

## XII. GROUND-WATER QUALITY

### Pertinent 30CFR<sup>1</sup> Sections:

- Description of hydrology and geology
- Ground-water information
- Surface-water information
- Alternative water-supply information
- Protection of hydrologic balance
- Operation plan

The objective of this chapter is to aid the applicant in understanding the chemistry of the ground water within aquifers that may potentially be affected by mining within the permit area and adjacent area.

Federal regulations 30CFR, parts 780.21(b)(1) and 784.14(b)(1) as applied to ground water state:

"Water quality descriptions shall include, at a minimum, total dissolved solids or specific conductance corrected to 25°C, pH, total iron, and total manganese."

Ground-water-sampling sites such as springs and base-flow sites can be sampled with little or no alteration of the natural chemical conditions of the water. Wells and test holes are not natural sites; thus, chemical analyses of water from these sources can reflect unnatural ground-water conditions, depending upon the drilling history, the type of well construction, well completion, and well-development, the well-pumping history, and the water-production system. Table XII-1 presents a checklist of factors that influence the quality of ground water from wells and test holes. These factors must be considered in the investigation of ground-water quality.

Water-quality data for both surface and ground water are available from the files of State and Federal agencies. (Sources of additional hydrologic information are given in chapter XV). A review of published reports on ground water quality may (1) provide information on the chemical types of ground water, (2) aid in determining the availability of potable water for water supply and water for mine spraying and washing operations, and (3) delineate the area acid mine drainage, if any.

Difference in the water quality within the ground-water flow system, from recharge points to discharge points is shown in figure XII-1. Solution chemistry and the mineral composition of soils and bedrock units largely control the concentrations of dissolved constituents. However, as the water moves from areas of recharge to areas of discharge, the dissolved-solids concentration increases. Ground-water in the local, shallow flow system and at the recharge area contains low dissolved solids and may be a calcium-magnesium-bicarbonate type water. Travel time through a shallow system may be months or years. In contrast, ground water in the regional, deep flow system and at the discharge area contains high dissolved solids and may be a sodium chloride type water. The travel time for these conditions may be hundreds or thousands of years. Ground water from coal-mine operations may be high in dissolved solids and may be a calcium sulfate-type water.

CFR<sup>1</sup> Code of Federal Regulations

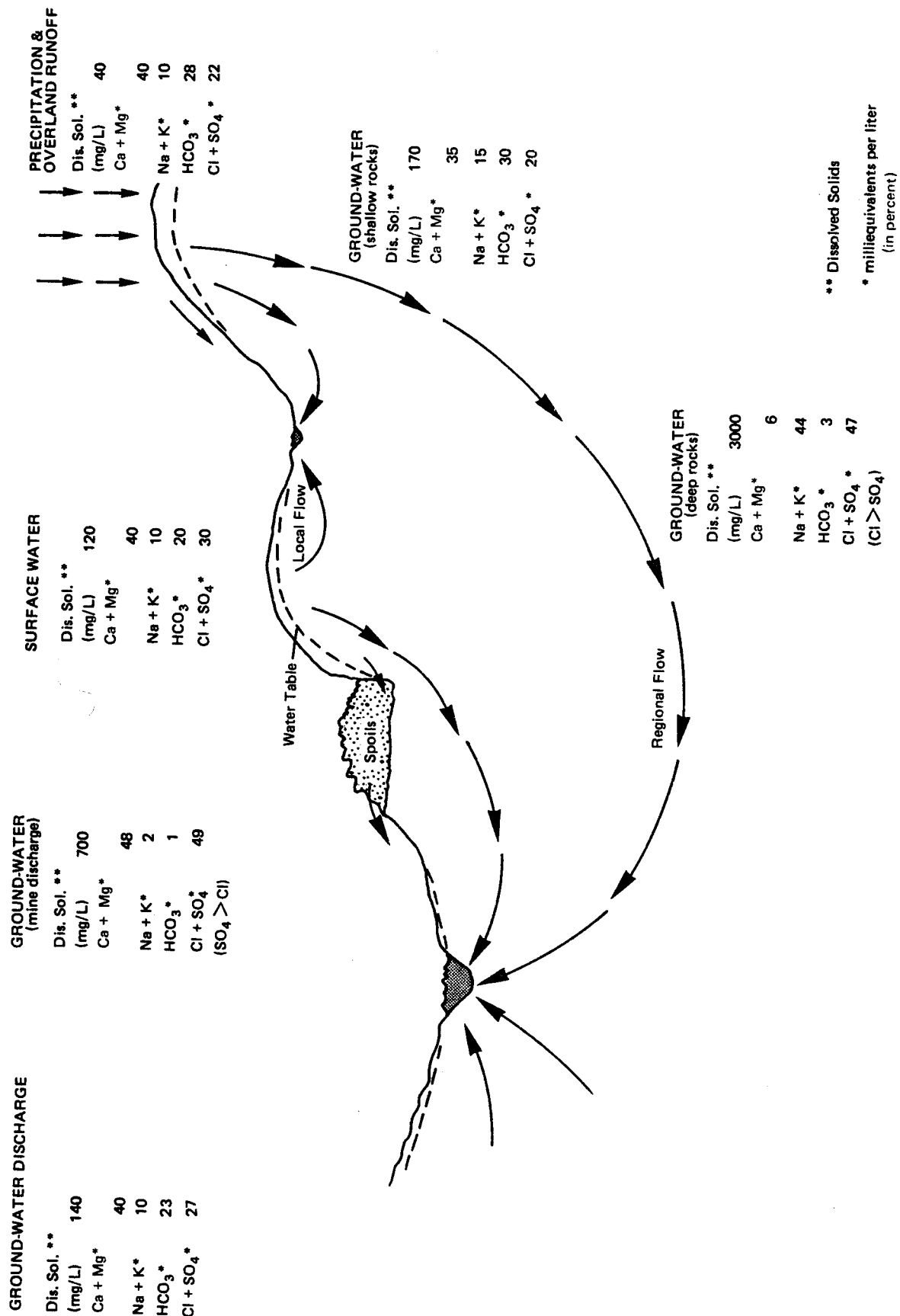


Figure XII-1.— Differences in chemical composition of water within surface-water and ground-water flow systems. (Modified from Hollowell and Koester, 1975, fig. 17)

After the available historical water-quality information has been reviewed, the first ground-water-quality inventory is made from ground-water samples collected from:

- wells and springs (chapter VII)
- base-flow stream sites (chapter XI)
- ground-water monitoring network (chapter XIV)
- test holes and core holes of the exploratory program (chapter XVI).

The sampling of ground water for chemical analysis requires experience, patience, care and appropriate equipment. During sampling, the water will change as it moves from the aquifer to the wellhead and to the analytical equipment. The major changes are in temperature and pressure. As stated in (10): "Some properties or constituents in ground water may change dramatically within a few minutes or hours after sample collection. Immediate analysis in the field is required if dependable results for these parameters - temperature, dissolved oxygen, pH, specific conductance, acidity, and alkalinity - are to be obtained." Therefore, onsite analysis is best for the most representative results.

Additional information on the determination of ground-water quality may be found in the references cited in chapter XVIII; these include Brown and others, 1970; Claassen, 1982; Fetter, 1980; Freeze and Cherry, 1979; Hem, 1970; Johnson Division, 1975; Rainwater and Thatcher, 1970; Todd, 1980; Wood, 1976; and U.S. Department of Interior, 1968; 1977a and 1981a.

As mentioned in chapter X-2.2, specific conductance can be measured during the aquifer test by a water-conductivity meter. Specific conductance is an indicator of the dissolved-ion concentration of a water sample. The major dissolved constituents in the water vary in proportion to specific conductance (9). The curve in Figure XII-2 depicts the decrease in specific conductance during an aquifer test as representative aquifer water replaces the altered water near the well. The water sample at  $t=200$  minutes is considered to be the "true aquifer value" for specific conductance of the aquifer tested. Thus, the criteria used to determine the acceptability of a ground-water sample as being representative of the aquifer water include: (1) a visibly clear water, and (2) identical specific conductance, pH, and temperature readings on at least three successive samples (9).

A record of the hydrologist's field visit to water-quality sites is necessary for the compilation of ground-water quality data and to prove the measured chemical constituent concentrations in the ground water at the permit site to management and to the regulatory authority. An example of a comprehensive water-sample schedule is shown in figure XII-3. This multi-purpose form is completed at the time of sampling and can be used for a flowing or nonflowing well, a spring, a base-flow site, a lake or reservoir, or could be used during an aquifer test. The chemical factors to be measured and recorded in the field are temperature, pH, and specific conductance. One form should be used per sampling site per visit.

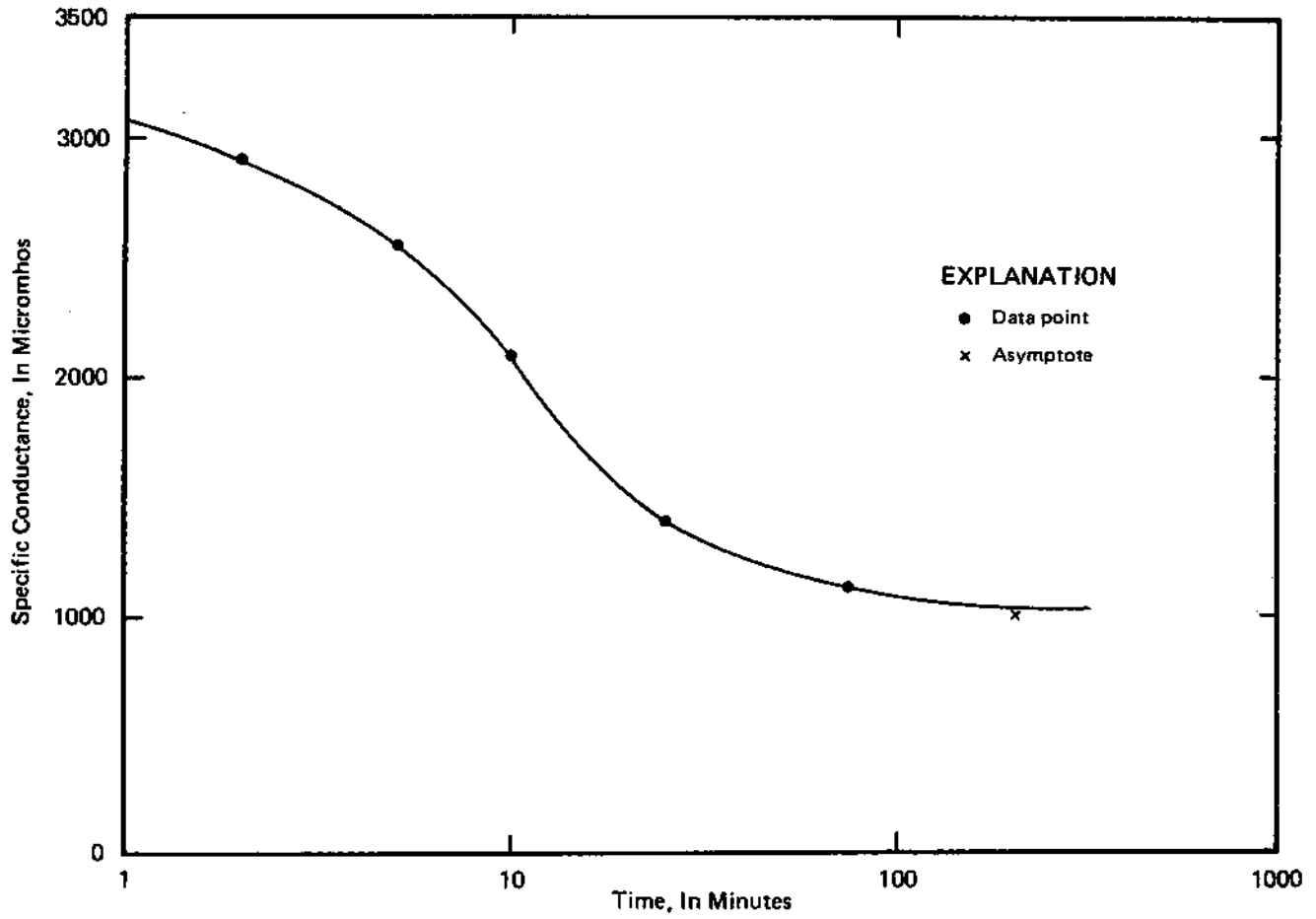


Figure XII-2.— Change in specific conductance with time during aquifer test.  
 (From Claassen, 1982, p. 14)

PERMIT SITE \_\_\_\_\_

Source (circle one) - flowing well, non-flowing well, spring, stream site, lake, pond, reservoir

Location description: Township \_\_\_\_\_ County \_\_\_\_\_ State \_\_\_\_\_

Owner's name \_\_\_\_\_ Address \_\_\_\_\_

\_\_\_\_\_ 1/4 \_\_\_\_\_ 1/4 \_\_\_\_\_ 1/4 Section \_\_\_\_\_ T \_\_\_\_\_ E \_\_\_\_\_ N \_\_\_\_\_ W R \_\_\_\_\_ S Field/Office No. \_\_\_\_\_

Latitude \_\_\_\_\_ Longitude \_\_\_\_\_ 7 1/2' Topo. Quad. Map Name \_\_\_\_\_

Date sample collected \_\_\_\_\_ Year \_\_\_\_\_ Time \_\_\_\_\_ Collected by \_\_\_\_\_

Water temperature (°C) \_\_\_\_\_ (°F) \_\_\_\_\_ pH \_\_\_\_\_ Specific Conductance (umho/cm) \_\_\_\_\_

Purpose of collecting sample \_\_\_\_\_

Appearance of sample (circle one) clear, rust colored, cloudy, clear with particles, muddy ODOR yes no

Sample number sent to lab. \_\_\_\_\_ Laboratory name \_\_\_\_\_ Address \_\_\_\_\_

SAMPLES COLLECTED (circle) General chemical Minor elements Radiochemical Other

Date submitted to lab. \_\_\_\_\_

Date results received back \_\_\_\_\_

WELL - Type (circle one) - used, unused, flowing, test hole. Date \_\_\_\_\_ Time \_\_\_\_\_

Use (circle one) - commercial, domestic, irrigation, industrial, stock, public supply, abandoned

Driller's log yes no Water-bearing formation(s) \_\_\_\_\_

Depth of well \_\_\_\_\_ ft (measured/reported) Cased to \_\_\_\_\_ ft (meas./rept.) Casing diameter \_\_\_\_\_ in.

Date drilled \_\_\_\_\_ Driller's name \_\_\_\_\_ Address \_\_\_\_\_

Well finish (circle one) open hole, screen, cemented, gravel pack CASING MATERIAL steel 'fiberglass'

Static water level \_\_\_\_\_ ft Date measured \_\_\_\_\_ Depth sampled \_\_\_\_\_ ft

Description of measuring point \_\_\_\_\_

Aquifer test - Static water level \_\_\_\_\_ ft Date \_\_\_\_\_ Time \_\_\_\_\_

Date \_\_\_\_\_ Time test started \_\_\_\_\_ Volume bore-hole storage \_\_\_\_\_ ft<sup>3</sup> \_\_\_\_\_ gal

Yield \_\_\_\_\_ gal/min Time \_\_\_\_\_ Pumping level \_\_\_\_\_ ft Drawdown \_\_\_\_\_ ft

Discharge sampled Date \_\_\_\_\_ Time \_\_\_\_\_ Quantity pumped before sampling \_\_\_\_\_ ft<sup>3</sup> \_\_\_\_\_ gal

SPRING - Type (circle one) - perched, contact, fracture Use (circle one) unused, stock, domestic

Discharge \_\_\_\_\_ gal/min (measured/reported/estimated)

Water-bearing formation \_\_\_\_\_

STREAM Gaging station name \_\_\_\_\_ Number \_\_\_\_\_

Gage height \_\_\_\_\_ ft Discharge \_\_\_\_\_ cubic feet per second (measured/estimated)

Sampling location (looking downstream) left bank center stream (depth of sample \_\_\_\_\_ ft) right bank

LAKE OR RESERVOIR Name \_\_\_\_\_ Location \_\_\_\_\_ 7 1/2' Topo. Quad. map name \_\_\_\_\_

Shore sample location \_\_\_\_\_ Off-shore sample location \_\_\_\_\_ Depth \_\_\_\_\_ ft

ADDITIONAL NOTES

Figure XII-3.— Example of field water-sample schedule for chemical analysis to be completed at the time of sampling.  
(Modified from Claassen, 1982, fig. 6)

Ground-water samples can be withdrawn from wells by the pump installed in the well, but the steel of the casing and pump column may cause the dissolved-iron values to be higher than those in the formation water (9). Discharge of more than two borehole volumes before sampling, will reduce this discrepancy. For example, a well with a static water level at 20 ft below land surface, with a well depth of 100 ft and a casing diameter of 4 inches has an approximate borehole volume of 7 ft<sup>3</sup>. With a well discharge of 2 gal/min, three borehole volumes pumped to waste would take 78 minutes. Measurement of three identical specific conductance values in succession, as mentioned previously, would indicate "true-aquifer" quality. At wells without pumps, water samples can be withdrawn by (1) placing a submersible pump in the well, (2) using "thief samplers"<sup>1</sup>, or (3) bailing and swabbing the well, which require a workover drilling rig.

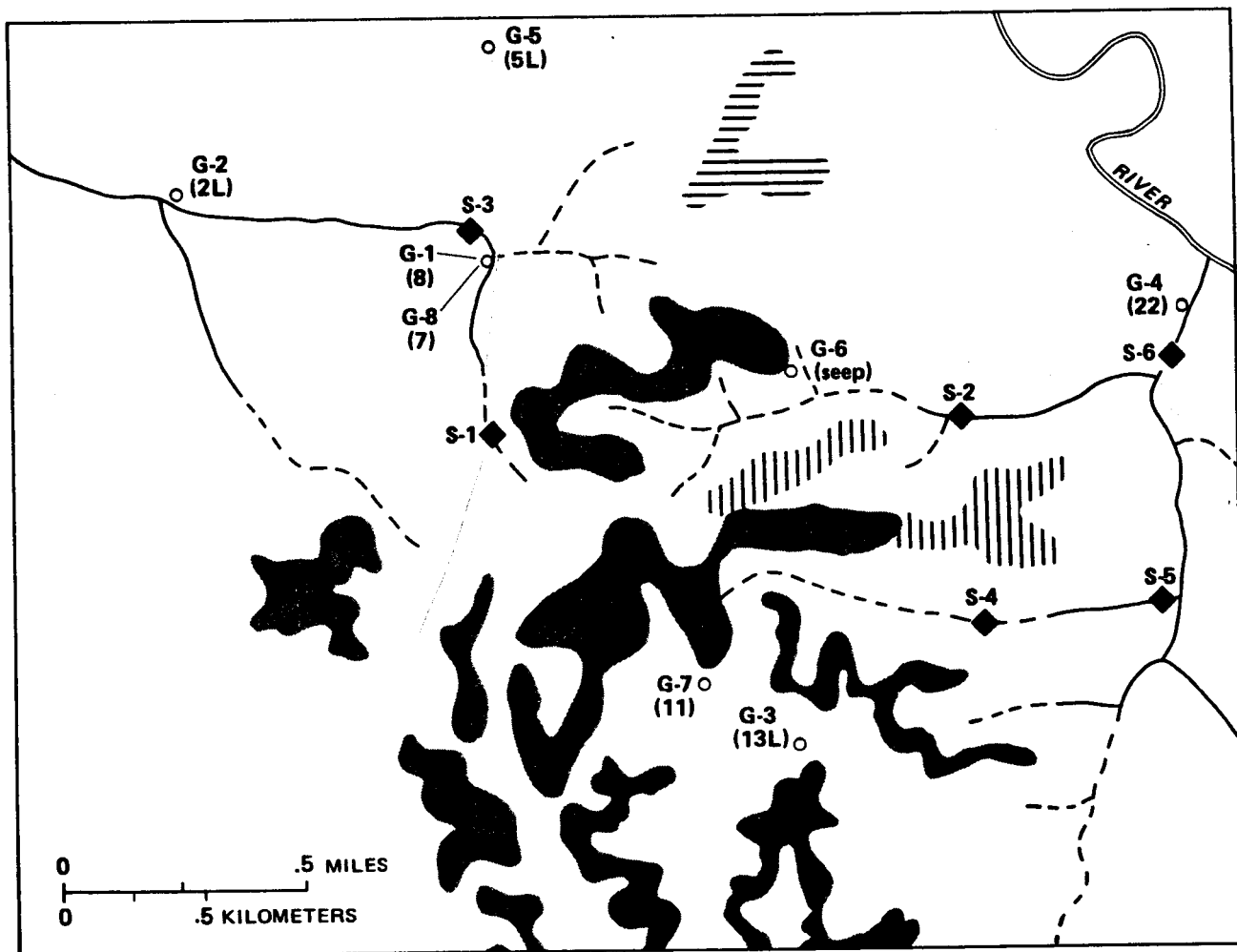
The ground-water sampling can be done concurrently with the exploratory program (chapter XVI). As one or more of the test holes or core borings are drilled and logged (chapter VIII), each aquifer unit should be defined, selectively pumped, and sampled. The sampling of individual aquifers during test drilling would provide background information on the variation of ground-water quality both laterally (between test holes, wells, springs, and streams) and vertically (between aquifers above and below the coal beds to be mined).

Analysis of water samples from the first well and spring inventory from base-flow stream sites, and from the test-drilling program should be tabulated by (1) aquifer or surface-water site, (2) well opening, (3) depth of well or stream discharge, (4) location in relation to the proposed permit area, and (5) water type (major chemical constituents). An example of a tabulation of chemical constituents is shown in table XII-2. These samples are from wells and base-flow sites in the vicinity of the permit area, as shown in figure XII-4.

If anomalous results are obtained, the hydrologist should first check the analysis and calculations, and second, consider resampling. An example of an anomalous result would be a sodium chloride type water in an area of calcium-magnesium-bicarbonate-type water. Upon confirmation of the anomalous results, the investigator must consider the possibility of ground-water contamination, perhaps caused by waste disposal or petroleum-exploration activities. Documentation of anomalous results is important for the protection of all parties, as is notification to the regulatory authority. Contamination may also be derived from agriculture runoff, mining, nuclear power development, or disposal of refuse, sewage, and industrial wastes. Pollution is defined as a level at which contaminant concentrations are considered to be objectionable (2), (7).

The potability of the ground water is determined by comparing the physical, chemical, and microbiological analyses of the water with the U.S. Environmental Protection Agency's 1983 Drinking Water Standards, which are presented in table XII-3.

<sup>1</sup>Well Reconnaissance Corporation, Houston, Texas



**EXPLANATION**






-  Area of active mining
-  Mined and reclaimed areas.
-  Proposed mine permit area.
- S-1**  Stream sampling site; water analysis listed in table XII-2
- G-1**  Ground-water sampling site; water analysis listed in table XII-2  
Number in parenthesis refers to well listed in well inventory table

Figure XII-4.— Example of location map of mining activities, proposed permit area, and water-quality sampling sites.  
(From Norris, 1991, fig. 2)

One method of comparing the results of chemical analyses of ground water is with a trilinear diagram (figure XII-5). This diagram consists of two lower triangles that show the percentage distribution, on the milliequivalent basis, of the major cations ( $Mg^{++}$ ,  $Ca^{++}$ , and  $Na^{+}$  plus  $K^{+}$ ) and the major anions ( $Cl^{-}$ ,  $SO_4^{-}$ , and ( $CO_3^{-}$  plus  $HCO_3^{-}$ )), and a diamond-shaped part above that summarizes the dominant cations and anions to indicate the final water type. This classification system shows the anion and cation facies in terms of major-ion percentages. The water types are designated according to the area in which they occur on the diagram segments. The water types are designated according to the area in which they occur on the diagram segments. Many coal-hydrology reports (chapter XV-1) describe the ground-water types with trilinear diagrams such as this.

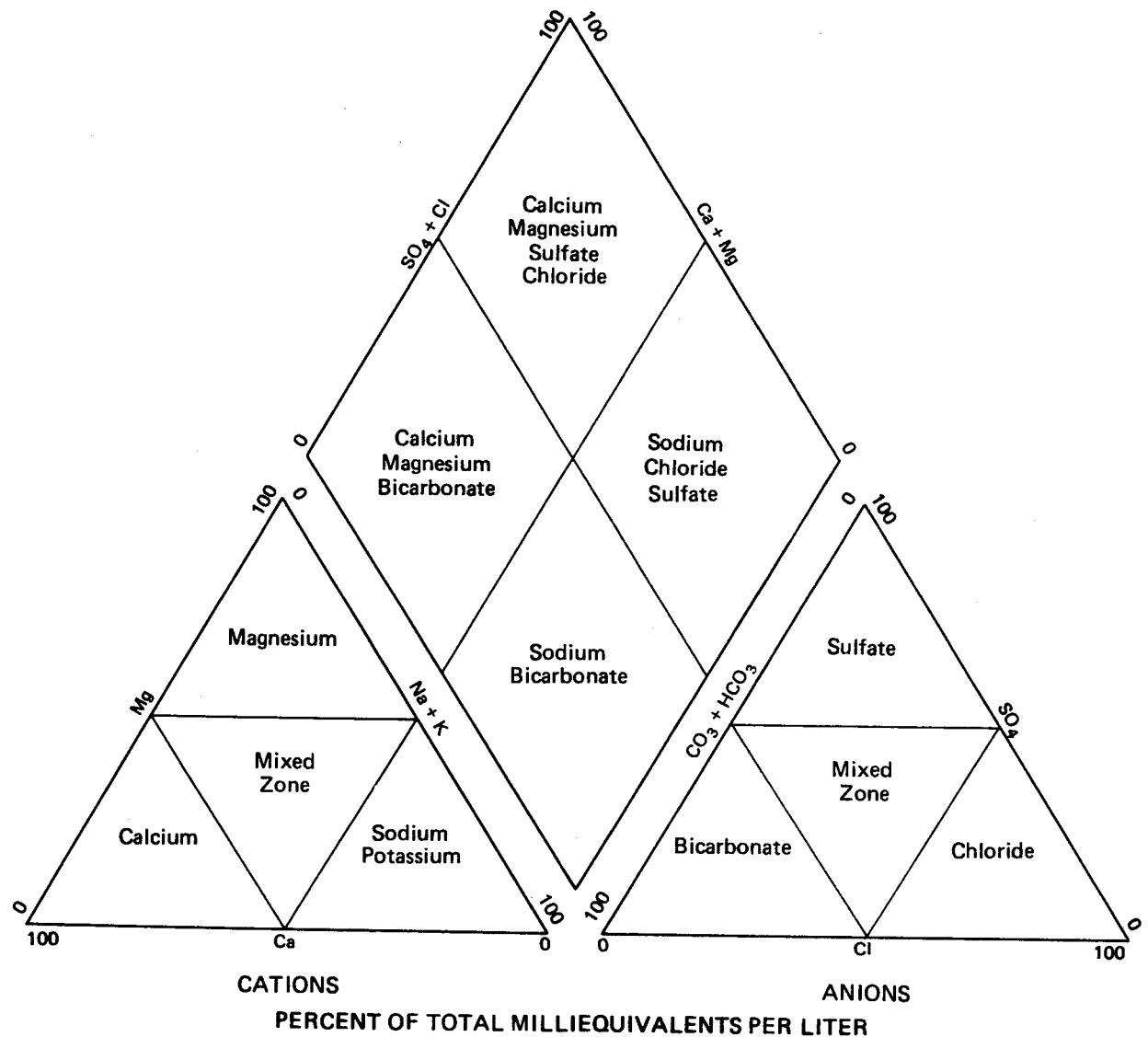


Figure XII-5.— Trilinear diagram showing water-type categories.  
(From Piper, 1944, fig. 1, and Roybal and others, 1983, fig. 4.7-1)



An example of a ground-water chemical analysis is shown in table XII-4; a plot of the values on a trilinear diagram are shown in figure XII-6. The high chloride content of the water sample from well 2085 (and point no. 2) suggests that the water is contaminated (6). The conversion factors from milligrams per liter to milliequivalents is given in references (3) and (7).

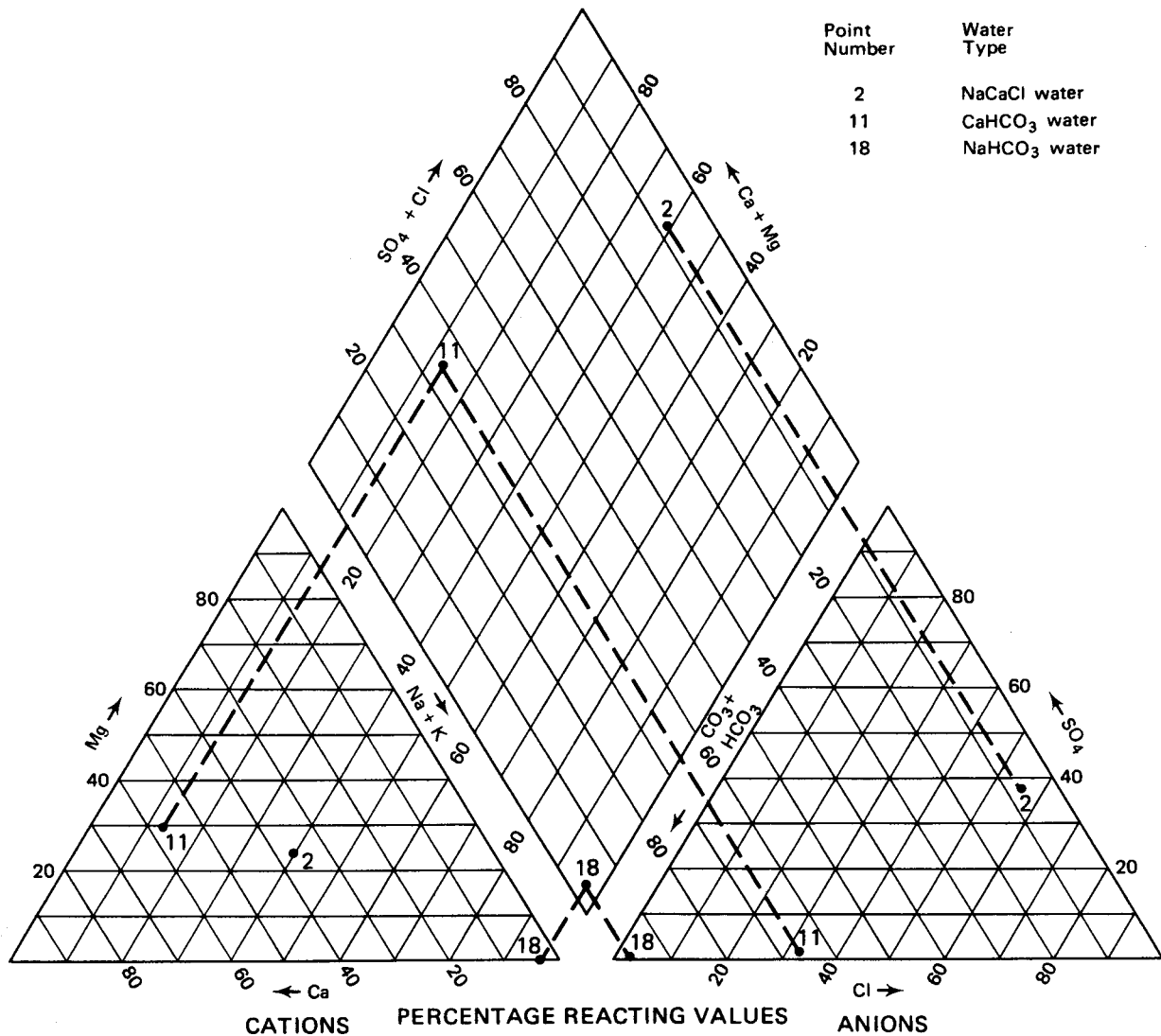


Figure XII-6.— Water-quality data from table XII-4 as plotted on trilinear diagram. (In part from Schiner and Runnel, 1976, fig. 12)

Table XII-1. – Checklist of data requirements for water-source definition and aquifer representation of ground-water samples.  
(Modified from Claassen, 1982, table 1.)

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- A. Drilling history
    - 1. Well depth and diameter
    - 2. Drilling method and drilling-mud composition
    - 3. Lithologic data from cores or cuttings
    - 4. Well development before casing installation
    - 5. Geophysical logs obtained
  
  - B. Well-completion data
    - 1. Casing sizes and depths
    - 2. Casing material(s)
    - 3. Cemented intervals
    - 4. Plugs and stabilizers left in the hole
    - 5. Gravel packing: volume, sizes, and type of "gravel" material
    - 6. Screened, perforated, or milled casing intervals that allow water to enter the borehole
    - 7. Pump type, setting, intake location, construction materials, and pump-column type and diameter
  
  - C. Well pumping history
    - 1. Rate
    - 2. Frequency
  
  - D. Estimation of effect of contaminants introduced into aquifer during well drilling and completion on native water quality
  
  - E. Effect of inplace water-production system on the composition of ground-water sample.
    - 1. Addition of contaminants
    - 2. Removal of constituents
      - a. Sorption
      - b. Precipitation
      - c. Degassing
-

Table XII-2. - Chemical constituents in surface water and ground water, (from Harris, 1981, table 2.)

[ft<sup>3</sup>/s, cubic feet per second; ft, feet; mg/L, milligrams per liter; H, hydrogen; HCO<sub>3</sub>, bicarbonate; CO<sub>2</sub>, carbon dioxide; Fe, iron; Mn, manganese; O, oxygen; SO<sub>4</sub>, sulfate; °C, degrees Celsius; Qal, Quaternary alluvium.]

SURFACE WATER																	
Stream Site*	Date	Instantaneous Discharge (ft <sup>3</sup> /s)	Total Sulfate (mg/L)	Acidity as H <sup>+</sup> (mg/L)	Air temp. (° C)	Bicarbonate HCO <sub>3</sub> (mg/L)	Carbon dioxide CO <sub>2</sub> (mg/L)	Carbonate CO <sub>3</sub> (mg/L)	Dissolved Iron Fe (mg/L)	Suspended Iron Fe (mg/L)	Dissolved manganese Mn (mg/L)	Dissolved oxygen (percent)	Dissolved oxygen (mg/L)	pH Field (units)	Specific Conductance (micro-mhos)	Dissolved sulfate SO <sub>4</sub> (mg/L)	Water Temp (°C)
S-1	4-11-79	0.10 (est)	5	—	16.5	59	376	0	0.01	0.12	0.02	78	9.6	5.4	350	120	6.5
	7-11-79	0.02	—	0.0	—	77	39	0	0.02	.29	.40	—	—	6.5	440	140	18.0
S-2	4-11-79	0.21	5	2.0	—	30	32	0	.23	.11	3.30	86	10.2	4.7	650	290	7.5
	7-12-79	0.03	—	1.3	—	0	0	0	.12	1.50	5.00	—	—	4.3	830	370	17.5
S-3	4-17-79	0.15	13	0.0	19.0	36	289	0	.05	.50	.47	100	11.6	5.3	380	150	10.5
	7-11-79	0.03	—	—	—	112	1.4	0	.03	.39	.08	—	—	8.1	480	130	22.0
S-4	4-17-79	0.29	3	0.0	18.5	0	0	0	.84	.06	10.00	96	10.0	3.6	1,400	910	14.0
	7-12-79	0.05	—	4.1	—	0	0	0	.51	.07	15.00	—	—	3.8	1,500	990	16.5
S-5	4-17-79	0.29	5	0.0	18.5	0	0	0	.45	.08	8.60	110	11.2	4.0	1,200	740	13.5
	7-11-79	0.03	10	3.3	—	0	0	0	.31	.05	14.00	—	—	3.2	1,250	970	20.0
	4-17-79	1.66	—	—	—	4	51	0	.19	.15	3.60	91	9.4	4.1	675	340	14.5
S-6	7-12-79	0.31	—	0.5	—	—	—	—	.08	.09	4.40	—	—	5.1	860	400	19.0

GROUND WATER																	
Well*	Date	Aquifer Group	Well Depth (ft)	Acidity as H <sup>+</sup> (mg/L)	Air temp. (Deg C)	Bicarbonate HCO <sub>3</sub> (mg/L)	Carbon dioxide CO <sub>2</sub> (mg/L)	Carbonate CO <sub>3</sub> (mg/L)	Dissolved Iron Fe (mg/L)	Suspended Iron Fe (mg/L)	Dissolved manganese Mn (mg/L)	Dissolved oxygen (percent)	Dissolved oxygen (mg/L)	pH Field (units)	Specific Conductance (micro-mhos)	Dissolved sulfate SO <sub>4</sub> (mg/L)	Water Temp (°C)
G-1 (8)	4-10-79	2	205	—	15.0	459	463	0	0.22	0.18	0.03	—	—	6.2	770	33	11.5
G-2 (2L)	4-18-79	3	253	0.0	—	515	21	0	.05	.11	.02	—	—	7.6	1,000	4.7	11.5
G-3 (13L)	4-18-79	3	535	0.0	22.5	906	15	0	.04	.07	.02	—	—	8.0	1,650	3.8	12.5
G-4 (22L)	4-24-79	Qal	34	0.0	—	430	17	0	6.20	3.80	.03	—	—	7.6	605	2.6	14.0
G-5 (5L)	4-18-79	2	68	0.0	18.5	580	369	0	.37	—	.02	—	—	6.4	2,000	1100	13.0
G-6 (sweep)	4-18-79	Spoll	—	7.0	21.5	0	0	0	1.20	0	37.00	—	—	3.2	2,100	1300	13.0
G-7 (11)	4-20-79	1	36	—	—	146	12	0	.09	.12	.01	—	—	7.3	951	230	11.5
G-8 (7)	7-11-79	2	200	—	—	530	27	0	.12	.08	.01	—	—	7.5	680	15	14.0

\*Locations shown on figure XII-4.

Table XII-3.— Environmental Protection Agency, 1983, Drinking Water Standards (information from Code of Federal Regulation 340, 1983, parts 141.11, 141.12, 141.13, 141.14, and 143.3)

<u>National Interim Primary Drinking-Water Regulations</u>	
(Data in milligrams per liter unless otherwise specified, tu = turbidity; pCi/L = picocurie per liter; mrem = millirem (one thousands of a rem).)	
Contaminant	Maximum contaminant levels
<u>Inorganic Chemicals (part 141.11)</u>	
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead 0.05	
Mercury	0.002
Nitrate(as N)	10.
Selenium	0.01
Silver	0.05
Fluoride	1.4-2.4
<u>Organic chemicals (part 141.12)</u>	
<u>Chlorinated hydrocarbons</u>	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
<u>Chlorophenoxys:</u>	
2,4-D	0.1
2,4,5-TP Silvex	0.01
Total trihalomethanes (the sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane (bronoform) and trichloromethane (chloroform))	
	0.10
Turbidity (part 141.13)	1-5 tu
<u>Microbiological (part 141.14)</u>	
Coliform bacteria	1 per 100 mL(mean)
<u>National Secondary Drinking-Water Regulations (part 143.3)</u>	
Chloride	250
Color	15 color units
Copper	1
Corrosivity	noncorrosive
Foaming agents	0.5
Iron	0.3
Manganese	0.05
Odor	3 threshold odor number
pH	6.5-8.5 units
Sulfate	250
Total dissolved solids (TDS)	500
Zinc	5

Table XII-4.— Determination of ground-water type from selected chemical analyses of northern Mercer county, Pennsylvania.

(Modified from Schiner and Runnel, 1976, tables 1A and 3)

[mg/L, milligrams per liter; meq/L, milliequivalents per liter; LSE, land surface elevation.

Aquifers – Qd, Pleistocene drift; Pco, Connoquenessing Formation (sandstone);

Msl, Shenango Formation (sandstone)

Cations – Na<sup>+</sup>, sodium; K<sup>+</sup>, potassium; Ca<sup>++</sup>, calcium; Mg<sup>++</sup>, magnesium;

Anions – CO<sub>3</sub><sup>-</sup>, carbonate; HCO<sub>3</sub><sup>-</sup>, bicarbonate; SO<sub>4</sub><sup>-</sup>, sulfate; Cl<sup>-</sup>, chloride.]

A. Well and chemical data

Well number	Point number	Aquifer	Well depth (feet)	Water level below LSE (feet)	Dissolved solids (mg/L)	Specific conductance (laboratory) (micronhos)	PH (laboratory)
1056	18	Msl	212	153	324	530	8.3
2074	11	Pco	115	55	72	179	6.2
2085	2	Qd	17.0	12.24	130	500	5.9

B. Concentrations of selected constituents from selected ground-water samples.

Well number	Cations (mg/L)				Anions (mg/L)			
	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	CO <sub>3</sub> <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>-</sup>	Cl <sup>-</sup>
1056	124	2.0	1.6	0.5	4	331	6.5	1.6
2074	4.1	.5	19	5.8	0	49	22	14
2085	31	14	30	13	0	18	79	83

C. Conversion of above concentrations to equivalent-weight units.

Well number	Cations (mg/L)					Anions (mg/L)				
	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	total*	CO <sub>3</sub> <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>-</sup>	Cl <sup>-</sup>	total*
1056	5.39	0.051	0.08	0.04	5.56	0.133	5.42	.135	0.045	5.74
2074	.18	.013	.95	.48	1.62	0	.80	.042	.40	1.24
2085	1.35	.358	1.50	1.07	4.28	0	.30	.64	2.34	4.28

D. Conversion of the equivalent-weight units to percentages

Well number	Cations (percent of total)				Anions (percent of total)			Water type
	Na <sup>+</sup> +K <sup>+</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	CO <sub>3</sub> <sup>-</sup> + HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>-</sup>	Cl <sup>-</sup>		
1056	97.8	1.4	0.7	96.8	2.4	0.8	NaHCO <sub>3</sub>	
2074	11.8	58.5	29.6	64.8	3.4	31.9	CaHCO <sub>3</sub>	
2085	39.9	35.0	25.0	6.9	38.4	54.7	NaCaCl	

\* Total equivalents of anions and cations do not match exactly because of analytical errors and unreported minor constituents.

## References Cited

- (1) Code of Federal Regulations #40 Revised as of July 1, 1983, Protection of Environment, parts 100 to 149, 399 p.
- (2) Freeze, R. A., and Cherry, J. A. f 1979, Groundwater: Englewood Cliffs, N. J., Prentice-Hall Inc., 604 p.
- (3) Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water Supply Paper 1473, 363 p.
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