XIII. POTENTIAL GEOHYDROLOGIC IMPACTS OF COAL MINING

Pertinent 30CFR[1] Sections:

Description of hydrology and geology
Ground-water information
Surface-water information
Cross sections, maps, and plans
Protection of hydrologic balance
Operation plan

1. Introduction

Both surface and underground mining have the potential to disrupt and permanently alter the physical and chemical characteristics of aquifer system(s). The changes may include:

1. Reduction of ground-water quantity through the removal of aquifers in the overburden, or of the coal itself;
2. Changes in ground-water storage as measured by significant water-level declines;
3. Changes in ground-water flow directions, (such as through aquifer dewatering related to "dry" mining operations, and through increased interaction between water-bearing rock units);
4. Alteration of stream base flow by creating losing reaches in areas of ground-water level declines, and creating gaining reaches in areas of mine refuse, abandoned mines, and, mine subsidence; and,
5. Alteration of chemical characteristics of ground water and as base flow of streams; also the degradation of ground-water quality through acid-mine drainage.

The impacts of these changes on the aquifer system(s) outside the permit area and adjacent area depend upon:

1. Value and use of the ground-water resources in the general area: (Are water supplies for municipalities and industries solely dependent upon potable ground water? Or is surface water the major water resource?)
2. Availability of alternative water supplies: (Are deeper aquifers available for water supply? Or could surface water be developed for water supply?)
3. Magnitude of the proposed mining operation relative to the ground-water availability: (Is the affected area inconsequential compared to the size of the aquifer system and the availability of ground water?)
4. Volume of coal-spoil piles and isolation of water draining from spoils from the general area.

[1] CFR = Code of Federal Regulations

2. Changes in Ground-Water Flow

Surface and underground coal mining can cause aquifer destruction, significant water-level declines in the vicinity of the excavation, and local changes in directions of ground-water flow.

Where the minable coal beds are below aquifers in the overburden and(or) below the base level of streams, the mine-excavation pit serves as a sump for ground-water discharge. The pumping necessary to dewater the working pit causes a decrease in saturated thickness of the overlying aquifer, which may cause wells and springs in the immediate area to go dry. (Partially penetrating water-supply wells could also "go dry" for other reasons, such as increased nearby pumpage, or prolonged drought. Careful hydrologic monitoring and investigation within the general area, will determine whether the wells and springs went "dry" as a result of mining.)

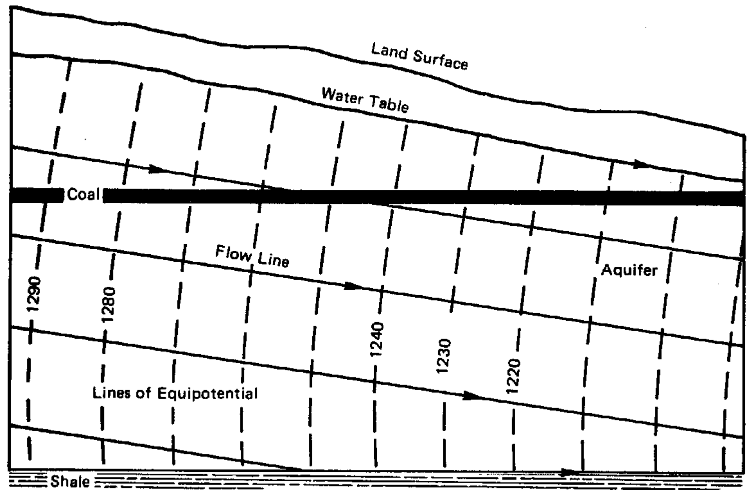
In surface mining, blasting can also cause changes in ground-water flow. A secondary effect of the use of explosives is the increased fracturing which increases the hydraulic connection between previously confined water-bearing rock units. In underground mining, underclays or shale beds, which can act as impermeable hydraulic boundaries, limit the infiltration into the excavation site. However, high hydrostatic heads and rock pressure on the pillars have caused mine floors to buckle and have allowed ground water to discharge into the underground mines.

An idealized ground-water flow system, within a flat-lying sedimentary bedrock (aquifer containing a commercial coal bed is illustrated before and during surface mining in fig. XIII-2-1. The coal excavation forms a hydraulic sink, which causes changes in ground-water directions. A similar setting before and during underground mining is illustrated in fig. XIII-2-2. The potentiometric maps in fig. XIII-2-3 illustrate the changes in ground-water flow before and during surface mining of the D-l coal aquifer in the Decker, Mont., area. The premining natural sink, or ground-water discharge area, was the Tongue River Reservoir, which has a spillway elevation of 3424 ft. After 3 years of mining, and with the mine floor at an elevation below 3380 ft. the ground water was locally diverted toward the mined area.

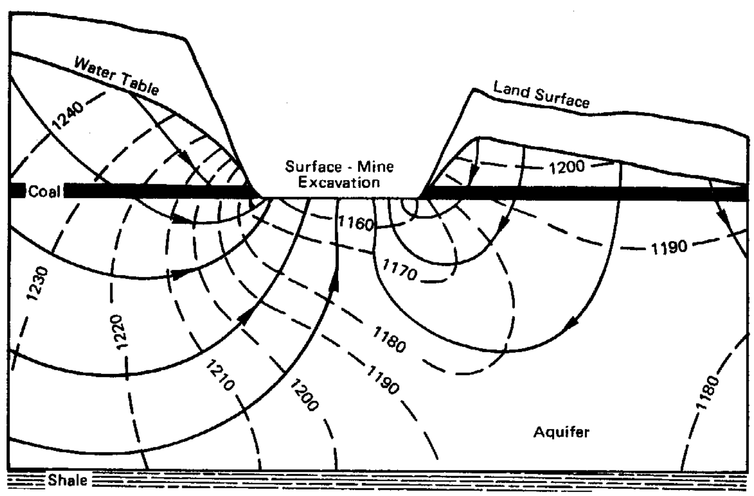
The change in ground-water flow is defined by the change in discharges from spring and in ground water levels (chapter XIV) within the adjacent area. Four-year well hydrographs from aquifers in an area affected by mining are shown in fig. XIII-2-4. (This effect is also evident in fig. IX-5). Details on the placement of observation wells are presented in the next chapter, table XIV-2.

The maximum drawdown within the mine-permit area in fig. XIII-2-3 during the 3-year period was 38 ft. The water-level-change map, fig. XIII-2-5, illustrates the estimated water-level declines, over a 20-year period of mining along the edge of the permit area at the time of cessation of mining. The maximum drawdown during this period is about 90 ft.

The areal extent and long-term effect of mining on ground-water flow depend on the geologic, hydrologic, and climatologic conditions at the mine site and the management of the spoils and "last cut" lakes. Generally water levels will begin to rise to premining equilibrium conditions upon completion of mining and reclamation.

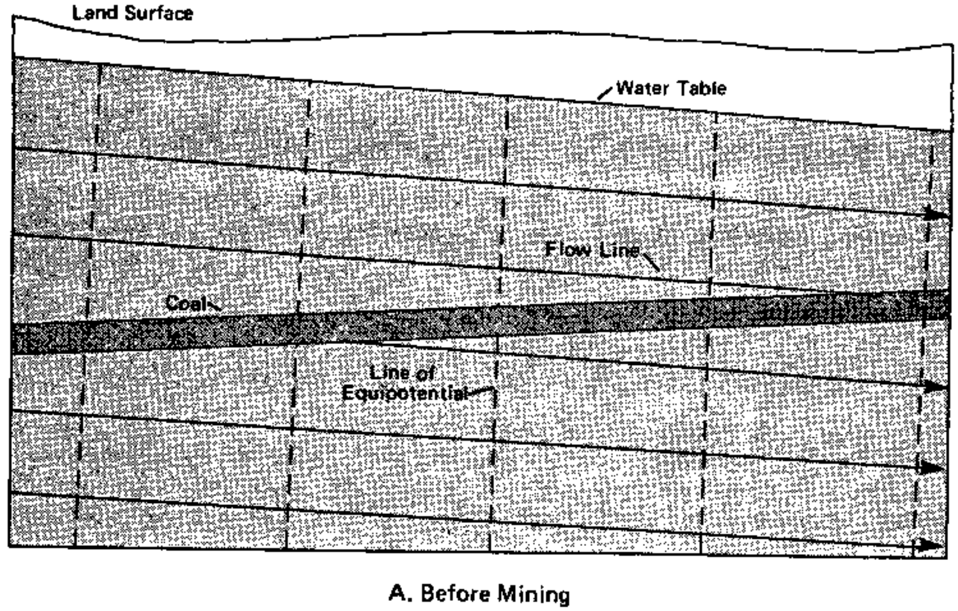


A. PREMINING GROUND - WATER FLOW



B. DURING MINING GROUND - WATER FLOW

Figure XIII-2-1.— Directions of ground-water flow in sedimentary sequence at a surface-mine area, before and during excavation. Modified from Wilson and Hamilton, 1978 fig. 4



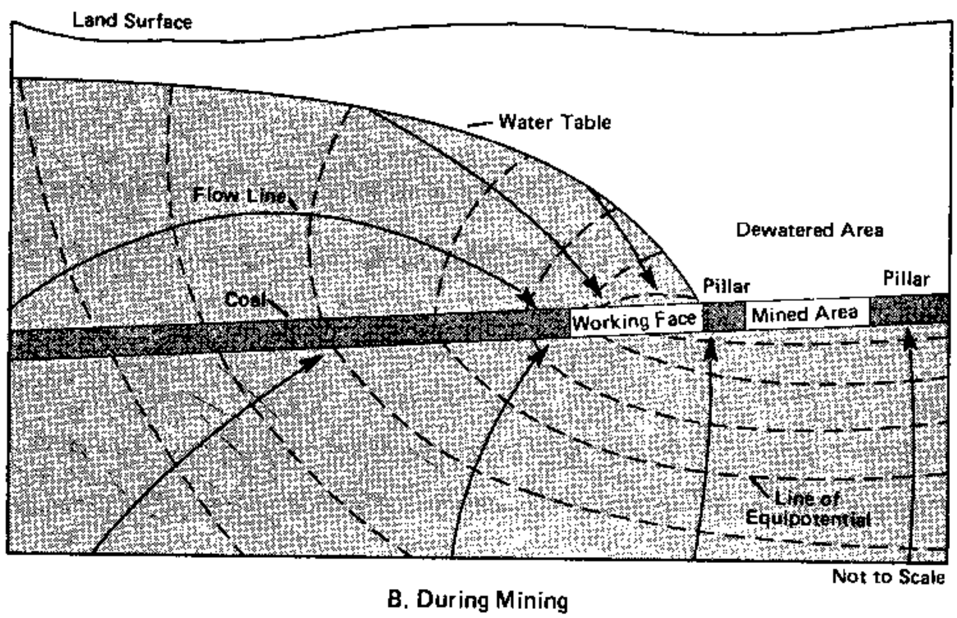


Figure XIII-2-2.— Directions of ground-water flow in a sedimentary sequence near an underground mine before and during excavation.
(From Lines and others, 1984, fig. 3.2-2)

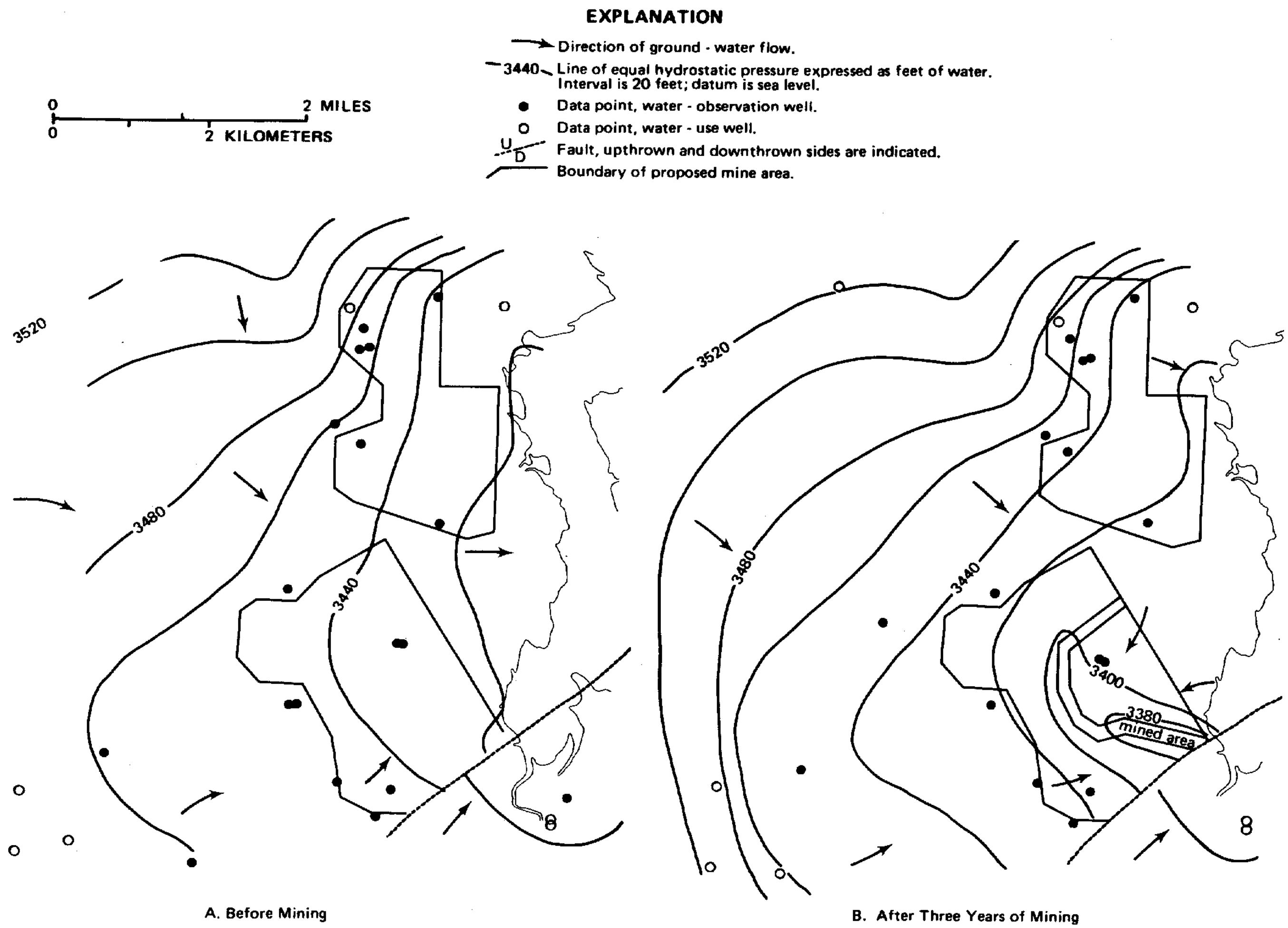


Figure XIII-2-3— Potentiometric surface maps of coal aquifer (D-1) before and after 3 years of mining in Decker, Montana area.
(From VanVoast and Hedges, 1975, pls. 4 and 7)

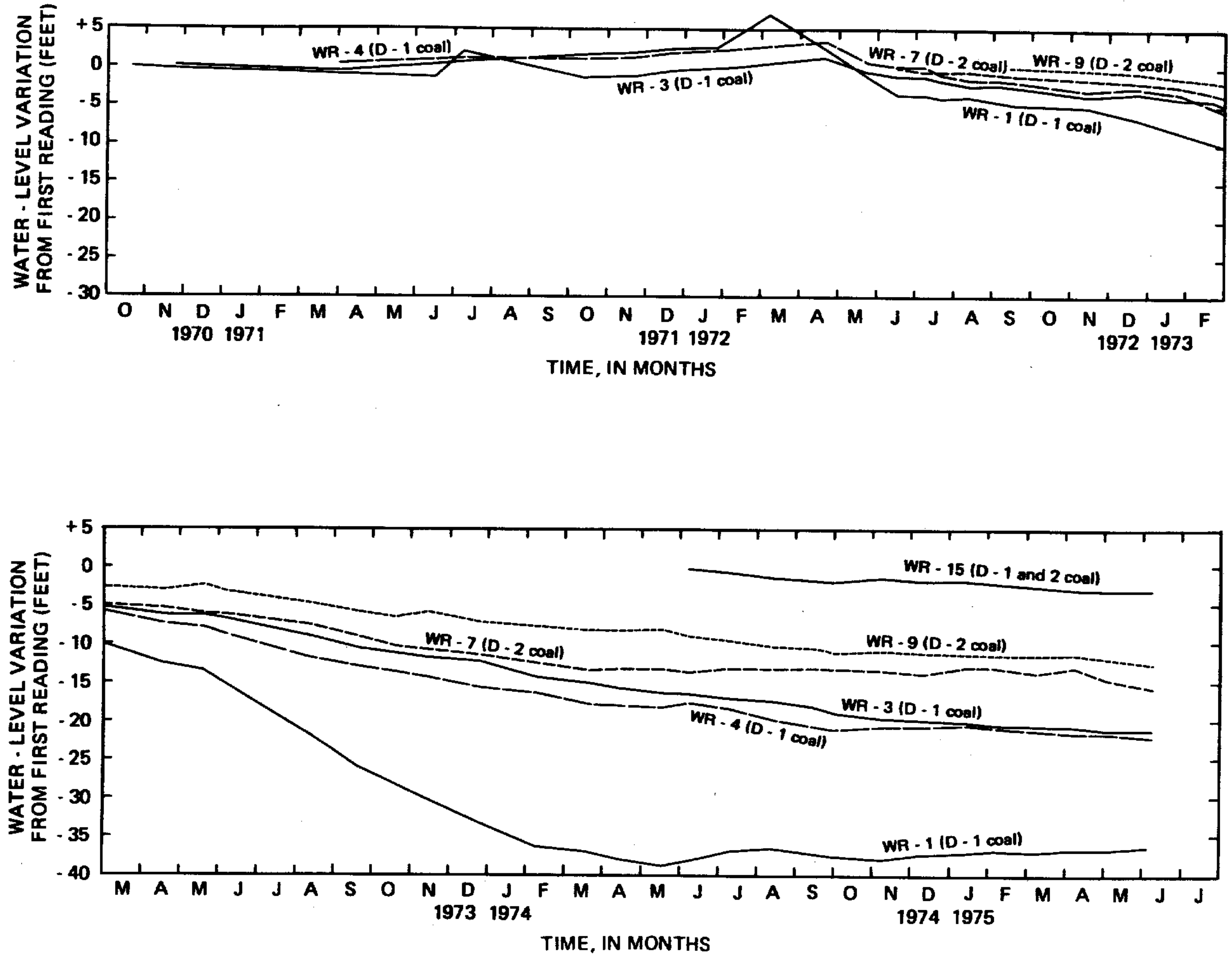


Figure XIII-2-4.— Water-level changes in selected observation wells before and during mining in the Decker, Montana area. (Modified from VanVoast and Hedges, 1975, pl. 10)

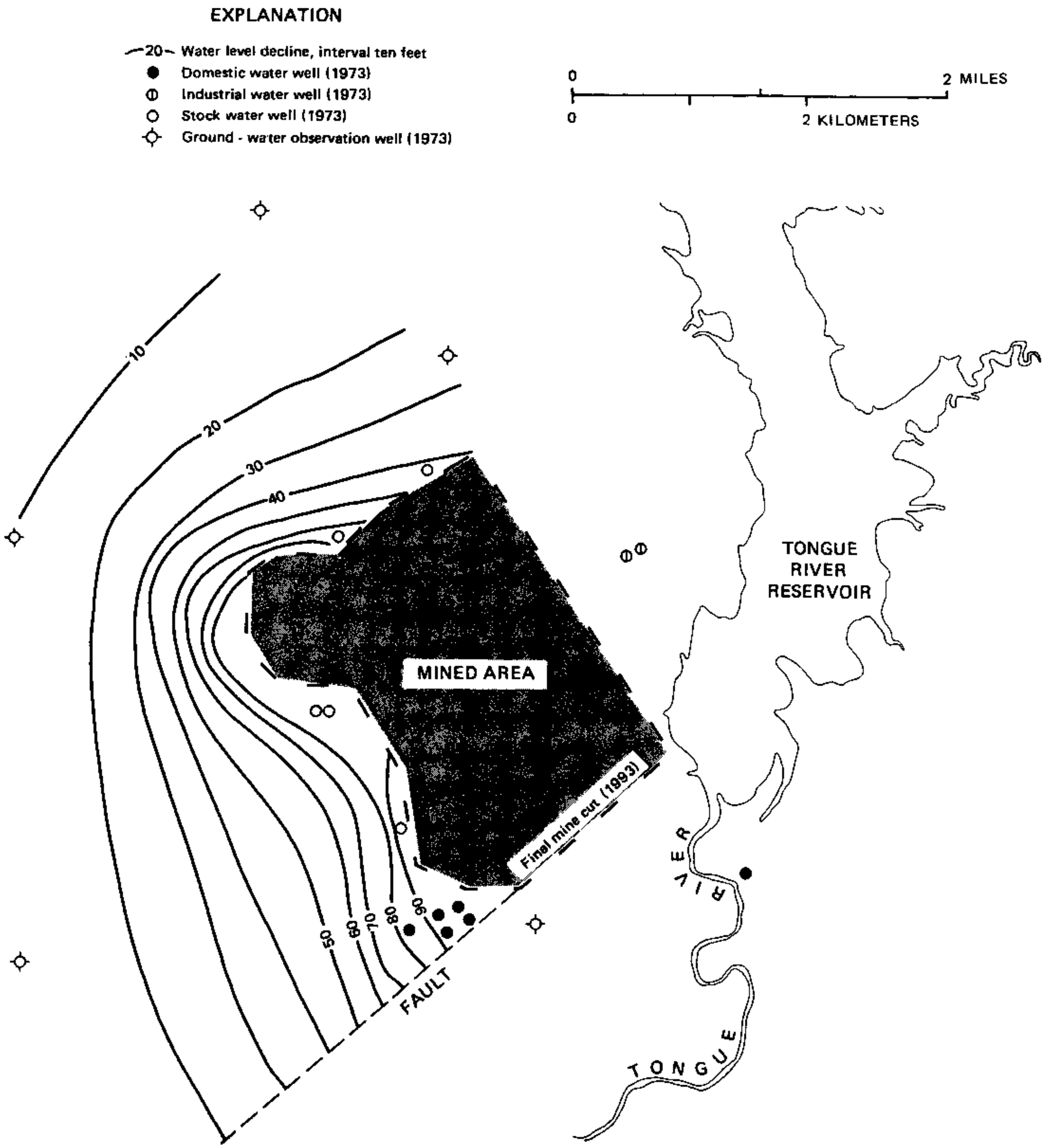


Figure XIII-2-5.— Predicted water-level declines at time of cessation of mining in D-l aquifer near Decker, Montana after 20 years of mining. (From VanVoast, 1974, fig. 11)

3. Changes in Ground-Water Storage and Modification of the Relationship between Ground Water and Surface Water

Surface and underground coal mining operations have the potential to create and increase the storage capacity of ground-water reservoirs through the formation of mine-spoil piles and the use of explosives. This alteration can modify storm runoff and baseflow characteristics. Streamflow can also be modified by the direct discharge of mine water.

In surface-mine operations, the excavation of coal and the associated backfilling with disturbed overburden creates an unconsolidated deposit with increased effective porosity and hydraulic conductivity. The increase in ground-water storage (porosity) can range from 1 percent to 30 percent.

In underground mining, the excavation of coal can cause subsidence cracks in the overburden, even where the mine depth is as much as 600 ft. This subsidence creates a fractured rock mass with an increased effective porosity and hydraulic conductivity. The percent of increase is highly variable. The effect of subsidence on shallow aquifers generally diminishes with increasing depth of underground mining. However, the extent of bedrock fracturing and subsidence depends upon mining methods, such as the "room and pillar" method and the "long-wall" method. In some reported cases, the effect of underground mining on overlying shallow aquifers was of short duration because the fractured overburden bedrock adjusted back to its original position with the cessation of mining.

The increase in effective porosity and hydraulic conductivity causes a comparable increase in aquifer storativity. This increase has several possible effects on the aquifer system(s), depending on whether the mining is at land surface or underground:

1. Surface operations and associated backfilling of overburden:
   a. creation of an unconsolidated (water-table) aquifer.
   b. increased discharge from the mine spoils, which increases stream base flow.
   c. degradation of base-flow quality through the hydration and oxidation of pyritic minerals within the spoils.
   d. degradation of shallow ground-water quality by the infiltration of water through mine spoil into the shallow aquifer.
2. Underground operations and associated subsidence:
   a. lowering of water table through the increased interconnection of confined aquifers and through dewatering.
   b. reduction in evapotranspiration by the removal of vegetation and the lowering of shallow water table.
   c. reduction in base flow where mining operations are beneath streams, which creates losing reaches (chapter XI) and as dewatering is continued,
   d. large fluctuations in ground-water levels, as much as several hundred feet, while pumping to maintain "dry" mine conditions.
   e. diversion of ground water out of the drainage basin.

Some of these effects are long lasting; others diminish and may recover to pre-mining conditions.

The effect of changes in ground-water storage on the ground-water flow system in the general area may be defined by:

1. measurements of water levels in observation wells (chapter XIV), tapping:
   a. mine spoils
   b. aquifers downgradient of the spoils (for surface-mine operations), and
   c. overburden aquifers potentially affected by underground mining.
2. measurement of spring discharges.
3. measurement of discharge at streamflow sites upgradient and downgradient from both surface- and underground-mining operations.
4. aquifer testing of the created spoil piles and of the aquifers within the subsidence area.
5. analysis of observation-well hydrographs.

A planimetric map and cross section of an area in West Virginia in which surface- and underground-mining of the Lower Kittanning coal continued from 1895 until 1971 are shown in figure XIII-3-1. The ground-water-storage modification is reflected in the change in stream base flows; the geologic setting is flat-lying coal, GS-1 (see chapter IV), the hydrologic setting is a coal bed in contact with an unconfined bedrock aquifer, HS-E (see chapter VI), and the coal bed is an unconfined aquifer, HS-F(2). The area of greatest increase in base flow is near Norton, where the maximum unit discharge increased from 0.27 $(ft^3/s)/mi^2$ in October 1965 to 4.25 $(ft^3/s)/mi^2$ in April 1979. The base-flow yield for unmined basins in this general area ranges between 1 and 2 $(ft^3/s)/mi^2$.

Flow-duration curves for three sites in West Virginia — Grassy Run, with a drainage area (DA) of 2.86 mi^2, Roaring Creek (DA 29.2 mi^2) and Sand Run (DA 14.5 mi^2) are given in figure XIII 3-2. The Grassy Run and Roaring Creek stations are near Norton (fig. XIII 3-1); the Sand Run station is a few miles to the west. Nearly all of the small basin has been mined out, whereas less than half of the large basin and none of the intermediate basin, has been mined. All three basins are similar in geology, topography, climate, and vegetation. Comparison of the unit base-flow discharges demonstrates the effect of mining on the ground-water discharge: Grassy Run (mined out) is 0.42 $(ft^3/s)/mi^2$, Roaring Creek (half mined) is 0.065 $(ft^3/s)/mi^2$, and Sand Run (unmined) is 0.03 $(ft^3/s)/mi^2$. Greater infiltration in the mined area, and the conversion of ephemeral streams to perennial streams are related to the increased ground-water storage due to mining. In this example, mining caused ground-water discharge to the stream to increase an order of magnitude.

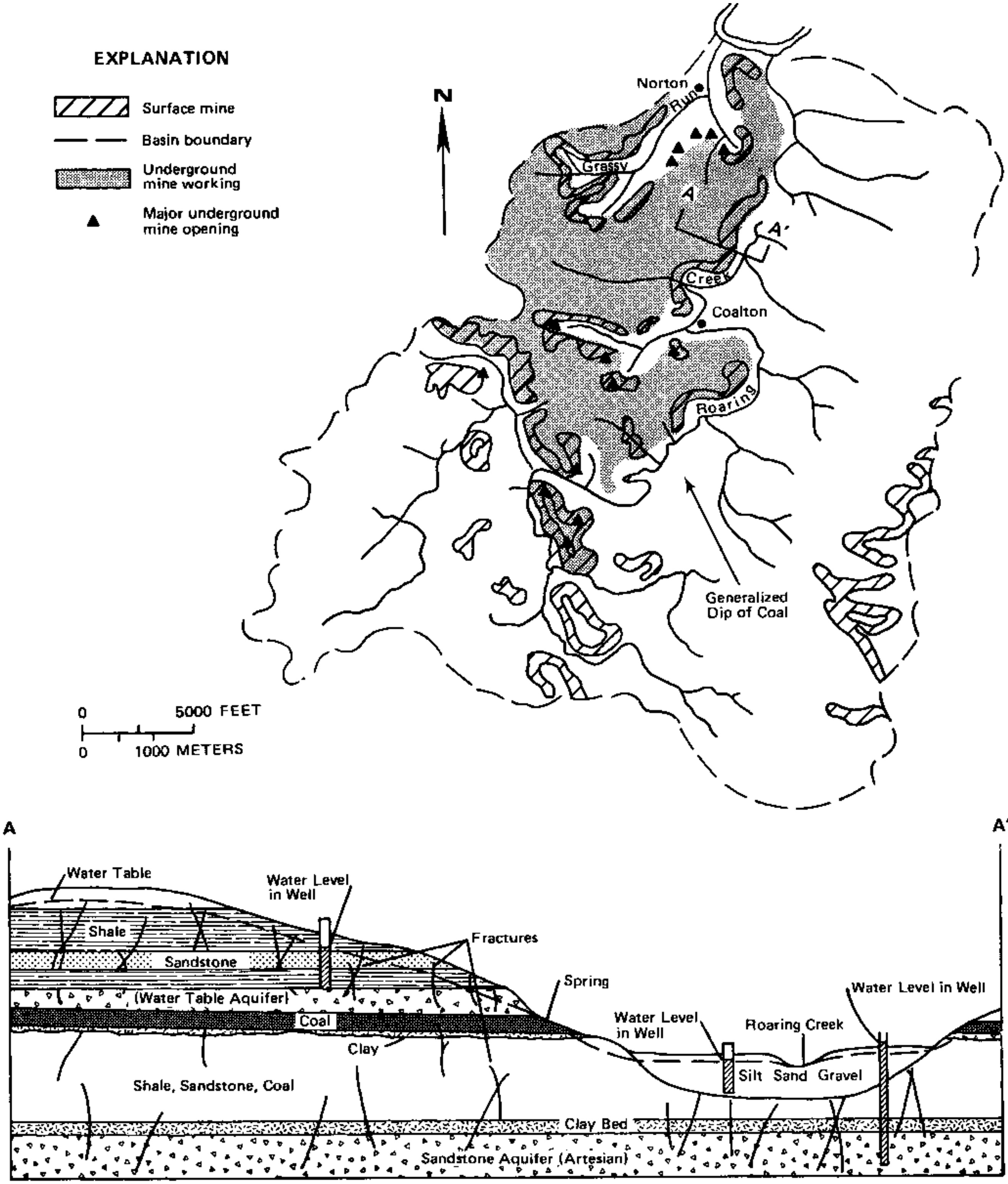


Figure XIII-3-1.— Area where mining caused increases in base flow of streams. (Effects on base flow are plotted on fig. XIII-3-2.) (Section A-A1 illustrates the geologic and hydrologic settings.) (Modified from Hobba, 1981, figs. 1.3-8 and 2.1.1-A)

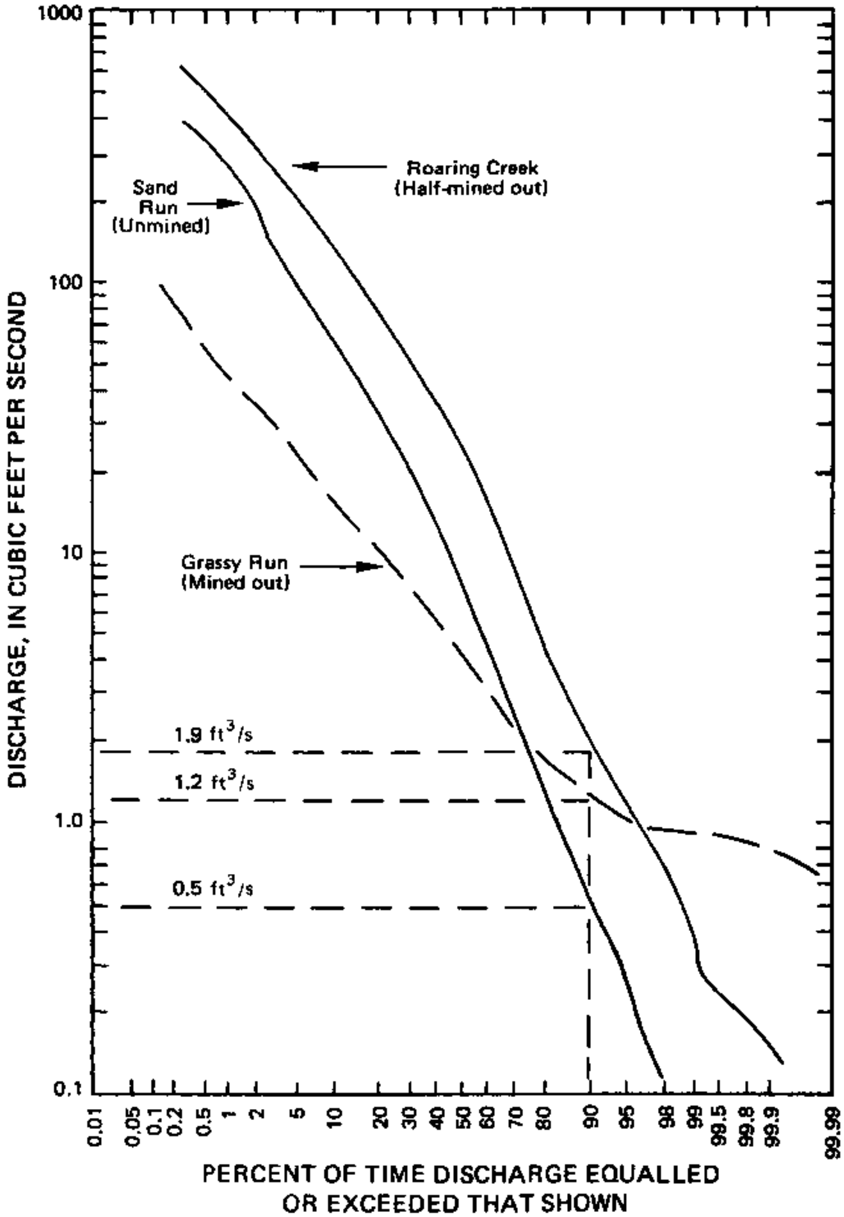


Figure XIII-3-2.— Flow-duration curves of three streams in the some terrain but mined to differing degrees.
(Modified from Hobba, 1981, fig. 2.2.2-B)

4. Modification of Ground-Water Quality

The chemical quality of ground water is locally variable (chapter XII), as a result of chemical reactions with the minerals in the soil-, and the unsaturated and saturated zones. Ground water within local shallow flow systems (chapter IV) is generally of good quality. In the coal areas, ground water within the regional flow system, commonly extends deeper than 300 ft, is highly mineralized, and generally does not meet the drinking-water standards (See table XII-4.). The changes in ground-water chemistry as the water moves from the local flow system to the regional flow system are plotted in figure XII-1. These changes included increased dissolved solids and a change in chemical composition.

A generalized vertical section showing ground-water flow in layered sedimentary strata containing coal seams was given in figure V-2; a detailed version, shown in figure XIII-4-1, indicates (1) the variation of hydraulic head with topographic and hydrologic position, (2) the movanent of ground water from the uplands down to the alluvium and the river, (3) the tendency of the water table to parallel land surface, and (4) the transition zone between the connate brine of the deep flow system and the freshwater of the local system.

The ground-water quality in an unmined area of a local flow system can be a calcium-magnesium bicarbonate type with pH of 6.5 to 7.0 and low iron and sulfate concentrations. As shown in figure XIII-4-2, the ground-water flow system changes during surface- and underground-mining. In surface mining, spoils are created, and the pyrite minerals in the disturbed shale bedrock are oxidized to form sulfuric acid and "yellow boy". The simplified formula is

$$FeS_2 + H_2O + O_2 \longrightarrow Fe(OH)_3 + H_2SO_4 .$$

In underground mining, not only is the local water table lowered, the ground-water flow direction changes from dominantly horizontal to dominantly vertical and, with the fractured overburden, the oxygenated water yields acidic water, as with surface mining, which is called acid mine drainage (MD).

The common characteristics of AMD are (1) pH less than 4.0, (2) iron concentrations of about 10 mg/L; and (3) sulfate concentrations greater than a 1,000 mg/L.

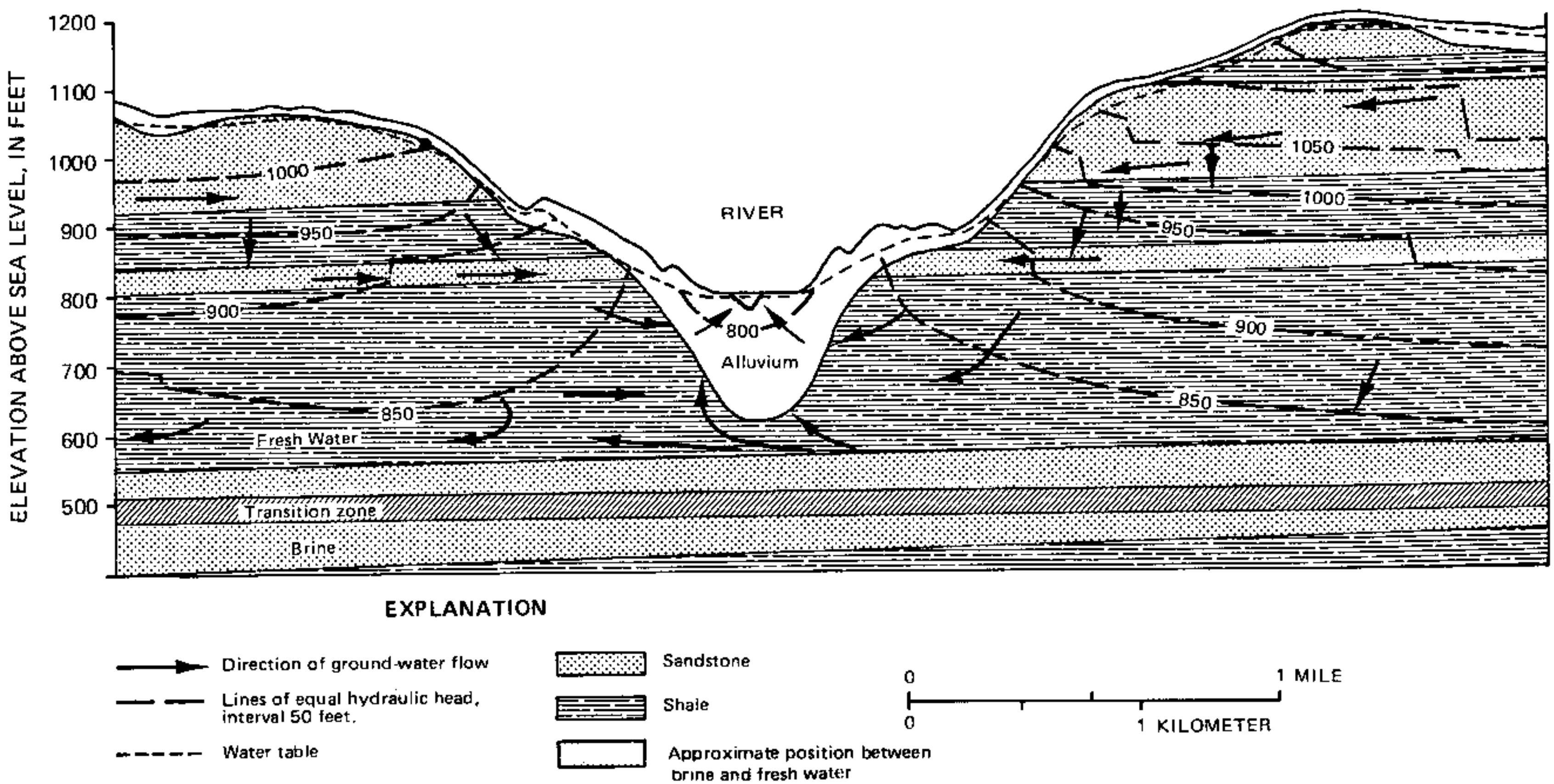


Figure XIII-4-1.— Example of a idealized geologic and hydrologic section in a sedimentary sequence showing directions of ground-water flow.
(Modified for Carswell and Bennett, 1963, pl. 3)

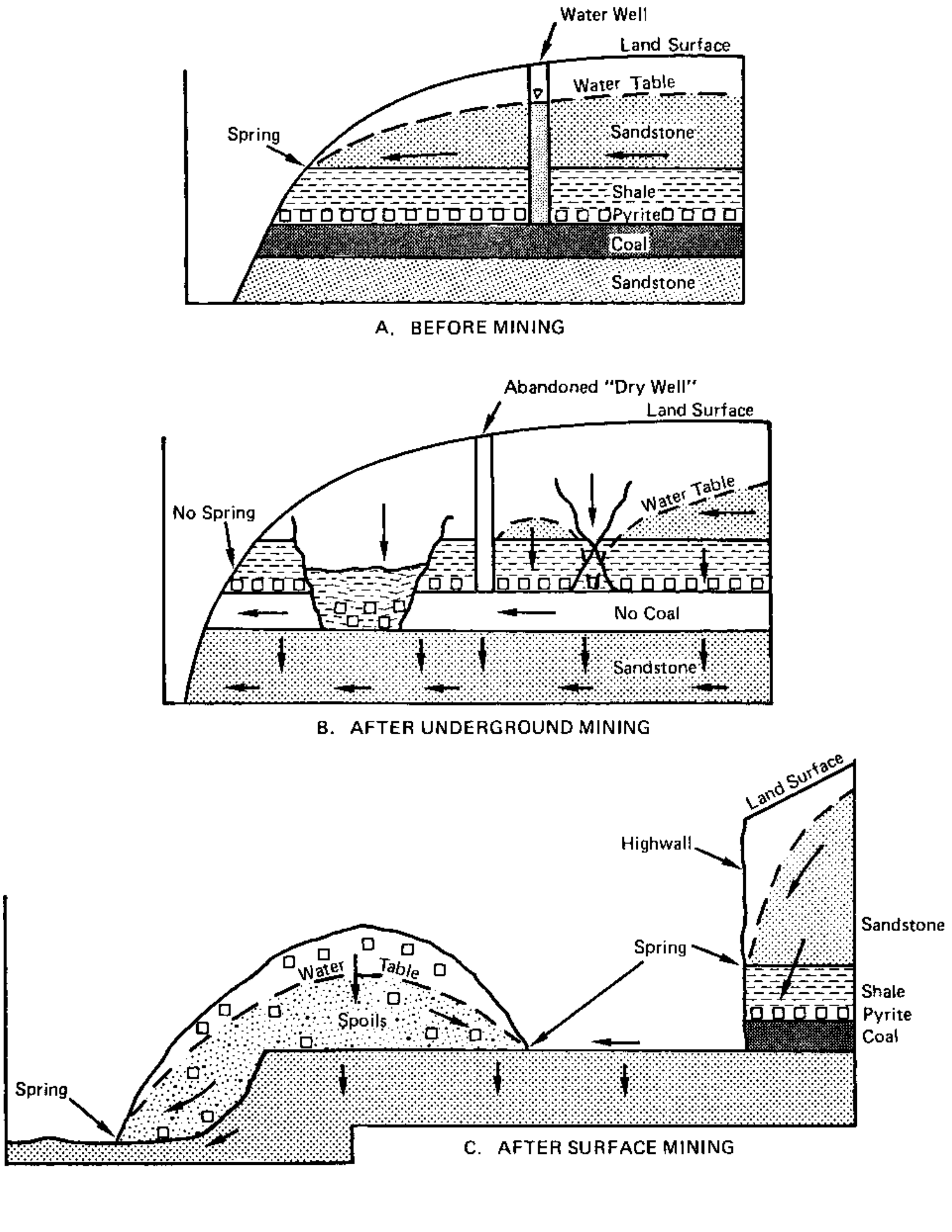


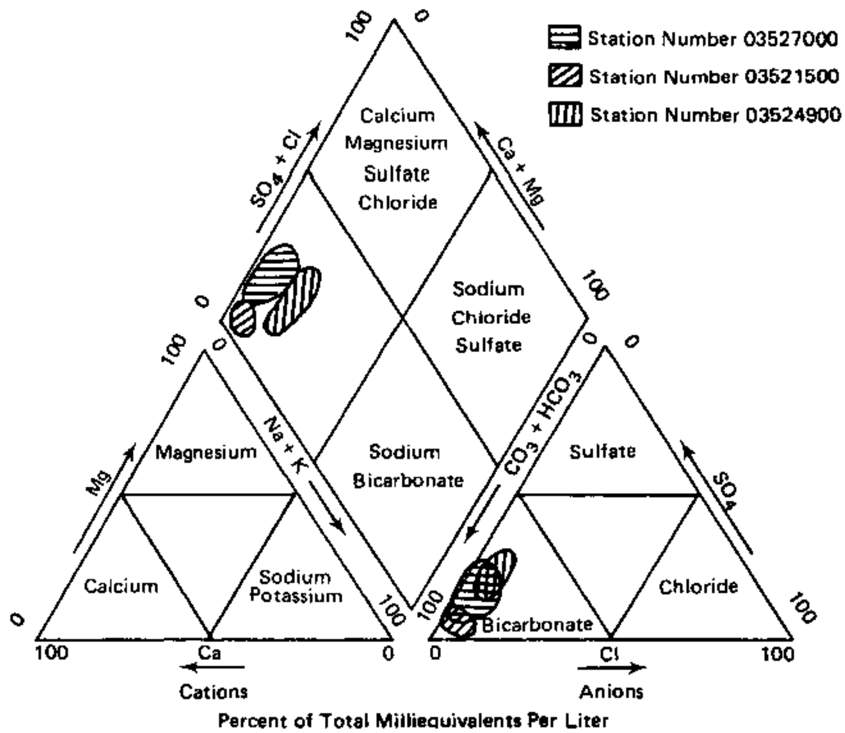
Figure XIII-4-2.— Effects of surface- and underground-coal mining on ground-water flow. (Modified from A.I.P.G., 1983, and Enrich and Merritt, 1969)

At surface- and underground-mining sites as well as abandoned mines, AMD discharges to streams, where it degrades surface-water quality, and into shallow aquifers, where it affects ground-water quality. A summary of these characteristics in ground water from a mined area in southwestern Pennsylvania is given in Table XIII-4-1. Other effects can include increased concentrations of total dissolved solids, including aluminum and manganese. Water of acid-mine drainage is typically hard, has objectionable amounts of iron that causes the staining of clothes and porcelain, has a laxative effect and a bad taste, and requires extensive filtration, softening, and settling before domestic use. Water with low pH may be corrosive and adversely affect commercial treatment processes including coagulation and chlorination. Water for cooling purposes outside the pH range of 5.0 to 8.9 are considered unusable for industrial purposes. The trilinear diagrams in figure XIII-4-3 summarize (1) ground-water quality in selected noncoal-bearing areas in western Virginia where the water type is calcium-magnesium bicarbonate, and (2) ground-water quality in adjacent mined and coal bearing areas, where water type is calcium-magnesium sulfate.

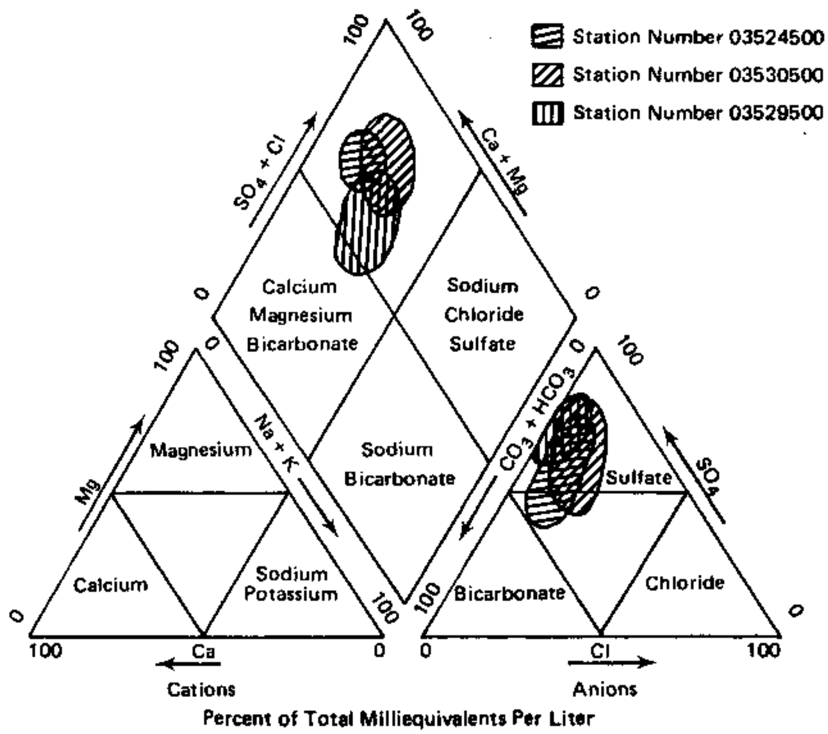
Ground-water quality can also be modified by other mineral-resource production activities such as intensive pumping of ground water, active petroleum production, abandoned oil and gas wells, and waste disposal. Intensive pumping of the ground water within the local flow system, for water supply can cause a significant reduction in hydrostatic head at the wells and cause an upward migration of salty ground water. Figure XIII-4-4 illustrates the upcoming of deep saltwater. Such well discharges commonly have concentrations of chloride in excess of 250 mg/L, which gives the water a salty taste.

A summary of the range and mean concentration of chemical constituents of ground water affected and unaffected by coal mining and saltwater intrusion in southern West Virginia is given in table XIII-4-2. Streamflow in this area is generally the calcium bicarbonate type, but ground water is variable. It may be contaminated by calcium sulfate water from mines or by brine disposal in the oil-and gas-producing areas. Ground-water discharge from abandoned mines in the headwaters results in an increase of the dissolved-solids concentration of the receiving stream (Ehlke and others, 1982).

Ground water from bedrock wells tapping the Lower Pennsylvanian Series (Pottsville age), that are affected, by saltwater typically has high specific conductance, dissolved solids, and chloride, whereas ground water from wells tapping the same system that is affected by coal has high specific conductance and dissolved solids, but also has high hardness, dissolved iron, and sulfate. This water is also typically low in alkalinity and pH. Characteristic ground water from the Lower Pennsylvanian Series that is unaffected by mining or saltwater intrusion has neutral pH (about 7), low specific conductance, dissolved solids, hardness, chloride, and sulfate, but high concentrations of dissolved iron. The ground water of best quality is in the alluvium, which is low in specific conductance, alkalinity, chloride, hardness, iron, and manganese.



A. For streams draining non - coal bearing strata



B. For streams draining coal - bearing strata and streams in mining areas.

Figure XIII-4-3.— Trilinear diagrams showing quality of water in six streams draining sedimentary strata in western Virginia. (From Hufshmidt and others,1981, fig. 5.1)

Active petroleum exploration and development commonly results in the production of brine (salty water) from deep formations. The improper disposal of brine can affect the quality of the ground water within the shallow flow system. Disposal methods include temporary storage in holding ponds and reinjection into the petroleum-production zones by pressure flooding.

Active and abandoned oil and gas wells that are improperly cased or are uncased allow brines and other fluids to discharge at the land surface or into aquifers of the local flow system. Fracture traces (chapter X-3.0) also allow the movement of brines and other fluids into the shallow flow system (Harrison, 1983).

Waste disposal operations may develop an effluent, or leachate, that has the chemical make-up of the waste material. Waste disposal could be of industrial, municipal, or agricultural origin: A hypothetical hydrogeologic cross section in figure XIII-4-5 shows common practices of land use, water use, and waste disposal in relation to the ground-water system. All of the practices shown affect the quality of ground water and, to some extent, the quality of stream-flow. Table XIII 4-3 lists some chemical constituents commonly found in ground water that originate from the wastes of the respective industries.

The effect of mining on water quality in the general area may be defined by sampling the following within the permit area and upgradient and downgradient from it before, during, and after mining:

1. water from observation wells (See chapter XIV) that tap the overburden, the aquifers, and the spoils?
2. spring discharges;
3. base flow of streams.

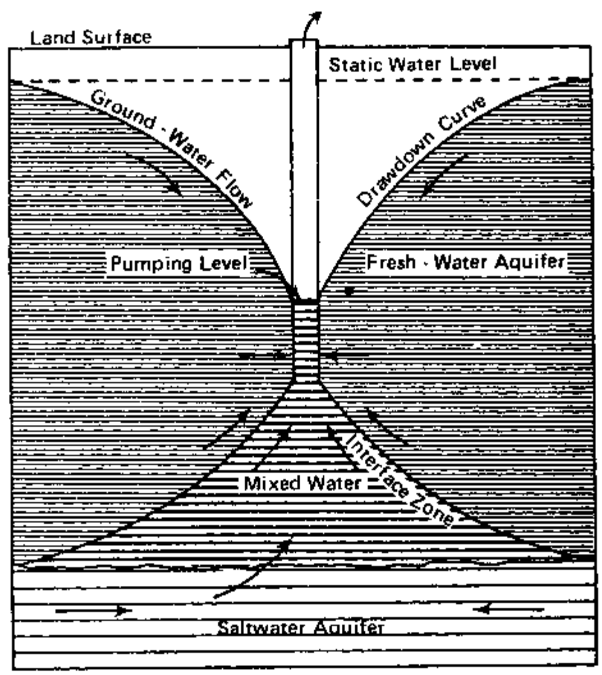


Figure XIII-4-4.— Upcoming of saline ground water into well discharge as a result of heavy pumping.
(Modified from U.S. Geological Survey, 1984, fig. 23)

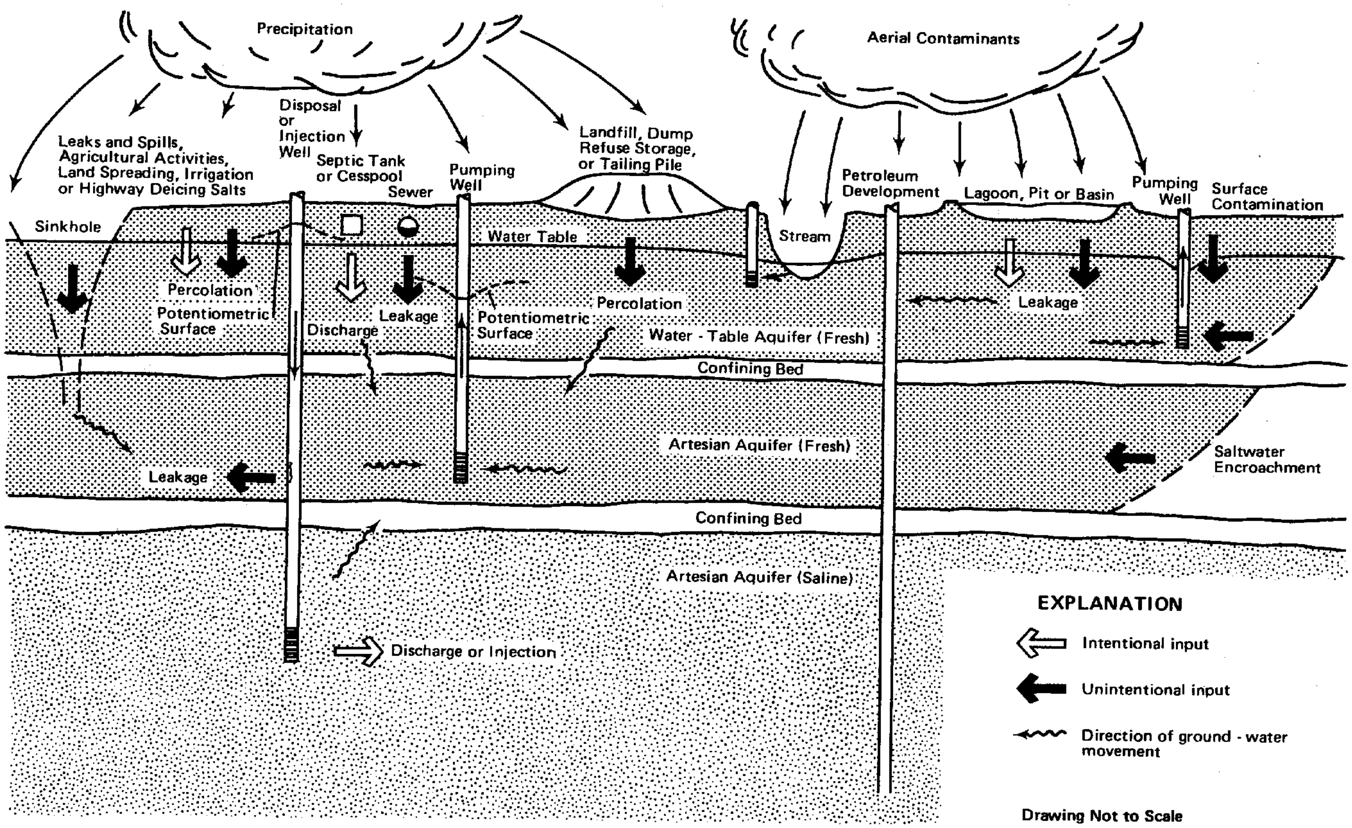


Figure XIII-4-5.— Typical sources and routes of ground-water contamination. (From U.S. Environmental Protection Agency, 1977a)

Table XIII 4-1.– Areas of suspected ground-water degradation due to coal mining in southwestern Pennsylvania.
(From Sgambat and others, 1980, table 8; and Green International, Inc., 1976.)
[Fe, iron; 804, sulfate; mg/L, milligrams per liter.]

County and township	Watershed	Average concentrations Fe mg/L	SO_4 mg/L	pH units
ALLEGHENY COUNTY				
West Deer Township	West Branch Deer Creek	6	922	3.83
Fawn Township	Bull Creek	50	–	–
Frazer, Harmar, & Springdale Townships	Little Deer Creek	22	1,307	6.71
Findley Township	Potatoe Garden Run	69	793	–
Penn, Patton, North Versailles , Mifflin & Pittsburgh Townships	Turtle Creek	21	433	–
ARMSTRONG COUNTY				
Madison & Washington Townships	Mahoning Creek & Allegheny River	34	665	3.05
Rayburn & East Franklin Townships	Cowanshannock Creek & Allegheny River	21	2,380	2.98
North & South Buffalo Townships	Allegheny River	82	2 ,631	3.45
BUTLER COUNTY				
Allegheny Township	Bear Creek	20	560	2.40
Connoquenessing Township	Little Connoquenessing Creek	14	475	3.60
Jackson Township	Connoquenessing Creek	7	560	–
FAYETTE COUNTY				
Springfield & Stewart Townships	Trib. Youghiogheny River	25	3,312	4.07
INDIANA COUNTY				
Banks Township	South Brady Run	37	829	4.48
Cherryhill Township	Two Lick Creek Little	34	955	4.26
Brush Valley & Center Townships	Yellow Creek Brush Creek Black Lick Creek Two Lick Creek	64	1,714	3.86
WESTMORELAND COUNTY				
Setfickley, Rostraver, South Huntingdon Townships	Sewickley Creek	23	1,076	5.05
South Huntingdon Township	Sewickley Creek	–	3,075	4.02

Table XIII 4-2. – Ground-water quality affected and unaffected by mining and/or salt-water intrusion.
(From Ehlke, and others, 1982, p. 31.)
[mg/L, milligrams per liter; $CaCO_3$, calcium carbonate.]

		Specific Conductivity (micromhos per centimeter)	pH(units)	Alkalinity (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Hardness as $CaCO_3$ (mg/L)	Hardness non -carbonate (mg/L)	Dissolved solids (sum) (mg/L)	Dissolved iron (mg/L)	Dissolved manganese (mg/L)	No. of wells
A. Comparison of water analyses from wells unaffected by mining or salt water												
Geologic material												
Quaternary alluvium	Max.	710	7.3	246	29	110	200	110	443	0.17	0.06	14
	Min.	100	5.51*	12	0	11	26	0	55	0	0	
	Mean	224	6.6	57	8.7	38	77	23	136	.10	.019	
Upper Pennsylvanian formations	Max.	1,000	8.9	435	120	100	300	53	646	32.0	3.9	94
	Min.	100	6.21*	0	1.0	0.1	3	0	119	0	0	
	Mean	499	7.2	229	19	21	109	3. 7	318	1.686	.274	
Lower Pennsylvanian formations	Max.	930	8.3	435	180	88	230	75	588	16.0	9.9	191
	Min.	45	4.51*	9	0.8	0	3	0	21	.01	0	
	Mean	269	7.0	94	14	34	68	6.5	152	3.266	.232	

* median value

B. Comparison of water analyses from wells tapping the lower Pennsylvanian Series (Pottsville age) that are unaffected, affected by mining, and affected by salt water

Water type	Specific Conductivity (micromhos per centimeter)	pH(units)	Alkalinity (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Hardness as $CaCO_3$ (mg/L)	Hardness non -carbonate (mg/L)	Dissolved solids (sum) (mg/L)	Dissolved iron (mg/L)	Dissolved manganese (mg/L)	No. of wells
Maximum values											
Unaffected	930	8.3	435	180	88	230	75	588	16.0	9.9	191
Affected by mining	2,000	8.0	130	250	1,200	1,300	1,300	1,790	180.	9.9	38
Affected by salt water	3,500	7.6	254	1,000	3	210	38	1,930	9.8	.65	10
Minimum values											
Unaffected	45	4.5	9	0.8	0	3	0	21	0.01	0	191
Unaffected by mining	70	4.1	0	1.0	0.4	24	13	42	0	0	38
Affected by salt water	650	6.7	123	140	0	32	0	385	.06	0.01	10
Mean values											
Unaffected	269	7.0*	94	14	34	68	6.5	152	3.27	0.232	191
Affected by mining	482	6.6*	32	19	172	183	150	324	16.5	4.23	38
Affected by salt water	1,250	.2*	174	304	1.2	100	3.8	696	2.587	.196	10

* median value

Table XIII 4-3.– Industrial wastewater constituents having or indicating significant ground-water contamination or potential. (From Hammer & MacKichan, 1981, table 5-2; and U.S. Environmental Protection Agency, 1977b.)

[COD - chemical oxygen demand; TOC - total organic carbon; Heavy metals include: aluminum, calcium, chromium, cobalt, copper, gold, iron, lead, manganese, mercury, nickel, platinum, Rare Earths, silver, tin, vanadium, zinc, and others.]

PULP AND PAPER INDUSTRY			
Ammonia	Heavy metals	Phenols	TOC
COD	Nutrients (nitrogen & phosphorous)		Total dissolved solids
Color	pH	Sulfite	
PETROLEUM REFINING INDUSTRY			
Ammonia	Cyanide	pH	Total phosphorous
Chloride	Iron	Phenols	Turbidity
Chromium	Lead	Sulfate	Zinc
COD	Mercaptans	Sulfide	
Color	Nitrogen	TOC	
Copper	Odor	Total dissolved solids	
STEEL INDUSTRIES			
Ammonia	Cyanide	Phenols	Zinc
Chloride	Iron	Sulfate	
Chromium	pH	Tin	
ORGANIC CHEMICALS INDUSTRY			
COD	pH	Total dissolved solids	
Cyanide	Phenols	Total nitrogen	
Heavy metals	TOC	Total phosphorous	
INORGANIC CHEMICALS, ALKALIES, AND CHLORINE INDUSTRY			
Acidity/alkalinity	Chromium	Phenols	
Aluminum	COD	Sulfate	
Arsenic	Cyanide	Titaniun	
Boron	Fluoride	TOC	
Chloride	Iron	Total dissolved solids	
Chlorinated benzenoids &	Lead	Total phosphorous	
polynuclear aromatics	Mercury		
PLASTIC MATERIALS AND SYNTHETICS INDUSTRY			
Ammonia	Mercaptans	Phosphorous	
Chlorinated benzenoids &	Nitrate	Sulfate	
polynuclear aromatics	Organic nitrogen	Total dissolved solids	
COD	Zinc	pH	
Cyanide	Phenols		
NITROGEN FERTILIZER INDUSTRY			
Ammonia	COD	Phosphate	
Calcium	Iron	Sodium	
Chloride	Nitrate	Sulfate	
Chromium	Organic nitrogen compounds	Total dissolved solids	
	PH	Zinc	
PHOSPHATE FERTILIZER INDUSTRY			
Acidity	Dissolved solids	Nitrogen	Uranium
Aluminum	Fluoride	pH	
Arsenic	Iron	Phosphorous	
Calcium	Mercury	Sulfate	