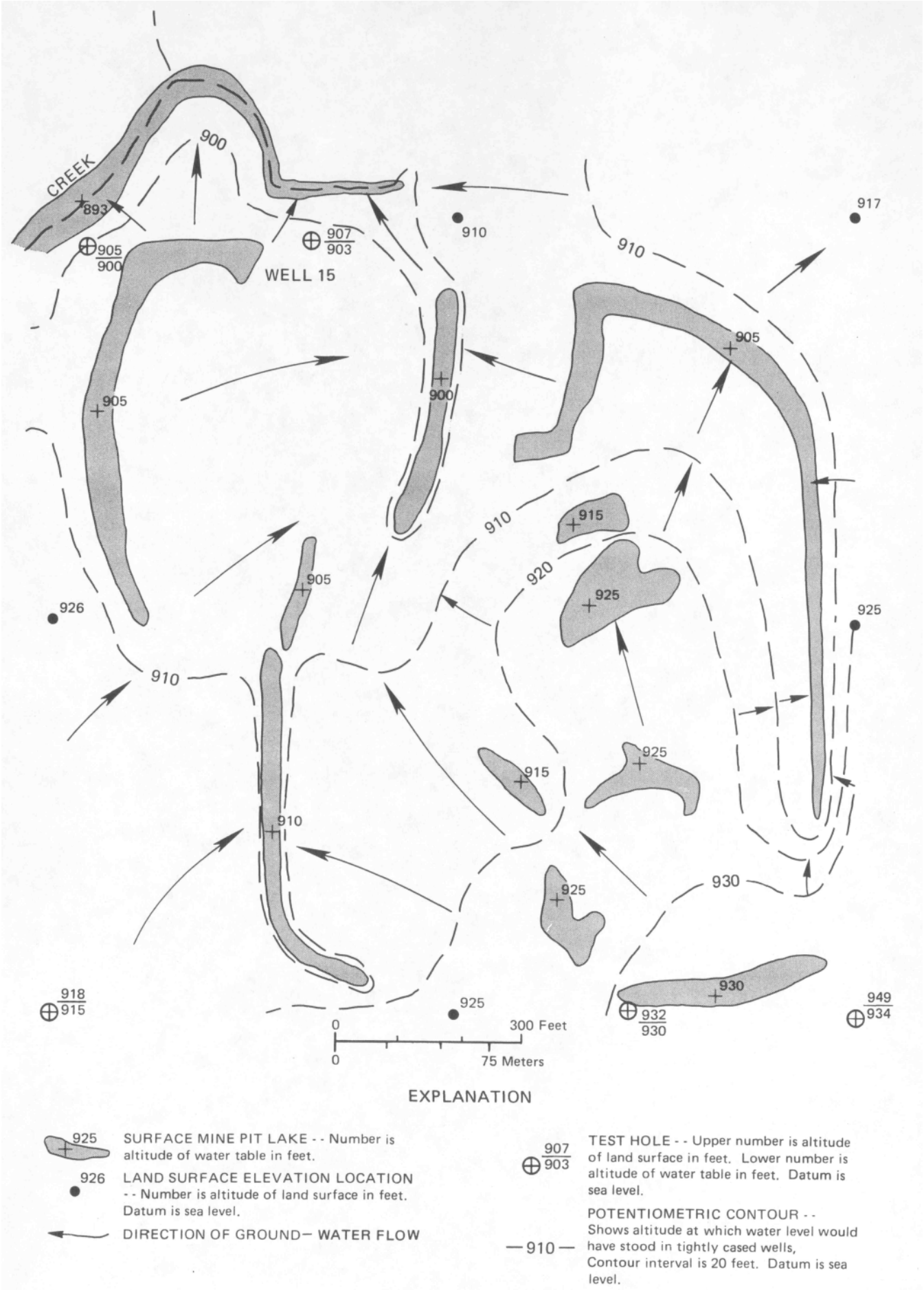


Figure 4.3-2.— Surface-mine aquifer discharging into an adjacent stream.

4.4 BASE-FLOW QUALITY

Coal mining in the area has increased concentrations of sulfate and dissolved solids in streams during base-flow conditions.

Base-flow water-quality data collected from October 1976 through September 1980 at 14 streams draining coal-mined areas were analyzed statistically (4,5). Mean values of selected parameters and constituents are presented in table 4.4-1. General conclusions about the base-flow water-quality characteristics of streams affected by coal-mining activities, are:

(1) Mean concentrations of dissolved solids, principally sulfate and bicarbonate, are significantly larger in streams draining mined areas than in streams draining unmined areas.

(2) Mean sulfate concentrations exceed mean bicarbonate concentrations for all stations in mined areas.

(3) Mean pH values are in the neutral range for all stations affected only by surface mining.

(4) Stream reaches receiving underground-mine discharge generally have acidic pH and contain small concentrations of bicarbonate and high concentrations of iron and manganese relative to streams draining surface-mined areas.

(5) Large variations in mean concentrations of dissolved solids and sulfate throughout the area appear to be related to the extent of mining.

Table 4.4-1.– Mean values of selected-quality parameters and constituents sampled in streams draining coal-mined areas during base-flow conditions, 1976-80
[ft^3/s, cubic feet per second; mg/L, milligrams per liter; ug/L, micrograns per liter]

Station Name	Lightning Creek near McCune	Deer Creek near West Mineral	Deer Creek near Hallowell	Deer Creek near Oswego	Lightning Creek near Oswego	Cherry Creek near West Mineral	Little Cherry Creek near West Mineral	Cherry Creel near Hallowell	Second Cow Creek at Pittsburg	First Cow Creek at Frontenac	East Cow Creek at Fronenac	East Cow Creek at Pittsburg	Cow Creek at Weir	Brush Creek near Weir
Hydrologic monitoring network map-index number	2	3	4	5	6	7	10	12	15	16	17	18	19	20
Streamflow, in ft^3/sec	3.7	0.49	1.2	1.7	5.0	1.2	3.2	5.2	1.8	1.7	0.87	3.7	15	1.1
Specific conductance, in micromhos per centimeter	912	3,960	3,540	3,260	1,740	2,250	1,590	1,560	1,850	1,860	2,440	1,820	1,300	1,290
pH, in standard units	7.3	7.9	7.8	7.5	7.8	7.5	3.6	6.4	7.6	7.5	7.8	6.6	7.3	3.6
Dissolved solids, in mg/L	592	3,310	3,130	2,830	1,330	2,260	1,300	1,210	1,400	1,370	1,970	1,450	875	930
Bicarbonate as HCO_3, in mg/L	220	310	230	210	200	220	0	42	220	230	250	35	120	0
Sulfate as SO_4, in mg/L	280	2,300	2,200	2,000	890	1,600	930	860	950	820	1,360	1,110	510	650
Total iron, in ug/L	1,100	360	440	620	320	400	2,000	490	820	380	390	890	790	5,000
Total manganese, in ug/L	1,400	990	540	630	390	990	7,600	4,800	980	710	730	14,400	3,800	5,000
Percentage of drainage area surface mined	2.5	42	57	55	7.7	21	11	11	7.7	16	38	22	12	12

The quality of base flow in mined areas is generally more affected by surface mining than by underground mining. Most underground mined areas are below the bedrock formations into which the streams are incised. Streams are affected by underground-mine drainage only in areas where the hydraulic gradient is from the mine to the stream and (1) the stream is incised deeply enough to intersect the mined formation or (2) air shafts or exploratory holes penetrate the underground-mined area and discharge mine drainage into the stream. In surface-mined parts of the area, the bedrock has been disturbed from the surface down to the coal bed and haphazardly piled back into the surface pits. Black shales and associated iron sulfide minerals, their surface areas multiplied many times by being broken into small fragments, are exposed to water at all depths, including the surface. The greater permeability of the spoils allows shallow ground water in these surface-mined areas to flow laterally into adjacent streams, especially in areas where the streambed itself was mined.

The relationships between the percentage of a stream's drainage area that has been surface mined and mean values of specific conductance, concentration of dissolved solids, and concentration of sulfate ion during low-flow conditions, are shown in figure 4.4-1. Results of correlation and regression analyses of these relationships are given in table 4.4-2. The regression equations are arithmetic linear equations of the form:

$$Y = mX + b$$

where Y = predicted value of the dependent variable,
m = slope of the regression line,
X = known value of the independent variable, and
b = Y-intercept value of the dependent variable.

The standard error of the estimate ($\sigma_{y/x}$), which is equivalent to the standard deviation of the dependent variable about the regression line, was computed for each relationship.

The significant coefficient of determination ($r^2 = 0.81$) associated with these relationships and the reasonable standard error of estimates, that would be expected when applying them, show that there is a strong direct relationship between surface mining an area and increased concentrations of sulfate and dissolved solids in the base flow of streams draining that area. These relationships provide a technique for estimating the effects of surface mining on the quality of base flow in streams of comparable geology and climate within the Western Interior Coal Basin.

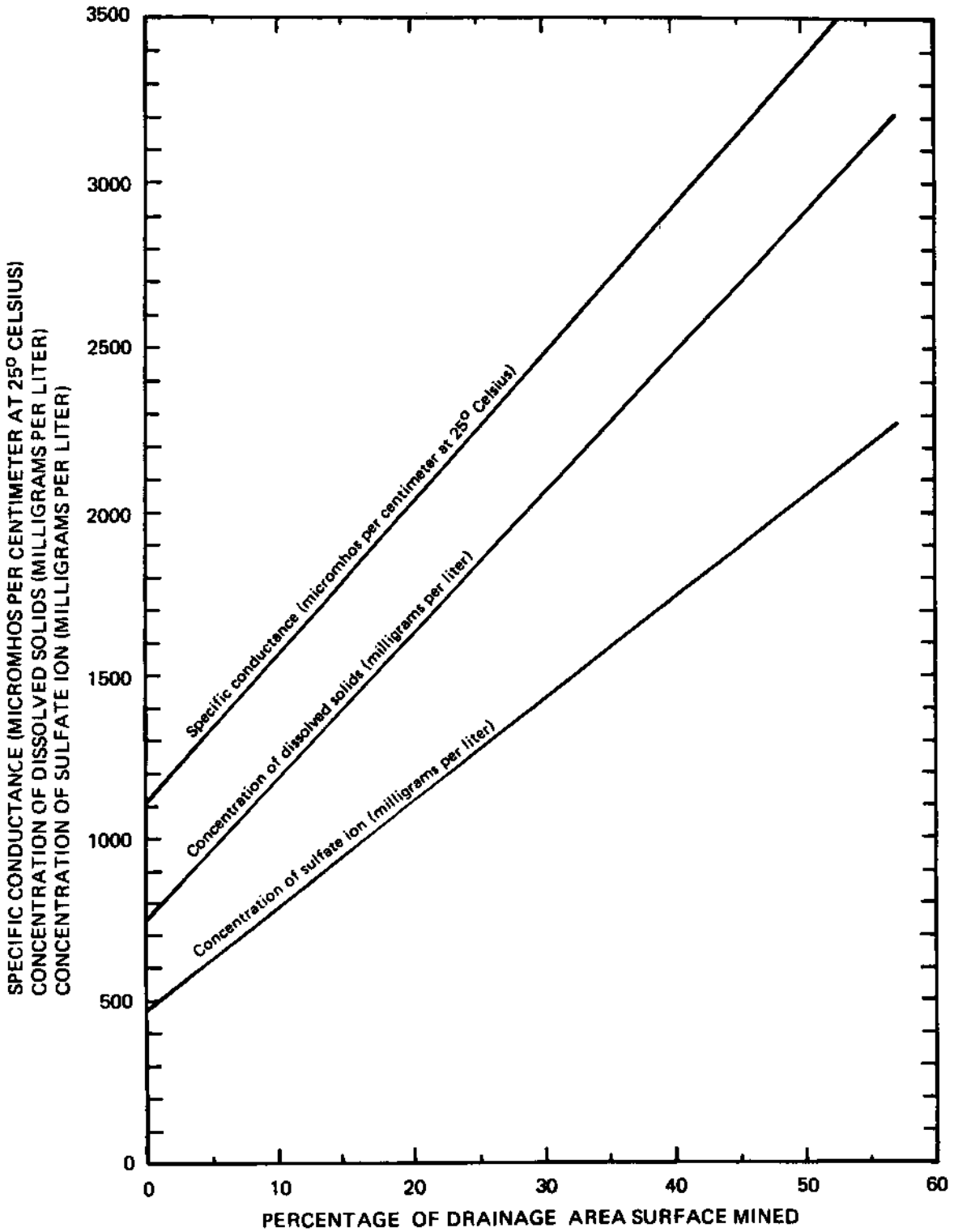


Figure 4.4-1.— Relationship of percentage of drainage area surface mined to (1) mean specific conductance, (2) mean concentration of sulfate ion, and, (3) mean concentration of dissolved solids during base-flow periods.

Table 4.4-2.– Results of correlation and regression anlyses (Y = mX+b) relating the percentage of drainage area surface mined to (1) mean specific conductance; (2) mean concentration of sulfate ion, and (3) mean concentration of dissolved solids during base-flew conditions.

Dependent variable (Y)	Slope (m)	Independent variable (X)	Y-intercept (b)	Correlation Coefficient (r)	Standard error of estimate ($^{\sigma}y/x$)
Specific conductance (micromhos per centimeter at 25˚ Celsius)	45.28	Percentage of drainage area surface mined	1,000	0.90	415
Concentration of sulfate ion (milligrams per liter)	31.42	Percentage of drainage area surface mined	470	.90	260
Concentration of dissolved solids (milligrams per liter)	43.01	Percentage of drainage area surface mined	744	.90	383

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