XIV. GROUND-WATER MONITORING PLAN

Pertinent 30CFR[1] Sections:

Ground-water information
Cross sections, maps, and plans
Hydrologic balance
Operation plan

The objectives of a ground-water monitoring plan for a mining area are to:

1. define the premining ground-water conditions in terms of quantity and quality;
2. monitor water-level changes in potentially impacted aquifers during and after mining operations and to provide documentation;
3. monitor water-quality changes in surface water (base flow) and ground water during and after mining operations and to provide documentation;
4. monitor directions of ground-water flow in the vicinity of mining operations;
5. monitor potentially dangerous ground-water conditions such as hydraulic-head differences across fault zones, or across confining beds separating aquifers from coal seam excavations, or within fault zones that might connect surface-water features, such as rivers, with mining excavations; and,
6. satisfy regulatory authority requirements for ground-water monitoring.

The considerations and procedures for developing a ground-water monitoring plan to satisfy these objectives includes the following:

1. Time and frequency of measurement of:
   a. ground-water levels
   b. surface-water discharge
   c. chemical quality of ground water and surface water
2. Hydrologic data collection sites:
   a. precipitation station
   b. ground-water sites—springs and wells
   c. surface-water sites—low-flow sites, swamps, ponds, lakes, reservoirs, and mine discharge sites,
   d. mine spoils
3. Activities causing variations in ground-water quantity and quality:
   a. natural—precipitation, evaporation, and transpiration,
   b. man-related stresses—ground-water use (pumping, See chapter VII), and mine discharge.
4. Aquifers that could be potentially impacted by proposed mining operations (See chapter XIII):
   a. bedrock aquifers in the overburden,
   b. bedrock aquifer in the underburden,
   c. coal as an aquifer.
   d. unconsolidated deposits aquifer in the overburden or within the adjacent area,
   e. mine spoils.

[1] CFR = Code of Federal Regulations

5. Hydrologic measurements:
   a. ground-water levels (See chapter IX)
   b. streamflow discharge(s) (See chapter XI)
   c. pumpage - recharge and discharge (See items 3a and 3b above and chapter VII).
   d. determination of aquifer characteristics (hydraulic properties) (See chapter X, section 2).
   e. ground-water quality sampling routine, including wells, springs, and low-flow stream sites (See chapter XIII, section 4).
6. Hydrologic boundaries (See chapter X, section 2.71).
7. Ground-water modeling (See chapter XV, section 7).

Features 1 and 2 are discussed below; features 3 through 7 are discussed elsewhere in the manual, as noted.

Time and Frequency of Measurement

The monitoring period starts prior to permitting to obtain base-line information and extends throughout the mining and reclamation operations. The schedule and frequency of measurements is subject to the approval of the regulatory authority. The frequency of measurements is flexible, depending upon:

1. Regulations – 'Permanent Regulatory Program (30CFR parts 780.21 and 784.14' – states "…water levels shall be monitored and data submitted to the regulatory authority at least once every three months for each monitoring location."
2. The amount of geohydrologic information available for the permit area (chapter XV)
   – When little information is available, measuring and sampling are frequent, such as biweekly, to develop a data base for the permit area and adjacent area and to define the hydrologic setting?
   – As hydrologic data are compiled, tabulated, and interpreted, and if changes in hydrologic conditions are considered natural, measuring and sampling may became less frequent, such as monthly or bimonthly;
3. Season
   – Water levels (chapter IX) and ground-water quality (chapter XII) change in response to precipitation. For example, the premining water-level October 1970 to March 1972 in the Decker, Mont, area shows a natural variation in recharge to the aquifers (fig. XIII 2-4). Annual precipitation in the area during 1970 - 1975, was above the mean annual for the area.
4. The impact(s) of the mining operation upon the aquifer system(s) (chapter XIII)
   – If water levels drop significantly (2 ft/month) and water-quality characteristics indicate signs of acid mine drainage, measurements and sampling frequency are increased to weekly bi-weekly. In figure XIII 2-4, the negative water-level variations from March 1972 to June 1975 illustrate the impact of excavation dewatering on the aquifers. locations of the observation wells in relation to the permit areas are shown in figure XIV-1. The resulting increase in depth to water is shown in figure 3X-5.
   – As the impacts of the mining operation become more pronounced, water-level recorders are installed, additional water-quality samples are analyzed, and, new monitoring sites, such as wells, springs, and stream sites, are added to the monitoring plan.

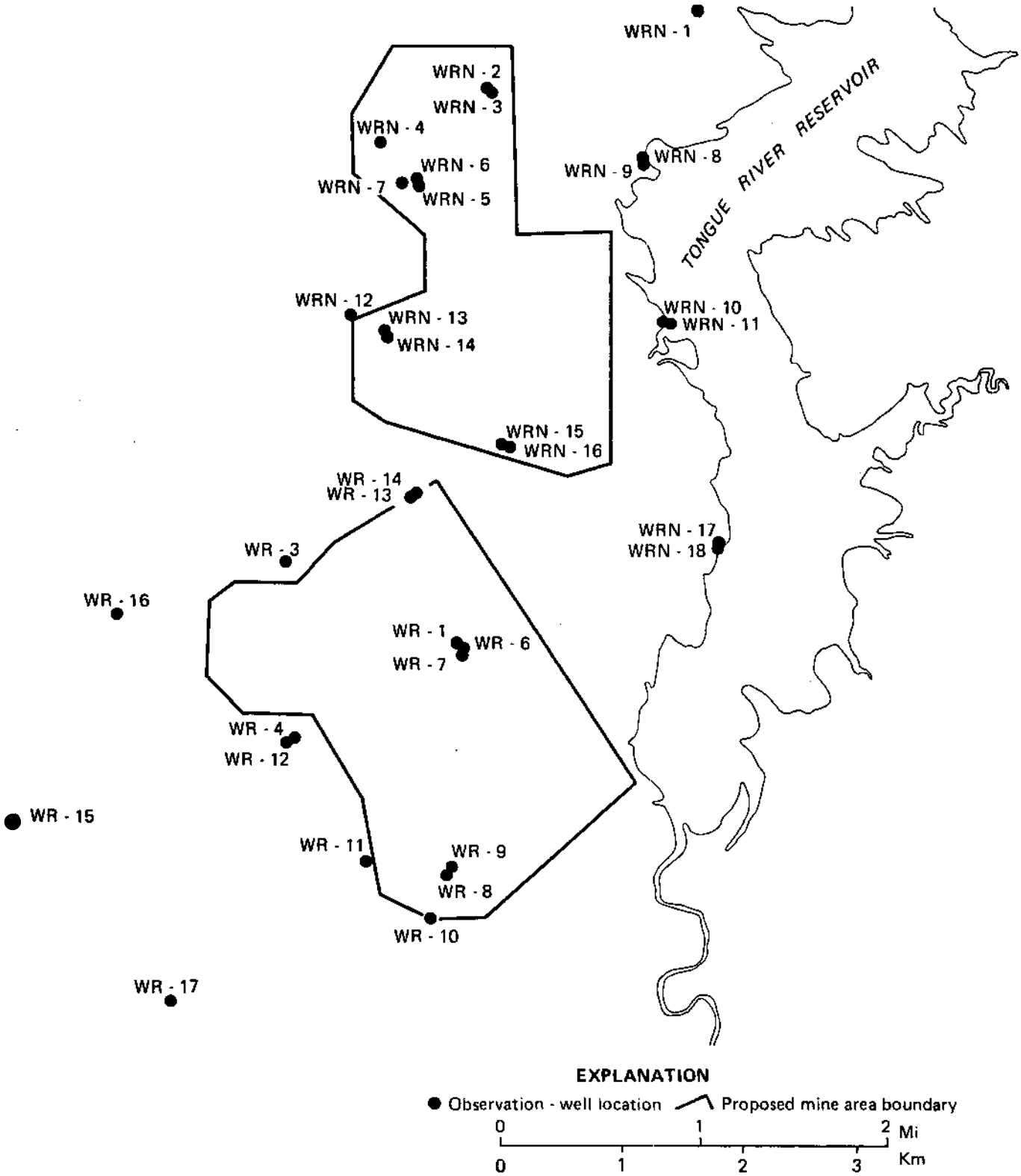

Figure XIV-1.— Observation-well system for proposed mine areas near Decker, Montana. (From VanVoast and Hedges, 1975, pl. 3)

Hydroloqic Sites

The hydrologic sites to be monitored before and during mining include a precipitation station, springs, wells, low-flow stream sites, swamps, ponds, lakes, reservoirs, mine-discharge sites, and mine spoils. The selection of monitoring sites after mining depends upon the effect of mining upon the hydrologic system but should include mine spoils within the permit and adjacent areas.

Precipitation station

Precipitation station records the snowfall and rainfall. A weighing-bucket recording rain gage would document the rainfall on the general area. This information is important when correlated with changes of base flow and changes of water levels in observation wells. For example, an extensive period of prolonged rainfall, in which water levels in wells fall and perennial streams go dry could indicate a potential aquifer-dewatering problem.

Ground water

Monitoring sites for ground water include observation wells, selected springs, and low-flow sites. Observation wells are located within the permit area and adjacent area and, to a lesser extent, within the general area. These wells are completed in aquifers that could be potentially impacted by mining operations; these aquifers can be both in bedrock overburden and underburden relative to the coal deposit. Overlying or nearby alluvial deposits may also be affected. The locations at which monitoring is advisable are listed in table XIV-1.

The purposes of the monitoring network are (1) measurement of water levels, (2) measurement of water quality, and (3) determination of aquifer properties, namely, transmissivity and storativity (storage coefficient). Changes in water levels in observation wells, completed in the aquifers, may reflect the effect of mining on the aquifer systems. The components of a monitoring network include the time period of monitoring—before, during, and after mining; the aquifer being monitored; and the position of measurement within the aquifer system—upgradient and downgradient from the proposed mine site. A suggested criteria for identifying observation wells within a monitoring network is given in table XIV-1. The alphabetic symbols, shown in this table, are introduced to demonstrate the applicability of this criteria to an example permit area, such as shown in figures XIV-2 and 3. Most of the wells installed before mining can be used during and after mining. Special attention should be given to the installation of special wells in the mine spoils to monitor the potential acid mine drainage.

An example premining ground-water monitoring plan for a combined surface-and underground-mining permit application involving several aquifers is given in figure XIV-2. A summary of measurements locations, for the example permit area, within the three areas—permit, adjacent and general—and the aquifers to be monitored is given in table XIV-2. The 16 wells are capable of monitoring water levels, and, water quality conditions in the overburden, underburden, and to a limited extent, the alluvium. In addition, a streamgaging station is established at the upstream and downstream ends of the affected watershed.

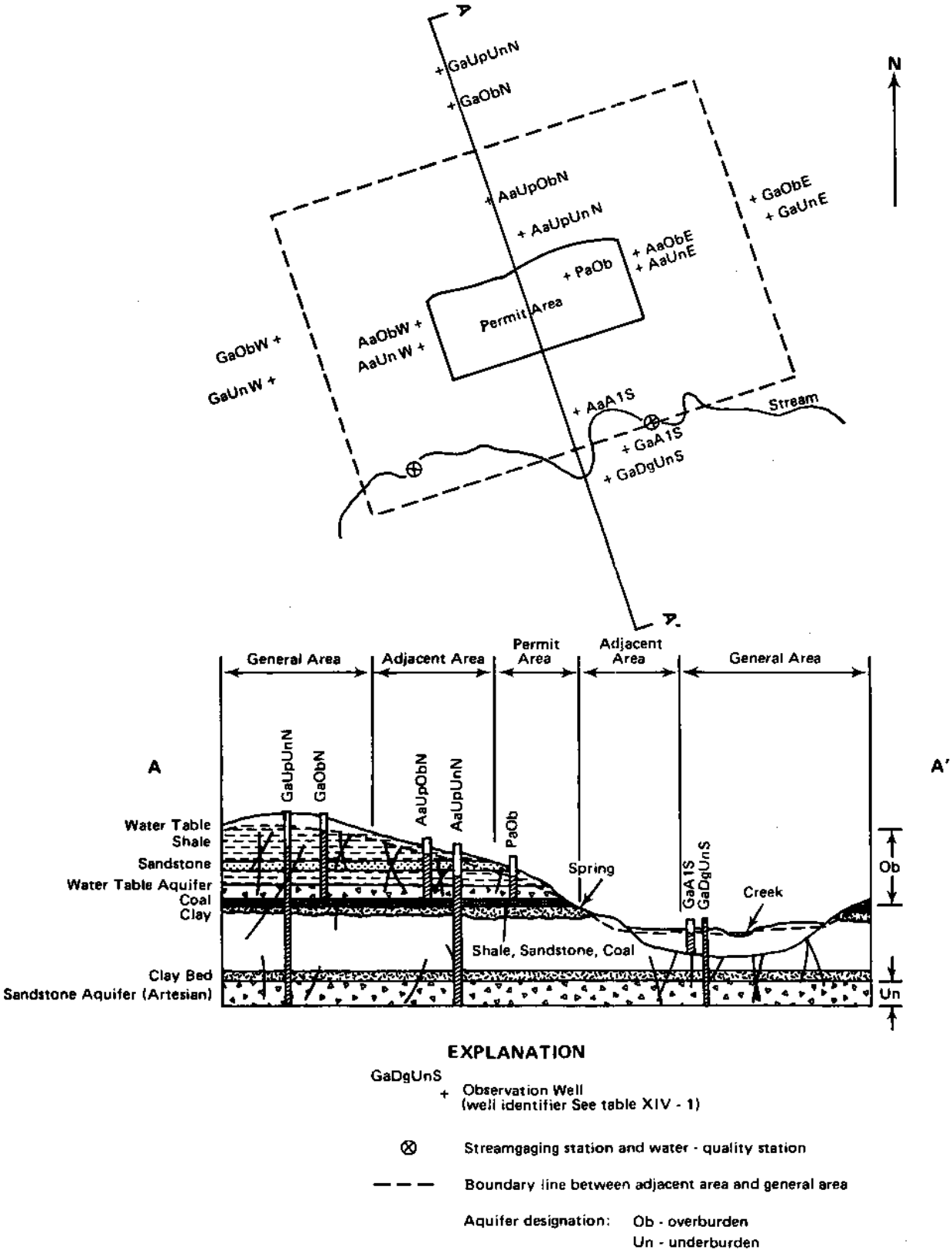

Figure XIV-2.— Planimetric map and vertical cross section of permit area showing ground-water monitoring plan before mining.

An example postmining ground-water monitoring plan for the same permit application is given in figure XIV-3; well locations and aquifers to be monitored are summarized in table XIV-3. Of the 19 wells listed 16 are from the premining program. If the bedrock aquifers within the general area were not impacted during mining, they need not be monitored after mining. Additional wells are drilled in the mine spoils and in the near-surface underburden (Un2); during mining in the permit area and in the adjacent area as applicable. Monitoring continues into the reclamation period as required by the regulatory authority.

The positioning of the observation wells depends on several factors including the nature of the aquifer—confined or water-table, hydrologic boundaries— streams or change in bedrock, and aquifer properties. Observation wells are also positioned between the permit area and surface water features to determine the direction of ground-water flow to or from the stream. Wells with four-inch diameter casings can be used for aquifer testing and for obtaining ground-water quality samples. After the aquifer properties are determined, the response time of the aquifer can be more accurately estimated. Knowledge of the confined nature of the aquifer(s) also aids in the selection of distance for the observation wells. As indicated in figure X-1,4-1, the drawdown in a confined systems (S = 0.0001) affects a greater area than the drawdown in a water-table system (S = 0.001). With the common low transmissivity of bedrock containing the coal seams, drawdown affects generally do not extend into the general area.

As an example, observation wells in the Decker mine area (fig. XIV-1) are within the permit area, on the perimeter of the permit area, and ½ mi, 1 mi, and 1½-mi from the permit area. The observation well most distant from permit area (WR-15) is completed in both the D-l and D-2 coal aquifers. After 3 years of mining, the water-level decline in this well was 3 feet. The storage coefficient for the confined aquifer (D-2 coal) is about 0.00003; and, for the water-table aquifer (D-l coal and Clinker), ranges from 0.1 and 0.3 (VanVoast and Hedges, 1975). The measured range in transmissivity of the D-l and D-2 coal beds combined was from 44 to 84 ft^2/d (Thompson and VanVoast, 1981).

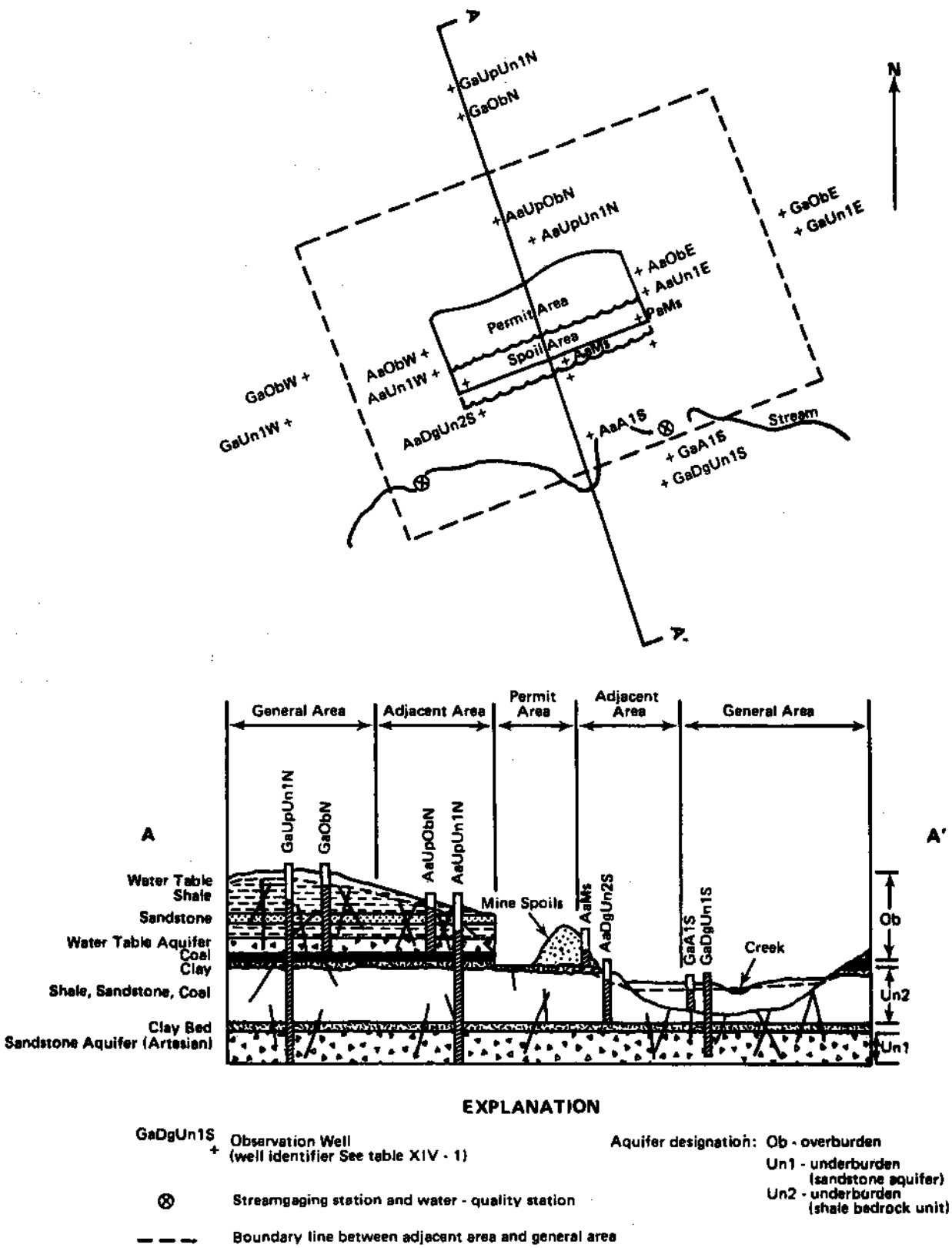

Figure XIV-3.— Planimetric map and vertical cross section of permit area showing ground-water monitoring plan after mining.

If significant water-level declines occur at the most distant observation wells, additional wells should be installed even farther from the permit area, as dictated by the regulatory authority. The distance of these additional wells can be determined from the aquifer transmissivity and storage coefficient. An approach is to:

(1) divide the discharge from the working pit, Q1, by the length of the pit to obtain Q,
(2) assume a drawdown, s, of 0.01 ft,
(3) use the T-value obtained in prior testing and the S-value from prior testing or from estimation (Lohman, 1972, p. 53).
(4) from a modification of equation X-2.3-1, calculate W(u) from the equation:

$$W(u) = \frac{4\pi T s}{Q} \qquad \text{XIV-1}$$

(5) determine u from table X-2.3-1, or any table of W(u) versus u (Lohman, 1972; Ferris and others, 1963; U.S. Department of Interior, 1981a; Johnson Division, 1975),
(6) from a modification of equation X-2.3-2, calculate r from the equation:

$$r^2 = \frac{4 T t u}{S} \qquad \text{XIV-2}$$

An example of an observation-well tabulation (table XIV-4) lists the well location, well numbers, well depths, land-surface altitude at the well head, the water-level altitude, and aquifers tapped. Hydrographs of water-level changes during mining are given in figure XIII-2-4. (The potentiometric map for the D-l coal aquifer after 3 years of mining, was given in figure XIII 2-3.) Chemical analyses of water samples from selected observation wells during the 3 year period of mining are presented in table XIV-5.

Surface water

Continuous-recording streamflow gages are installed upstream and downstream of the permit area as shown on figures XIV-2 and XIV-3. For ground-water purposes, only the low-flow stage-discharge relationship is significant (See chapter XI). Streamflow stations enable the determination of base flow and chemical quality of base flow. Water quality monitors that measure specific conductance, pH, dissolved oxygen, and temperature could also be installed at these sites.

The interaction between streamflow and ground water is determined from measurements of water levels in observation wells near the stream; but can also be determined from this well-and stream-stage-recording combination, and from other observation wells within the adjacent area and permit area.

Mine Spoils

Monitoring the quality of water within the spoil piles requires that observation wells, preferably 4-inch diameter, be installed in the waste-spoil piles. Observation wells should also be installed downgradient of the spoil material to determine what effect, if any, water from the mine-spoil pile has on water in the underlying bedrock unit. An example of well positions in mine spoils is shown in figure XIV-3.

Table XIV-1.– Criteria for locating observation wells.

[alphabetic symbols in parentheses represent components in the monitoring network; the components in the three columns are independent of each other, as demonstrated in tables XIV-2 and 3 and figures XIV-2 and 3.]

Time of Measurement	Potentially Impacted Aquifer Systems	Position of Measurement within the aquifer system(s)
		Compass Direction of the Observation Well Relative to the Permit Area North (N); South (S); East (E); West (W)
	Alluvium(Al)	
		General Area* (Ga) hydraulically upgradient (Up)
	Overburden (Ob)	
Before Mining		
		Adjacent Area (Aa) hydraulically upgradient (Up)
	Underburden (Ub)	
		Adjacent Area (Aa) lateral hydraulic measurement
During mining		
	Coal (CD	
		Permit Area (Pa)
	Mine spoils (Ms)	
		Adjacent Area (Aa) hydraulically downgradient (Dg)
After mining		
		General Area* (Ga) lateral hydraulic measurement
		General Area* (Ga) hydraulically downgradient (Dg)

* measurement position in General Area is necessary if mining impacts Adjacent Area significantly.

Table XIV-2.– Suggested observation-well network before mining.

[applicant refer to figure XIV-2 for map showing locations of observation wells and refer to table XIV-1 for explanation of alphabetic symbols.]
(Subject to approval by regulatory authority.)

Area	Position of measurement observation wells	Aquifer System	Geologic Material
General Area (Ga)	GaObN GaObW GaObE	Overburden (Ob) (water table aquifer)	Fractured sandstone and shale
	GaUpUnN* GaUnW GaUnE GaDgUnS	Underburden (Un) (confined aquifer)	Sandstone
	GaAlS	Alluvium(Al) (water-table aquifer)	Silt, sand, and gravel
Adjacent Area(Aa)	AaUpObN AaObW AaObE	Overburden (Ob) (water-table aquifer)	Fractured and sandstone shale
	AaUpUnN AaUnW AaUnE	Underburden (Un) (confined aquifer)	Sandstone
	AaAlS	Alluvium(AL) (water-table aquifer)	Silt, sand, and gravel
Permit Area (Pa)	PaOb	Overburden (Ob) (water-table aquifer)	Fractured and sandstone shale

* example - observation well located in the General Area hydraulically upgradient of the permit area monitoring the underburden aquifer north of the permit area.

Table XIV-3. – Suggested observation-well network after mining.

[applicant refer to figure XIV-3 for map showing locations of observation wells and refer to table XIV-1 for explanation of alphabetic symbols.]
(Subject to approval by regulatory authority.)

Area	Position of measurement observation wells	Aquifer System	Geologic Material
General Area (Ga)	GaObN * GaObW * GaObE *	Overburden (Ob) (water-table aquifer)	Fractured sandstone and shale
	GaUpUn1N * GaUn1W * GaUn1E * GaDgUnlS *	Underburden No.l (Uhl) (confined aquifer)	Sandstone
	GaAlS	Alluvium (Al) (not optional - necessary for water quality comparison with water from AaAl)	Silt, sand, and gravel
Adjacent Area (Aa)	AaUpObN AaObW AaObE	Overburden (Ob) (water-table aquifer)	Fractured sandstone and shale
	AaUpUn1N AaUn1W AaUn1E	Underburden No.1(Un1) (confined aquifer)	Sandstone
	AaDgUn2S **	Underburden No.2 (Un2) (confined aquifer)	Shale, sandstone, clay, and coal
	AaAlS **	Alluvium (Al) (water-table aquifer)	Silt, sand, and gravel.
	AaMs **	Mine Spoil (Ms) (water-table aquifer)	
Permit Area (Pa)	PaMs **	Mine Spoil (Ms)	

* perhaps optional depending upon the impacts during mining, if aquifers in the General Area were not impacted during mining, observation wells are not necessary after mining.
** primary objective is monitoring of ground-water quality.

Table XIV-4.– Example of data on wells in an observation-well network in Decker mine area, Montana.
(From VanVoast and Hedges, 1975, plate 3.)

Well location	Decker well number		Land-surface altitude (feet)	Well Depth (feet)	Water-level altitude, April, 1975 (feet)	Aquifer monitored
8S 40E 26 OCCB	WRN	1	3,463	40	3,434	D-2 Coal
8S 40E 33 $AACB_1$		2	3,492	90	3,439	D-2 Coal
8S 40E 33 $AACB_2$		3	3,491	59	3,438	D-l Clinker
8S 40E 33 CABB		4	3,493	39	3,479	D-l Coal
8S 40E 33 $CADA_1$		5	3,475	85	3,459	D-2 Coal
8S 40E 33 $CADA_2$		6	3,476	50	3,465	D-l Coal
8S 40E 33 CADC		7	3,482	49	3,472	D-l Coal
8S 40E 34 DEAD		8	3,424	50	3,417	D-2 Coal
8S 40E 34 DBDA		9	3,424	185	3,422	D-3 Coal
9S 40E 03 $DABA_1$		10	3,433	79	3,421	D-2 Coal
9S 40E 03 $DABA_2$		11	3,437	50	3,417	D-l Coal & Clinker
9S 40E 04 BCAA		12	3,525	77	3,456	D-l Coal & Clinker
9S 40E 04 $CABC_1$		13	3,515	124	3,452	D-2 Coal
9S 40E 04 $CABC_2$		14	3,514	78	3,448	D-l Coal
9S 40E 09 $AADD_1$		15	3,500	140	3,426	D-2 Coal
9S 40E 09 $AADD_2$		16	3,500	89	3,418	D-l Clinker
9S 40E 11 $CBCC_1$		17	3,424	104	3,418	D-2 Coal
9S 40E 11 $CBCC_2$		18	3,425	20	3,416	Alluvium
9S 40E 08 DCAA	WR	3	3,612	215	3,431	D-l Coal
9S 40E 09 $BDDA_1$		14	3,598	192	3,419	D-l Coal
9S 40E 09 $BDDA_2$		2	3,595	192	—	D-2 Coal
9S 40E 09 BDDB		13	3,592	247	3,436	D-2 Coal
9S 40E 16 ABCA		1	3,498	104	3,404	D-l Coal
9S 40E 16 $ABCD_1$		6	3,499	135	3,406	D-l Coal
9S 40E 16 $ABCD_2$		7	3,498	207	3,445	D-2 Coal
9S 40E 17 DACB		4	3,585	220	3,428	D-l Coal
9S 40E 17 DACC		12	3,486	230	3,427	D-l Coal
98 40E 18 ABAD		16	3,640	237	3,451	D-l & D-2 Coal Combined
9S 40E 19 BAC		15	3,685	390	3,445	D-l & D-2 Coal Combined
9S 40E 21 $ACCA_1$		8	3,537	165	3,426	D-l Coal
9S 40E 21 $ACCA_2$		9	3,537	255	3,458	D-2 Coal
9S 40E 21 BCAC		11	3,575	210	3,429	D-l Coal
9S 40E 21 BCAD		5	3,574	200	—	D-l Coal
9S 40E 21 CADA		10	3,537	169	3,426	D-l Coal
9S 40E 29 BBAC		17	3,570	300	3,455	D-l & D-2 Coal Combined

* refer to referenced report for detailed explanation of township-range-section and quarter-quarter-quarter-quarter subdivision of section; the subscripted number indicates the number of wells inventoried within the 2½ acre area.

Table 5.– Chemical analyses of waters from observation wells in the Decker area, southeastern Montana. (From VanVoast & Hedges, 197, table 4.)

[Analyses by Montana Bureau of Mines and Geology water laboratory, Butte. Concentrations in milligrams per liter.]

[Analyses by Montana Bureau of Mines and Geology water laboratory, Butte. Concentrations in milligrams per liter.]

Observation well location	Well number	Date of collection	Temperature (°C)	Calcium	Magnesium	Sodium	Potassium	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Silica (SiO_2)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Iron (Fe)	Manganese (Mn)	Dissolved solids (calculated)	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific Conductance (micromhos at 25°C.)	pH
D-1 UPPER AND LOWER COALS COMBINED																						
9S. 40E. 16ABCD	WR- 6*	8/14/71	12	4.2	0.7	435	5.9	1,156	0	6.6	3.5	5.0	3.5	0.0	0.00	0.0	1,621	13	8	51.7	1,585	8.2
D-2 COAL																						
9S. 40E. 16ABCD$_2$	WR- 7	8/13/71	14	4.6	1.0	413	6.4	1,087	0	3.8	3.5	5.1	4.3	0.0	0.00	0.0	1,529	15	0	45.5	1,515	8.2
9S. 40E. 03DABA	WRN-10	4/02/75	12	74	57	448	13	698	0	787	15	13	2.0	.3	.00	.01	2,108	420	0	9.5	2,384	7.9
9S. 40E. 09AADD	WRN-15	4/30/75	11	5.2	2.3	415	4.2	1,132	0	2.8	20	7.1	2.2	.5	.59	.03	1,592	22	0	38.1	1,595	8.0
D-1 and D-2 COALS COMBINED																						
9S. 40E. 18ABAD	WR- 16	4/14/74	-	5.2	1.9	415	3.6	1,123	0	5.5	11	7.5	3.3	4.7	.10	.00	1,581	21	0	39.4	1,640	7.9
9S. 40E. 29BBAC	WR- 17	6/04/74	-	5.9	2.5	458	4.3	1,105	58	3.7	9.2	25	3.3	.0	.00	.00	1,675	25	0	39.9	1,816	8.9

* refer to figure XIV-1 for well location.

XV. SOURCES OF PUBLISHED (GEOLOGIC AND HYDROLOGIC INFORMATION

Pertinent 30CFR[1] Sections:
- Description of hydrology and geology.
- Ground-water information.
- Surface-water information.
- Cross sections, maps, and plans.

1. U.S. Geological Survey Coal Area Hydrology Reports

Coal-area hydrology reports, published by the U.S. Geological Survey, contain a text with maps, charts, graphs, and other illustrations and provide hydrologic information to describe the hydrology of areas within the coal provinces. The areas represented by each report is shown in figure XV-1-1. The information should be useful to mine owners and operators and to consulting engineers in the preparation of permits and also to regulatory authorities in appraising the adequacy of permit applications. These reports are available at no charge from the U.S. Geological Survey offices listed in table XV-1-1.

A need for hydrologic information and analysis on a scale never before required nationally was recognized when the "Surface Mining Control and Reclamation Act of 1977" was signed into law as Public Law 95-87, August 3, 1977. The hydrologic information presented in, or available through sources identified in, these reports may be used in describing the hydrology of the general area of any proposed mine. However, it is expected that this information will be supplemented by the applicant's site-specific information as well as data from other sources to provide a detailed coverage of the hydrology of the mine and vicinity and the anticipated hydrologic consequences of the proposed mining operation.

The coal area reports include discussions of bedrock geology, water use, hydrologic networks, surface-water information, chemical quality of surface water, ground-water information, chemical quality of ground water, and hydrologic-data-collection stations.

[1]CFR = Code of Federal Regulations