GROUND-WATER STUDY 8

by

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1.0 ABSTRACT

Geology and the Occurrence of Coal

The area is underlain by nearly horizontal sedimentary rocks of Tertiary age consisting of shales interbedded with sandstones, siltstones, and subbituminous coal beds. The coal beds, which occur in the Tongue River Member of the Fort Union Formation and in the Wasatch Formation, are extensive and variable in thickness. In the mine area, the Anderson, Dietz-1, and Dietz-2 coal beds coalesce to form a single bed 80 feet thick. The geologic structure of the area is broadly synclinal and is traversed locally by several normal faults. A large part of the area is underlain by clinker deposits, which were produced by the burning of coal beds near their outcrops.

Hydrology and Hydrologic Monitoring

In the area, the coal beds are the principal sources of good quality ground water for domestic and stock wells. Most wells completed in these beds yield less than 10 gallons per minute. The sandstones are aquifers, but their yields vary considerably. Wells in the alluvial aquifers commonly yield 10 gallons per minute or more. Variations in primary and secondary hydraulic conductivity cause an order of magnitude difference in transmissivity. Clinker deposits are very permeable and allow precipitation to recharge the underlying aquifers. The sandstone beds, underlying the coal beds, are alternate water sources for municipal and industrial uses. Ground-water data for the area were obtained from existing springs and wells, and from specially drilled and constructed observation wells. Ground-water quality is variable between aquifers and within aquifers in different areas. The quality of water from the sandstone overlying the uppermost coal generally does not meet U.S. Environmental Protection Agency standards for domestic use, owing to excessive concentrations of dissolved solids. Natural ground-water flow patterns generally parallel the land-surface profile in the unconfined alluvial and clinker aquifers. The area of natural ground-water discharge is along the Tongue River valley.

Mining Method and Other Stresses on Aquifer System

The coal is removed only by surface mining. The total ground-water use does not exceed 30,000 gallons per day (21 gallons per minute). Nevertheless, ground water from the wells and springs is critical to the economy and population of the area.

Probable Hydrologic Consequences and Proposed Hydrologic Monitoring Network

The principal shallow aquifers (coal and sandstone) will be disrupted by surface mining. The natural shallow ground-water flow has been changed by mining and by dewatering of the mine pit. From 1972 to 1975, water levels in wells completed in the Dietz-1 coal bed declined as much as 40 feet near the mine pit.

Ground-water model results illustrate the relationship between coal mining and aquifer dewatering. The results include water-level declines in space and time, with variable aquifer properties and with different hydrologic-boundary conditions. Wells completed in the coal beds several miles from the mines might undergo water-level declines, but the water-level declines would probably cause only a very small loss of yields.

Ground water from the mine spoils contains larger concentrations of dissolved constituents than water from natural aquifers. Calcium, magnesium, and sulfate concentrations also were substantially larger in mine-spoils waters.

A proposed hydrologic monitoring scheme includes wells outside of the mine-permit area. Water from these wells will also be analyzed periodically to determine any variations in ground-water quality. The Tongue River, upstream from the Tongue River Reservoir, will also be routinely sampled.

2.0 GEOLOGY

2.1 STRATIGRAPHY OF GEOLOGIC UNITS

NEAR-SURFACE CRETACEOUS AND TERTIARY BEDROCK COMPOSED OF SANDSTONE, SILTSTONE, CLAYSTONE, SHALE, AND COAL

Geologic units important to coal mining include the Fort Union Formation and the Wasatch Formation.

The area is underlain by several thousand feet of sedimentary rocks that range in age from Cambrian to Holocene. The continental deposits of the Upper Cretaceous Hell Creek Formation and the Tertiary Fort Union and Wasatch Formations overlie the marine deposits of the Upper Cretaceous Bearpaw Shale and Fox Hills Sandstone (fig. 2.1-1).

The Bearpaw Shale is a massive bentonitic shale and sandy shale that contains a few thin beds of silty sandstones and siltstones. The Fox Hills Sandstone is predominantly sandstone that contains thin beds of sandy shale. The lower part of the Hell Creek Formation consists of interbedded shale, siltstone, and sandstone and the upper part consists of massive shale with lenticular sandstone and siltstone with traces of coal and coaly shale.

The Fort Union Formation contains the Tullock, Lebo Shale, and Tongue River Members. The Tullock Member is composed of sandstone, sandy and silty shale, and thin coal beds. The Lebo Shale Member is predominantly shale, mudstone, and claystone with interbeds of siltstone and thin coal beds. The Tongue River Member contains alternating layers of sandstone, siltstone, and shale interlain with thick and extensive coal beds (fig. 2.2-1).

The Wasatch Formation contains lenticular sandstones interbedded with shale and coals. The coal beds are as extensive as those in the underlying Fort Union Formation. Clinker or baked sedimentary rocks formed by burning coal beds crop out throughout the area.

System	Series	Formation and member		Thickness in feet	
Quaternary	Holocene and Pleistocene	Alluvium (flood plain and terraces)		0 - 100 ±	
Tertiary	Eocene	Wasatch Formation		0 - 400 ±	
	Paleocene	Fort Union Formation	Tongue River Member	1600 ±	Shallow aquifers
			Lebo Shale Member	500 ±	Confining bed
			Tullock Member	500 ±	
Cretaceous	Upper Cretaceous	Hell Creek Formation		300 ±	Deep aquifers
		Fox Hills - Lower Hell Creek		600 ±	
		Bearpaw Shale		300 ±	Confining bed

Figure 2.1-1.— Generalized geologic column of the major aquifers in the mine area.

2.0 GEOLOGY

2.2 COAL BEDS IN THE MINE AREA

ANDERSON, DIETZ 1, DIETZ 2, AND CANYON COAL BEDS SUITABLE FOR SURFACE MINING IN AREA

The Andersen and Dietz 1 coal beds coalesce to form a single bed 52 feet thick.

At least nine persistent beds 5 to 35 feet thick and numerous thinner beds are contained in the Tongue River Member of the Fort Union Formation. Most of the thick beds have been mapped over hundreds of square miles and are the target coal beds in other mines in the region.

The coal beds mined in the area include the Anderson, Dietz 1, Dietz 2, and Canyon beds. In parts of the area, the Anderson and the Dietz 1 coal beds coalesce to form a single unit 52 feet thick. West of the mine area, the combined Anderson-Dietz 1 bed coalesces with the underlying Dietz 2 to form an 80-foot bed of coal.

Because of the coalescing nature, coal beds are difficult to correlate from one area to another. Correlation problems have resulted in wide use of local names for individual coal beds.

The relative position and approximate thickness of the coal beds underlying proposed mines in the area are shown in figure 2.2-1. The cross section illustrates the variable thickness of strata between the major coal beds. Also evident is the widespread occurrence of altered rocks formed by burning of coal beds. Such rocks, which are locally termed, "clinker," occur near the Anderson and Dietz 1 coal beds.

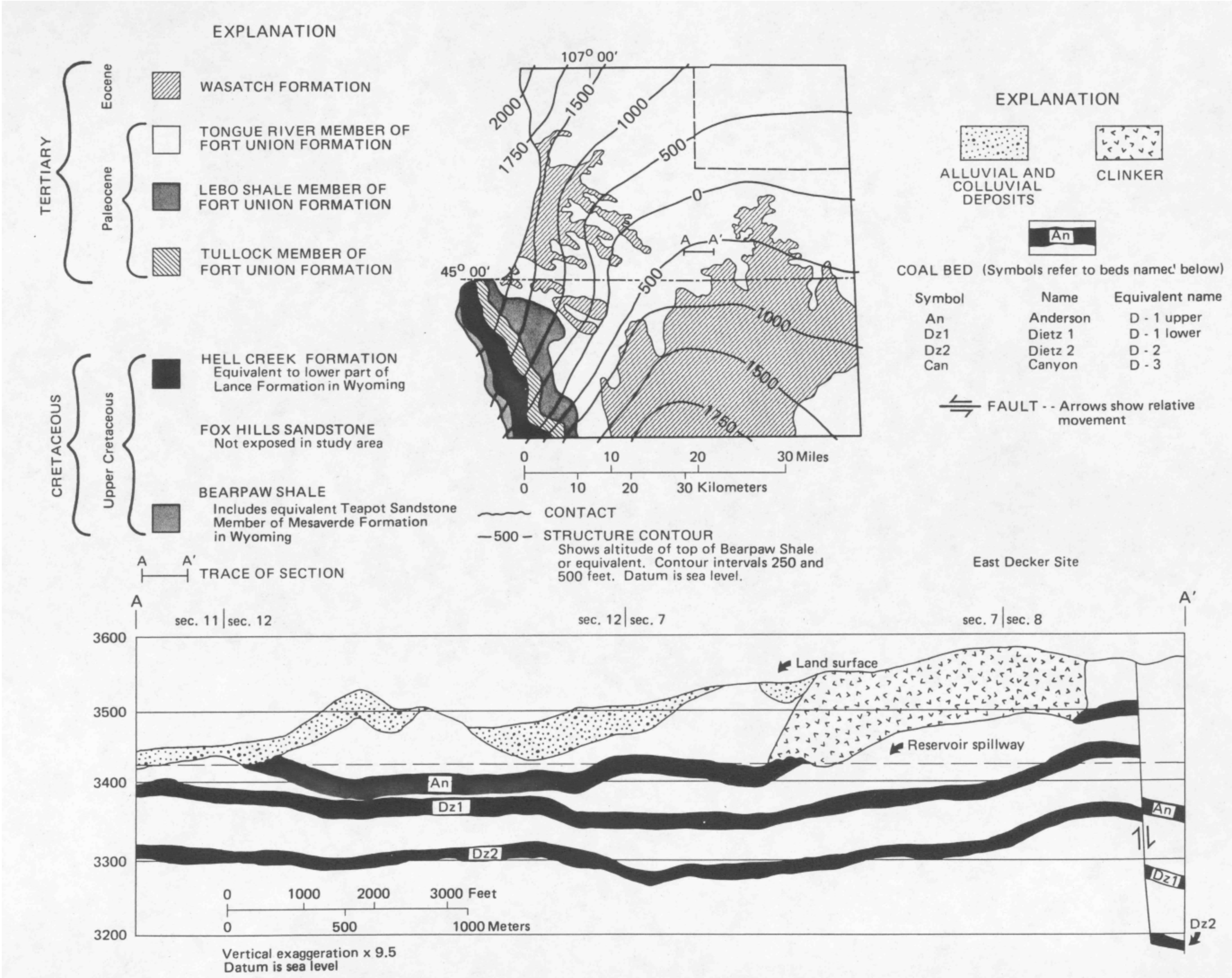


Figure 2.2-1.— Map and cross sections showing generalized geology and major coal beds in the mine area.

3.0 HYDROLOGY

3.1 CLIMATE

MINE AREA CHARACTERIZED BY SEMIARID CLIMATE

The mine area has cold winters, warm summers, and large variations in annual and seasonal precipitation and temperature.

The semiarid climate in the mine area is the continental steppe type characteristic of the Northern Great Plains. Cold winters, warm summers, and large annual and seasonal variations in precipitation and temperatures are common. Microclimate varies appreciably over the area as a result of local differences in relief, slope, exposure, and plant cover.

Precipitation records have been collected continuously by the National Weather Service since 1931 at a site about 25 miles southwest of the mine area. Daily precipitation records have been collected almost continuously since 1949 at a site in the mine area.

Annual precipitation at the area weather station has ranged from 6.5 inches in 1960 to 17.6 inches in 1968 (fig. 3.1-1). Average annual precipitation for the period of record is 11.8 inches. Nearly one-half of the mean annual precipitation falls from April through June. Much of the remainder (30 percent) falls as snow from October through March. Summer rain storms commonly accompanied by strong winds and hail account for the remaining 20 percent of annual precipitation.

Temperature variations are extreme for both seasonal and daily periods. Daily variations of 30˚F to 35˚F are common because of low humidity and strong solar radiation. Temperatures recorded at a site 25 miles southwest of the mine area ranged from -30˚F to 103˚F. At a weather station 20 miles northeast of the mine area temperatures have ranged from -45˚F to 107˚F. The growing season usually lasts 100 to 130 days.

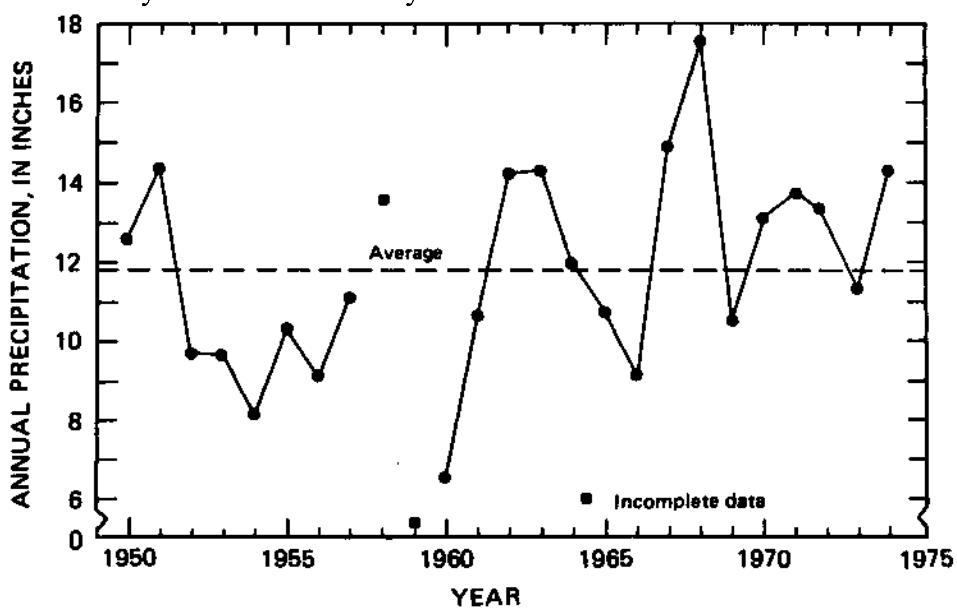


Figure 3.1-1.— Range of annual precipitation 1949-75 at Decker Post Office. (From U.S. Geological Survey and Montana Department of State Lands, 1977, p. 103.)

3.0 HYDROLOGY

3.2 GROUND WATER

3.2.1 AQUIFERS OVERLYING THE LEBO SHALE MEMBER

COAL BEDS, ALLUVIUM, AND SANDSTONE PROVIDE WATER TO WELLS IN MINE AREA

Coal beds are the most reliable sources of ground water in the mine area owing to their widespread occurrence and continuity.

The coal beds underlying the mine area are the principal source of ground water for domestic and stock wells. Although coal is virtually impermeable and has no appreciable primary porosity, the beds are usually fractured sufficiently to allow storage and transmission of water. Coal-bed aquifers are laterally extensive and continuous under the entire area and, therefore, are a reliable source of ground water. Most wells produce less than 10 gal/min but larger yields have been obtained locally. Ground-water use locations, namely wells and springs, for water supply are shown in figure 3.2.1-1. Some of the well-inventory information is presented in table 3.2.1-1.

Sandstone aquifers occur above and between coal beds in the Tongue River Member of the Fort Union Formation. Generally, the sandstones are lenticular bodies of fine sand, which were deposited in channels, and are surrounded by layers of less permeable siltstone and shale. The sandstones differ considerably in their ability to yield water to wells. The yields depend upon the amount of fine-grained material in the rock, the degree of fracturing, and the extent of the unit. Yields greater than 10 gal/min have been reported for wells completed in the sandstones.

Alluvial aquifers are limited to the unconsolidated deposits in the Tongue River valley and tributary streams. Because of the limited areal extent of the alluvial aquifers, only a few wells obtain water from them.

Clinker is an extremely permeable rock type in the mine area and is a significant aquifer where saturated. However, the clinker is generally located in topographically high areas above the saturated zone. Some ground water may occur near the base of clinker units as a perched water body and may contribute to spring flows along hill slopes or valley sides. Few wells penetrate the clinker because it is difficult to penetrate by drilling.

Aquifer-test results are given in table 3.2.1-2. They provide an indication of the aquifer properties of the various coal beds, sandstones, and alluvium in the mine area. Several types of aquifer-test analyses were used to determine aquifer transmissivity, hydraulic conductivity, and storage coefficient for various aquifer units.

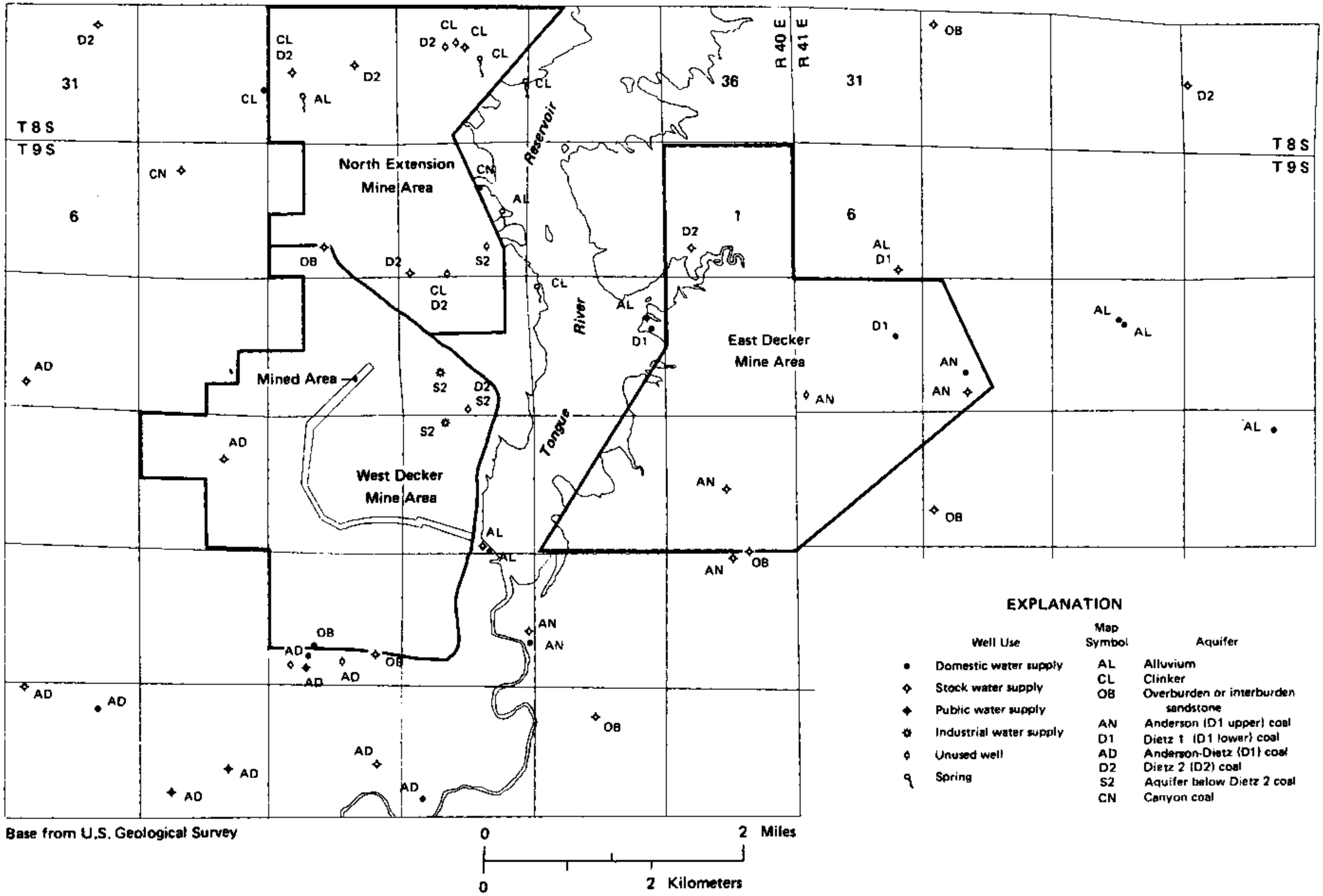


Figure 3.2.1-1 — Locations of wells and springs used for water supply in the general area. (From U.S. Geological Survey and Montana Department of State Lands, 1977.)

Table 3.2.1-1. – Example of water-well data for the mine area.
(From VanVoast and Hedges, 1975, p. 11)

[Location: Township, Range, Section with quarter-quarter-quarter subdivision.
(refer to referenced report for well location details)
Altitude: Land surface elevation at well estimated from U.S.G.S. 7½-minute quadrangle topographic maps, accurate to 10 ft.
Aquifer: Interpretations by Montana Bureau of Mines and Geology. Coded sources D-l
C1 = D-1 Clinker; Sub D-2 = unspecified aquifers below mineable coal beds.
Depth to water: Depths to nearest 0.1 foot measured; depths to nearest 1.0 foot reported; + indicates flowing well.
Discharge: gal/min, gallons per minute to nearest 0.1 measured; gal/min to nearest 1.0 reported.
Drawdown: Drawdown (at indicated discharge) to nearest 0.1 foot, measured; drawdown to nearest 1.0 foot, reported.
Specific Conductance: Field electrical conductance of water, in micromhos per centimeter at 25˚ C; L indicates laboratory conductance.
Data source: MBMG, Montana Bureau of Mines and Geology; USGS, U.S. Geological Survey. Water analyses: refer to water quality table in referenced report.]

Location	Water use	Altitude (feet)	Well Depth (feet)	Aquifer	Depth to water (feet)	Dis-charge (gal/min)	Draw-down (feet)	Specific conduc-tance (umhos/cm)	Data source	Water analysis
9S 39E 14DCBB	Unused	3,647	391	Sub D-2	160.9	—	—	4,000	USGS	
9S 39E 24DCDC	Unused	3,610	244	D-1& D-2 Coal	106	10	—	—	MBMG	
9S 39E 24ACDA	Unused	3,590	235	D-l & D-2 Coal	88	10	—	—	MBMG	
9S 39E 25DDC	Stock	—	150	D-l Overburden	—	10	—	—	USGS	
9S 40E 010CA	Stock	3,445	125	D-2 Coal	26.4	—	—	1,900	USGS	
9S 40E 03ACAB	Stock	3,424	200	Sub D-2	+	33	—	1,380	MBMG	yes
9S 40E 03DCA	Stock	3,440	462	Sub D-2	3	4	44	—	USGS	
9S 40E 04CDAB	Stock	3,542	—	D-2 Goal	95	10	—	3,980	MBMG	
9S 40E 05BACC	Stock	3,580	260	Sub D-2	70	6	—	2,000	MBMG	
9S 40E 070CAB	Stock	3,720	274	D-l Coal & Overburden	138	50	—	—	MBMG	
9S 40E 10CDDD	Industrial.	3,465	498	Sub D-2	29	60	88.5	—	MBMG	
9S 40E 10DDBA	Industrial.	3,452	160	D-2 Coal & Sub D-2	23	20	6	1,714L	MBMG	yes
9S 40E 11ADA	Stock	3,430	32	D-l Lower Coal	17.5	—	—	1,750	MBMG	
9S 40E 13CAAA	Stock	3,500	108	D-l Upper Coal	63.4	—	—	2,400	USGS	
9S 40E 13DCCD	Stock	3,520	75	D-l Overburden	31.2	—	—	925	USGS	
9S 40E 21CACD	Domestic	3,554	110	D-l Overburden	—	—	—	5,010	MBMG	yes
9S 40E 210CDB	Unused	3,642	200	D-l Overburden	131.6	—	—	—	MBMG	
9S 40E 21CDAC	Unused	3,565	280	D-l Coal	123	—	—	2,700	MBMG	
9S 40E 21CDBB	Domestic	3,578	—	Unknown	—	—	—	—	MBMG	
9S 40E 21CDBD	Commercial	3,574	227	D-l Coal	117	5	73	1,570	MBMG	yes
9S 40E 21DDBA	Stock	3,502	171	Sandstone	26	20	39	4,500	MBMG	
9S 40E 22DAAD	Stock	3,455	269	D-l Coal	40.7	5	—	2,500	USGS	yes
9S 40E 22DADA	Domestic	3,460	170	D-l Coal	41	—	—	2,340	MBMG	yes
9S 40E 24ABBB	Stock	3,520	140	D-l Upper Coal	82	5	48	—	USGS	
9S 40E 26BADD	Stock	3,490	40	Above mineable beds	15	36	15	2,200	MBMG	

Table 3.2.1-2— Aquifer-test results for observation wells in the Squirrel Creek area.
[ft, feet; ft^2/d, square feet per day; ft^3/min, cubic feet per minute]

Pumped well location	Pumped well number	Test date	Observation well	Test analysis	Pumping rate (ft^3/min)	Pumping duration (minutes)	Transmis-sivity (ft^2/d)	Hydraulic conduc-tivity* (ft/d)	Storage coeffi-cient
				ALLUVIUM ALONG SQUIRREL CREEK					
9S. 39E. 14DDBD	WR-58	03/12/80	WR-58A	Jacob (1940) drawdown	3.0	480	3,050	76	0.05
14DDCC	WR-58D	03/13/80	WR-58E	Boulton (1963) delayed-yield	2.1	500	3,000	75	.02
14DDCD	WR-58B	03/11/80	pumped well	Jacob drawdown	3.6	480	2,700	82	–
"	"	03/11/80	WR-58C	Theis (1935) drawdown	3.6	480	2,750	83	.34
9S. 40E. 19CBCC	WR-56	10/24/79	pumped well	Jacob drawdown	2.4	225	1,600	32	–
29CACB	WR-52B	10/26/79	"	"	8.0	180	9,150	352	–
"	"	"	WR-52F	Boulton delayed-yield	8.0	180	9,150	352	.0004
"	"	"	WR-52A	"	8.0	180	6,800	262	.0002
"	"	"	WR-52C	"	8.0	180	11,400	438	.0013
29CBDA	WR-52A	10/23/79	pumped well	Jacob drawdown	10.7	290	3,750	101	–
"	"	"	WR-52B	Boulton delayed-yield	10.7	290	4,100	158	.0018
"	"	"	WR-52F	"	10.7	290	2,450	94	.0023
29CBDC	WR-52F	10/25/79	pumped well	Jacob drawdown	7.2	385	1,600	59	–
"	"	"	WR-52A	Boulton delayed-yield	7.2	385	1,350	50	.0034
"	"	"	WR-52E	"	7.2	385	1,750	65	.0021
				FORT UNION CLASTICS (ANDERSON OVERBURDEN)					
9S. 39E. 23DACC2	WR-18A	10/07/79	pumped well	Skibitzke (1958) bailer recovery			0.2	0.005	–
9S. 40E 19CBBD2	WR-55A	10/07/79	"	Cooper, et al (1967) slug recovery	–	–	.008	.0006	.000004
29BBAC3	WR-17B	10/04/79	"	Skibitzke bailer recovery	0.12	60	46	1.5	–
29BDCB2	WR-51A	10/02/79	"	Theis recovery			6.3	.7	–
				SPOILS AT THE DECKER MINE (DISTURBED ANDERSON OVERBURDEN)					
9S. 40E 09DCAB2	DS-5B	04/15/77	pumped well	Skibitzke bailer recovery	0.07	15	0.2	0.002	
15CACD	DS-3	04/12/77	"	"	.13	20	87	3.5	.00002**
15CBDA	DS-4	04/11/77	"	"	.07	17	.3	.025	.00003**
15CDBC	DS-1A	03/24/76	"	Jacob recovery	.27	170	130	8.4	–
15CDBC2	DS-1B	04/13/76	"	"	.67	250	83	5.2	–
15DBCC2	DS-2B	04/12/76	"	Skibitzke bailer recovery	.13	20	.02	.001	–
				CLINKER					
9S. 39E. 32ACAA	WR-33	10/18/77	pumped well	Theis (1963) specific capacity	4.7	120	3,350	48	–
				ANDERSON COAL BED					
9S. 39E. 16AABA2	WR-20	10/09/79	pumped well	Jacob drawdown	.36	300	120	3.9	–
28CCAD2	WR-37	11/04/77	"	"	.42	50	12	.5	–
29ABAA	MR-26	03/10/76	"	"	.53	50	3.2	.1	–
9S. 40E. 13DCCD	WRE-11	02/25/75	"	Theis specific capacity	.24	80	26	1.0	–
23BCCD	WRE-12	02/26/75	"	Sicibitzke bailer recovery	–	–	42	1.6	–
				DIETZ 1 COAL BED					
9S. 40E. 13DCCB	WRE-10	02/25/75	pumped well	Theis specific capacity	.43	35	16	1.0	–
23BCCD2	WRE-13	04/04/75	"	Jacob drawdown	1.8	220	150	8.1	.00006**
				DIETZ 2 COAL BED					
9S. 40E. 09AADD	WRN-15	04/30/75	pumped well	Jacob drawdown	.27	103	20	1.5	–
09DCAB2	DS-5A	04/13/77	"	"	.43	360	138	7.2	–
11CBCC	WRN-17	04/15/77	"	"	.86	150	441	29	.00007**
13DCBC	WRE-9	02/20/75	"	Theis recovery	.44	20	6.5	.5	–
16ABCD2	WR-7	07/15/71	"	Jacob drawdown	1.1	480	65	4.1	.00001**
23CBBA	WRE-14	02/26/75	"	Theis specific capacity	.67	150	7.5	.5	–
				COMBINED ANDERSON AND DIETZ 1 COAL BEDS					
9S. 40E. 16ABCD	WR-6	07/13/71	pumped well	Jacob drawdown	.90	300	190	3.8	.00002**
29BDCB	WR-51	10/05/79	"	"	.59	330	240	4.2	–
				COMBINED ANDERSON, DIETZ 1 AND DIETZ 2 COAL BEDS					
9S. 39E. 33DBBD	WR-27	03/23/76	pumped well	Jacob Drawdown	.67	240	17	.2	–
35BADB	WR-28	02/18/81	"	Cooper, et al slug injection	–	–	96	1.1	–
9S. 40E. 19CBBD	WR-55	10/06/79	"	Jacob drawdown	.83	360	120	1.5	–
				COMBINED DIETZ 1 AND DIETZ 2 COAL BEDS					
8S. 39E. 32DBBC	WR-21	03/23/76	pumped well	Jacob drawdown	.80	180	58	1.2	–
9S. 38E. 01AADC	WR-23	03/19/76	"	"	1.6	130	44	.8	–
9S. 39E. 16AABA	WR-19	10/08/79	"	"	1.5	320	84	1.6	–
28CCAD	WR-36	11/05/77	"	Theis recovery	.44	60	52	1.0	–
				CANYON COAL BED					
9S. 39E. 29BBDD	WR-24	03/09/76	pumped well	Jacob drawdown	1.2	165	48	3.2	–

* Hydraulic conductivity values based upon aquifer thicknesses at pumped wells.
**Designated storage-coefficient values calculated from barometric efficiencies (Jacob, 1940, p. 583).

3.0 HYDROLOGY

3.2 GROUND WATER

3.2.2 AQUIFERS UNDERLYING THE LEBO SHALE MEMBER

ALTERNATIVE WATER SUPPLIES AVAILABLE FROM AQUIFERS UNDERLYING THE LEBO SHALE MEMBER

Several aquifers underlie the Lebo Shale Member of the Fort Union Formation. The deep aquifers are not likely to be disrupted by surface-mining activities.

Surface mining is expected to disrupt or remove only the upper 100 to 200 feet of overburden in the mine area. The Tongue River Member of the Fort Union Formation, which is composed of about 50 percent sandstone, may extend to about 2,100 feet below land surface in this area (fig. 2.1-1). Wells could be drilled into the deeper sandstones as alternative supplies to replace shallower wells lost to mining. Yields are expected to be similar to yields of shallower sandstone wells.

The Lebo Shale Member underlies the Tongue River Member throughout the mine area. Geophysical logs of deep test holes indicate that the Lebo consists of about 500 feet of siltstone and shale containing less than 10 percent sand. Vertical movement of water through this massive, relatively impermeable unit would be limited even under large vertical gradients. Therefore, hydrologic impacts due to mining are not likely to extend below the Lebo Shale Member.

The Tullock Member of the Fort Union Formation, which underlies the Lebo Shale Member is composed of 60 to 70 percent sand and is about 500 feet thick. Although no wells have been completed in this aquifer in the mine area, the unit yields as much as 40 gal/min in nearby areas.

The Fox Hills-lower Hell Creek aquifer lies about 3,000 feet below land surface in the mine area. This widely used aquifer is about 600 feet thick and could provide significant quantities of water for municipal or industrial use. Wells drilled to the Fox Hills-lower Hell Creek aquifer in nearby areas yield as much as 200 gal/min.

3.0 HYDROLOGY

3.2 GROUND WATER

3.2.3 GROUND-WATER FLOW

GROUND-WATER FLOW PATTERNS ARE AFFECTED BY TOPOGRAPHY, STRUCTURE, AND AQUIFER PROPERTIES

Recharge to shallow aquifers occurs in topographically high areas and discharge occurs in topographically low areas. The pattern of ground-water flow between the two areas is affected by faults and aquifer permeability.

Clinker outcrops in the higher areas surrounding the mine site are the major recharge areas for shallow aquifers. Ground water flows from the recharge areas toward the discharge points in the valley of the Tongue River and its tributaries. Because the recharge areas roughly coincide with topographic highs and discharge areas with topographic lows, the water table or potentiometric surface approximates the general slope of the land surface.

Ground-water flow patterns most closely approximate the land surface profile in the water-table alluvial and clinker aquifers. The potentiometric surface for the Dietz 1 (D-l) coal aquifer is unconfined (water table) and is shown in figure 3.2.3-1. The flow patterns in the confined coal and sandstone aquifer and are less likely to approximate the slope of the land surface.

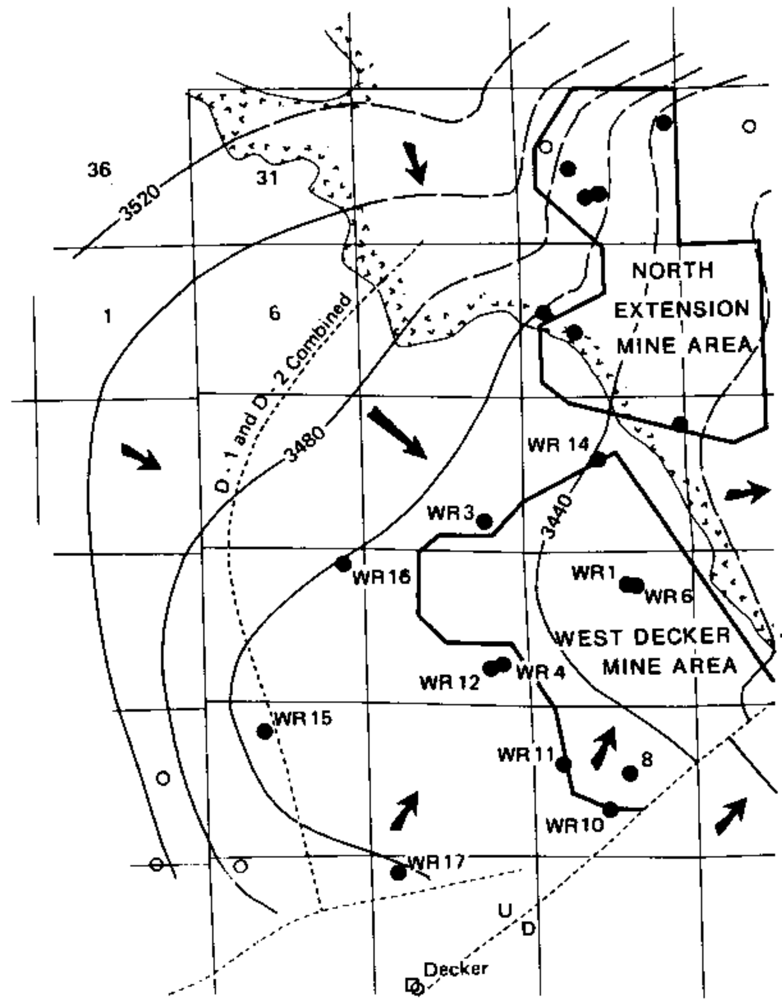
Faults, like the ones in figures 2.2-1 and 3.2.3-1 that have offset the coal and sandstone aquifers, appear to form barriers to ground-water flow. Displacement or offset of permeable zones interrupts ground-water flow paths. Also, fault gouge along the fault zone may be relatively impermeable.

Faults can also increase aquifer permeability, particularly in coal beds. The stresses on coal beds near fault zones can significantly increase the number of fractures and joints that are the major avenues of flow through coal-bed aquifers. Increases in fracture permeability in coals also occur along major structural features such as synclines or folds.

EXPLANATION

- (arrow) DIRECTION OF LATERAL GROUND - WATER FLOW
- —3440— POTENTIOMETRIC CONTOUR - - Shows altitude at which water level would have stood in tightly cased wells, April 1975. Contour interval 20 feet. Datum is sea-level.
- D - 1 AND D - 2 AQUIFER INFORMATION COMBINED
- BOUNDARY OF PROPOSED MINE AREA
- ● WR 3 DECKER - OBSERVATION WELL
- ○ WATER - USE WELL
- FAULT - - U, Upthrown side; D, Downthrown side
- LIMIT OF CLINKER DEPOSITS

0 1 2 Miles
0 1 2 Kilometers



Decker Observation Wells Completed in D - 1 Coal

Well location (all are in 9S 40E) Section	Decker number	Land - surface altitude (feet)	Well depth (feet)	Water - level altitude April 1975 (feet)
08 DCAA	WR 3	3612	215	3431
09 BDDA₁	14	3598	192	3419
16 ABCA	1	3498	104	3404
16 ABCD₁	6	3499	135	3406
17 DACB	4	3585	220	3428
17 DACC	12	3486	230	3427
18 ABAD	16*	3640	237	3451
19 BAC	15*	3685	390	3445
21 ACCA₁	8	3537	165	3426
21 BCAC	11	3575	210	3429
21 CADA	10	3537	169	3426
29 BBAC	17*	3570	300	3455

*Aquifers D - 1 and D - 2 combined.

Figure 3.2.3-1.— Potentiometric surface of Dietz 1 coal aquifer before mining began near Decker. (From Van Voast ands Hedges, 1975, pl. 4.)

3.0 HYDROLOGY

3.2 GROUND WATER

3.2.4 QUALITY OF GROUND WATER

GROUND-WATER QUALITY VARIES BETWEEN AQUIFERS AND BETWEEN AREAS

Ground-water quality is extremely variable...not only between aquifers but within aquifers over different areas.

Water from coal beds in the Decker area is characteristically a sodium bicarbonate type, with very large sodium concentrations. Concentrations of dissolved solids range from about 675 to 3,400 mg/L and average about 1,600 mg/L. The coal beds on the east side of the Tongue River contain water with larger concentrations of dissolved solids than coal beds west of the river (fig. 3.2.4-1). Water from coal beds is used extensively for domestic and stock use in the area, but is of limited use for irrigation because of large sodium concentrations and salinity hazard.

Water from sandstone overburden and interburden generally contains larger concentrations of dissolved solids than water from coal beds. The sandstone waters generally contain sodium as the dominate cation and sulfate and bicarbonate as the dominant anions. Because of the large concentrations of dissolved solids, the waters are generally considered to be unfit for domestic use. Dissolved-solids concentrations range from about 2,100 to 7,200 mg/L and average more than 5,000 mg/L.

Water from alluvium and clinker is extremely variable in quality depending upon the source of recharge. In uplands near recharge areas, water from clinker zones may have dissolved-solids concentrations of less than 1,000 mg/L, and be a magnesium-calcium bicarbonate type water. In valley areas near discharge points, water from the alluvium may have dissolved-solids concentrations in excess of 6,000 mg/L and be a calcium-magnesium sulfate type water. In general, water from alluvium is used for irrigation because of its small sodium concentrations, but it is not used for domestic or stock supplies if deeper, more suitable sources are available.

As a general indication of variability of water quality between aquifers and between areas, specific conductances of samples from numerous wells and springs in the mine area are shown in figure 3.2.4-1. Specific conductance is a rough indication of dissolved-solids concentration.

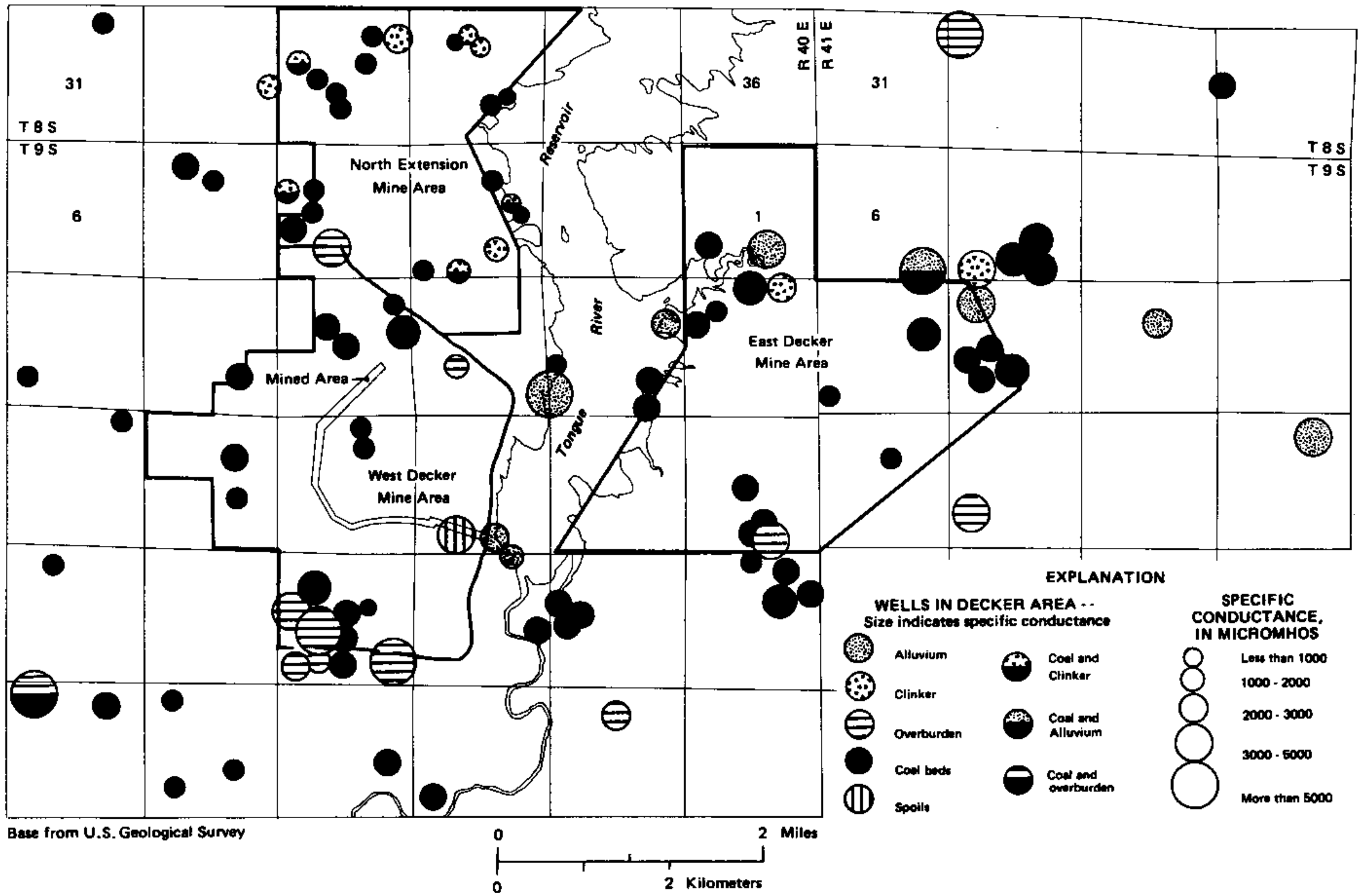


Figure 3.2.4-1.— Specific conductance of water wells completed in various aquifers in the general area. (From U.S. Geological Survey and Montana Department of State Lands, 1977.)

3.0 HYDROLOGY

3.2 GROUND WATER

3.2.5 EVOLUTION OF GROUND-WATER QUALITY

AQUIFER MINERALOGY AND GROUND-WATER FLOW PATHS CONTROL QUALITY

The quality of ground water depends upon the geochemistry of the rocks through which it flows.

When water first enters the ground-water system in recharge areas, it typically contains small concentrations of dissolved solids and is generally dominated by magnesium, calcium, and bicarbonate (fig. 3.2.5-1). Because the water has recently been in contact with the atmosphere, it may contain relatively large levels of dissolved oxygen and be undersaturated with respect to many soluble minerals contained in the aquifer.

This extremely reactive water tends to dissolve many of the minerals, such as gypsum, calcite, dolomite, nahcolite, and albite, present in the aquifers. The dissolution of these and other minerals results in increasing concentrations of the dissolved constituents in the water.

As the ground water moves away from the recharge area and into a more stable environment, the dissolution process commonly becomes less important in controlling ground-water chemistry. Instead, cation exchange or "natural softening" becomes the dominant geochemical process. The calcium and magnesium ions in solution are replaced by sodium ions as the water percolates through the sodic clays abundant in the Fort Union Formation. This process results in the development of water containing large concentrations of dissolved solids with cations dominated by sodium.

Simultaneous with cation exchange, sulfate reduction occurs as sulfate-reducing bacteria convert sulfate ions and simple organic compounds (coal) to water, bicarbonate, sulfide, and carbon dioxide. The presence of carbon dioxide and sulfide gases in water from coal beds affirms the sulfate-reduction process.

The end result of these processes is the formation of ground water containing large concentrations of sodium and bicarbonate (fig. 3.2.5-1). Because recharge and mixing occur over most of the area, intermediate water-quality types can be almost anywhere in the flow system.

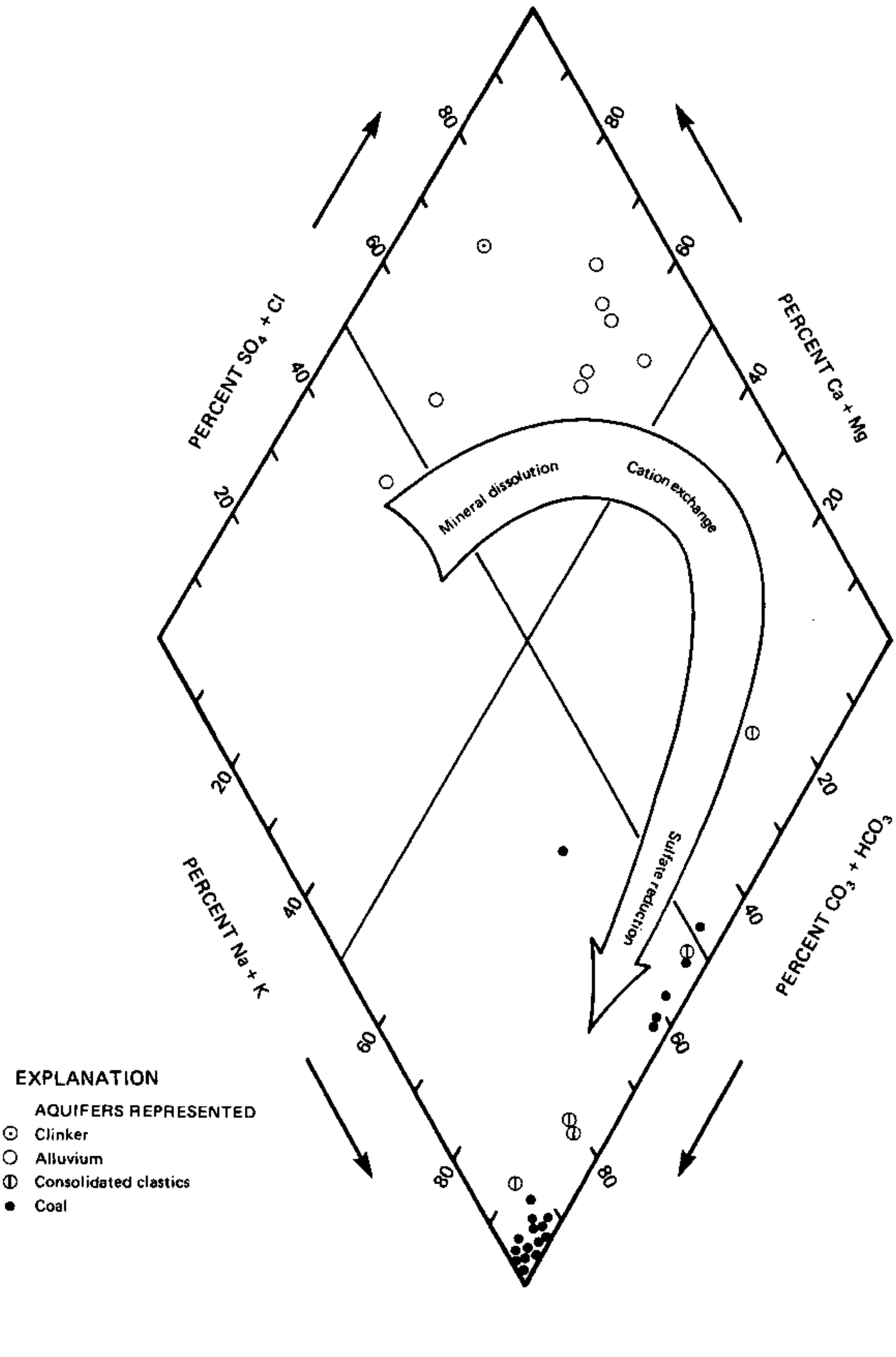


Figure 3.2.5-1.— Evolution of ground-water quality along flow path. (From Thompson and Van Voast, 1981, p. 34.)

3.0 HYDROLOGY

3.2 GROUND WATER

3.2.6 GROUND-WATER/SURFACE-WATER RELATIONS

REACHES OF SOME STREAMS HAVE ALMOST CONTINUOUS FLOW AS A RESULT OF GROUND-WATER DISCHARGE

The Tongue River Reservoir is the major discharge area for the shallow ground-water system but many of the tributary streams drain alluvial aquifers in their valleys.

The operation of the Tongue River Reservoir significantly affects the rate of ground-water discharge in the mine area. When the reservoir stage is low, the ground-water gradient is steep and the ground-water discharge is large. When the reservoir stage is high, the gradient is flattened and may even be reversed in some areas. The long-term average gradient is toward the reservoir, and ground-water discharge has been estimated to be 4 to 6 ft^3/s.

Of the major streams traversing the mine area, Deer Creek, Spring Creek, and South Fork Spring Creek commonly flow in their upper reaches until early summer. During unusually wet years, the streams may flow along most of their reaches well into summer.

Evapotranspiration from phreatophytes occurs in the stream bottoms. Evapotranspiration probably uses most of the ground-water discharge in the area.

Recharge to the alluvial aquifers during snowmelt and spring rains raises water levels in the valley aquifers and increases the water in storage. After the recharge season, the alluvial aquifers drain to the streams; the seasonal discharge varies according to the amount and timing of the earlier recharge.

Low flow of the streams cannot be defined because of lack of data. However, the direct relationship between streamflow and ground-water levels is illustrated in fig. 3.2.6-1.

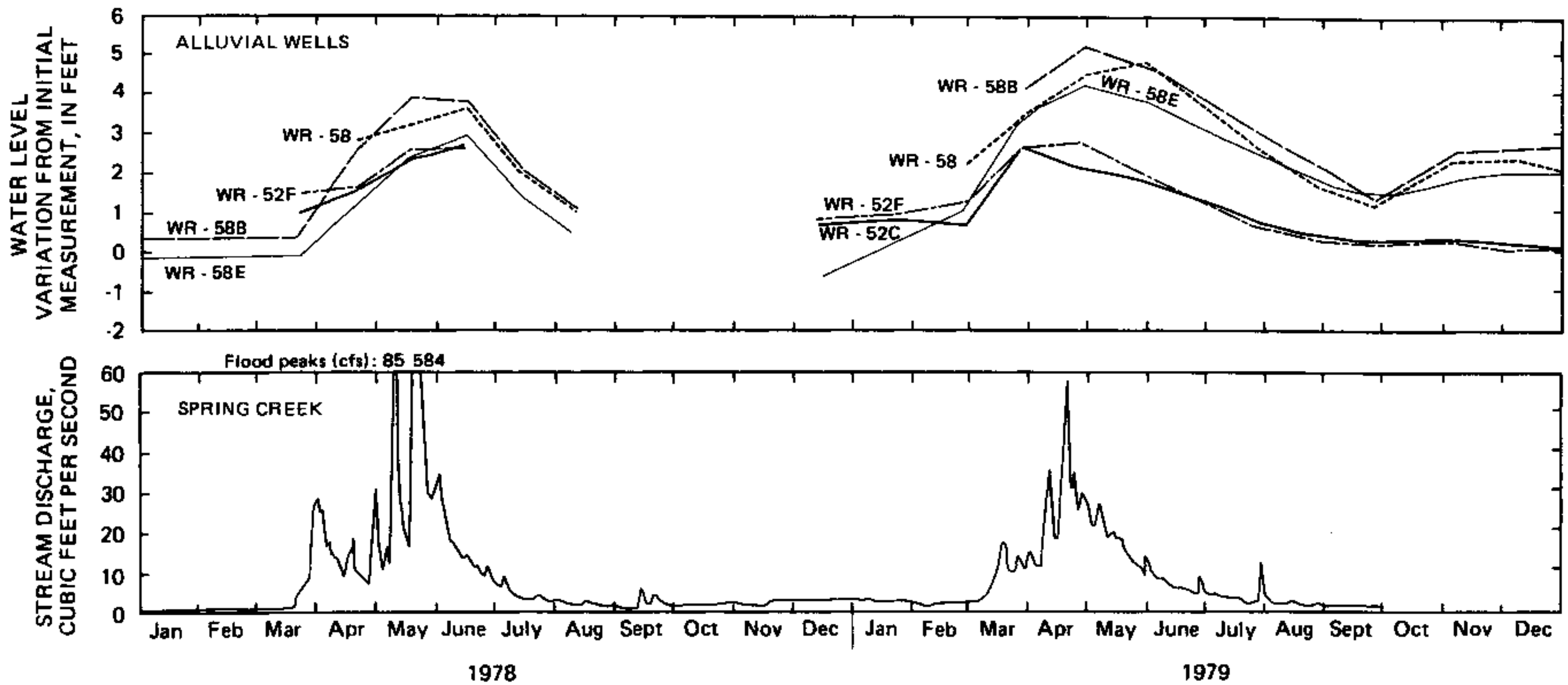


Figure 3.2.6-1.— Stream discharge in Spring Creek and water levels in alluvial wells. (From Thompson and Van Voast, 1981, p. 25.)

3.0 HYDROLOGY

3.3 GROUND-WATER MONITORING

OBSERVATION WELLS DRILLED BEFORE AND AFTER MINING PROVIDE DATA ON AQUIFER CHARACTERISTICS, WATER-LEVEL FLUCTUATIONS, AND GROUND-WATER QUALITY

Sixty-four wells in the mine area monitor hydrologic conditions before and after mining.

Observation wells have been installed throughout the area to be mined (fig. 3.3-1). Some wells have been installed as far as 1.5 miles from the maximum anticipated mined area to monitor water-level declines in coal beds.

The locations of observation wells were selected on the basis of geologic and hydrologic conditions to obtain as much information on pre- and post-mining conditions as possible in areas where water-level or ground-water quality changes might occur. Wells were installed to observe water levels near the Tongue River Reservoir, across faults suspected of forming barriers to ground-water flow, and both upgradient and downgradient from the proposed mine areas.

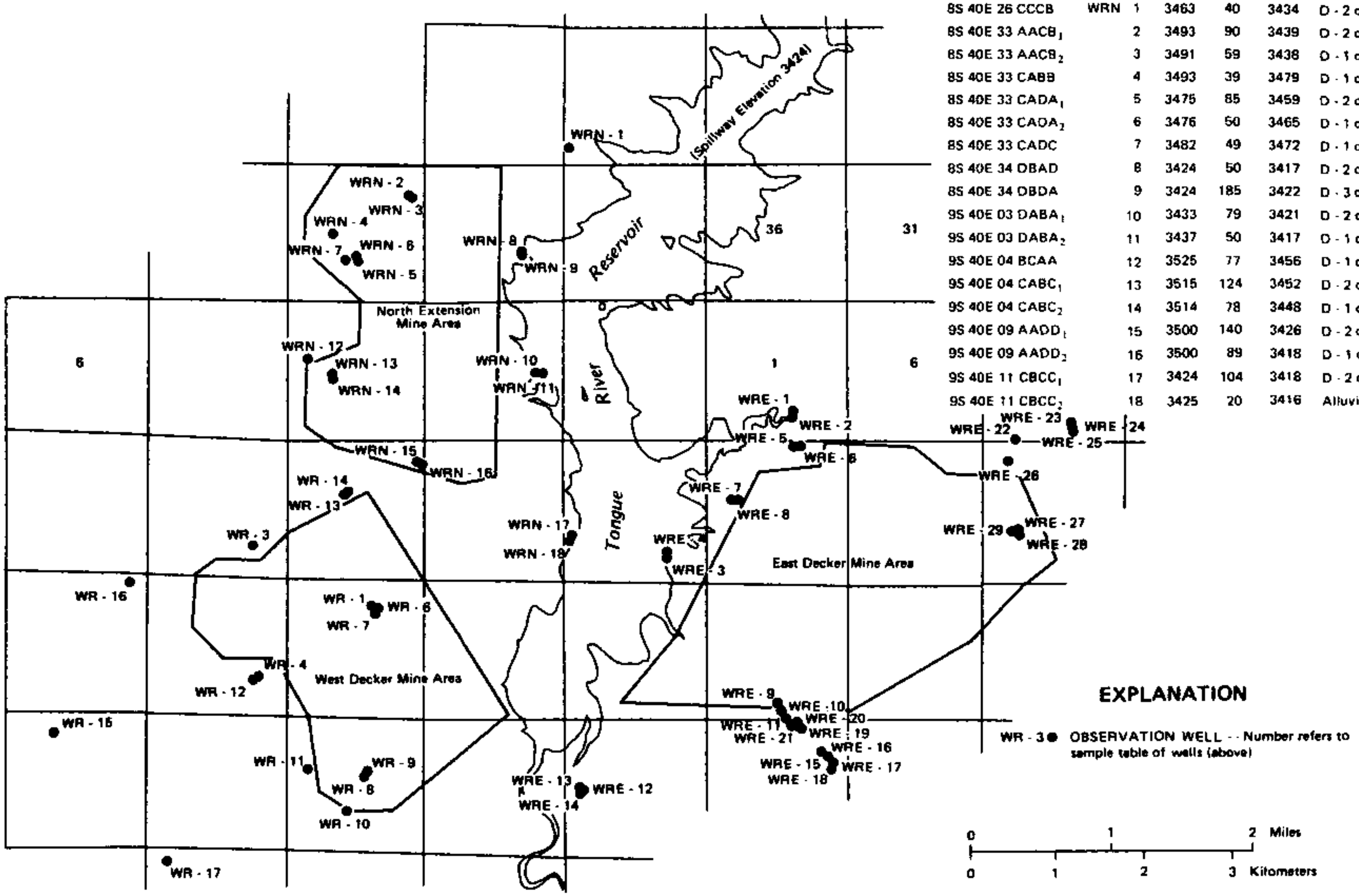
Each observation well was installed to monitor conditions in a single aquifer unit. Where more than one aquifer was identified at a location, several wells were installed with each well perforated in an individual aquifer.

During drilling, each well was logged to record the materials penetrated. Thus, the first information obtained from the wells was an accurate description of the geology. This information was useful in defining vertical and areal extent of each major water-bearing zone in the area.

After observation wells were installed, pumping tests were made to determine the hydraulic characteristics of the major aquifers. Where multiple observation wells were installed, the effectiveness of confining layers was evaluated from the pumping tests and water-level differences.

Samples collected during the pumping tests provided information on ground-water quality between aquifers and over the total area. Samples collected later provided information on water-quality changes caused by natural recharge or mining.

Water levels are monitored regularly at all sites to determine water-level changes due to natural or manmade causes. Continuous recorders were installed on selected wells where rapid water-level changes were anticipated. The frequency of measurements in other wells ranged from monthly to annually depending upon location and anticipated water-level changes.



North Decker Observation Wells

Well location	North Decker number	Land - surface altitude (feet)	Well depth (feet)	Water - level altitude (feet) April, 1975	Aquifer isolated for observation
8S 40E 26 CCCB	WRN 1	3463	40	3434	D - 2 coal
8S 40E 33 AACB$_1$	2	3493	90	3439	D - 2 coal
8S 40E 33 AACB$_2$	3	3491	59	3438	D - 1 clinker
8S 40E 33 CABB	4	3493	39	3479	D - 1 coal
8S 40E 33 CADA$_1$	5	3475	85	3459	D - 2 coal
8S 40E 33 CADA$_2$	6	3476	50	3465	D - 1 coal
8S 40E 33 CADC	7	3482	49	3472	D - 1 coal
8S 40E 34 DBAD	8	3424	50	3417	D - 2 coal
8S 40E 34 DBDA	9	3424	185	3422	D - 3 coal
9S 40E 03 DABA$_1$	10	3433	79	3421	D - 2 coal
9S 40E 03 DABA$_2$	11	3437	50	3417	D - 1 coal and clinker
9S 40E 04 BCAA	12	3525	77	3456	D - 1 coal and clinker
9S 40E 04 CABC$_1$	13	3515	124	3452	D - 2 coal
9S 40E 04 CABC$_2$	14	3514	78	3448	D - 1 coal
9S 40E 09 AADD$_1$	15	3500	140	3426	D - 2 coal
9S 40E 09 AADD$_2$	16	3500	89	3418	D - 1 clinker
9S 40E 11 CBCC$_1$	17	3424	104	3418	D - 2 coal
9S 40E 11 CBCC$_2$	18	3425	20	3416	Alluvium

Figure 3.3-1.— Network of observation wells used to monitor effects of mining. (From Van Voast and Hedges, 1975, pl. 3.)

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.1 OBSERVED WATER-LEVEL DECLINES

DEWATERING MINE PITS CAUSES GROUND-WATER LEVELS TO DECLINE

Water levels in wells perforated in the Dietz 1 coal bed declined as much as 40 feet during the first 3 years of mining.

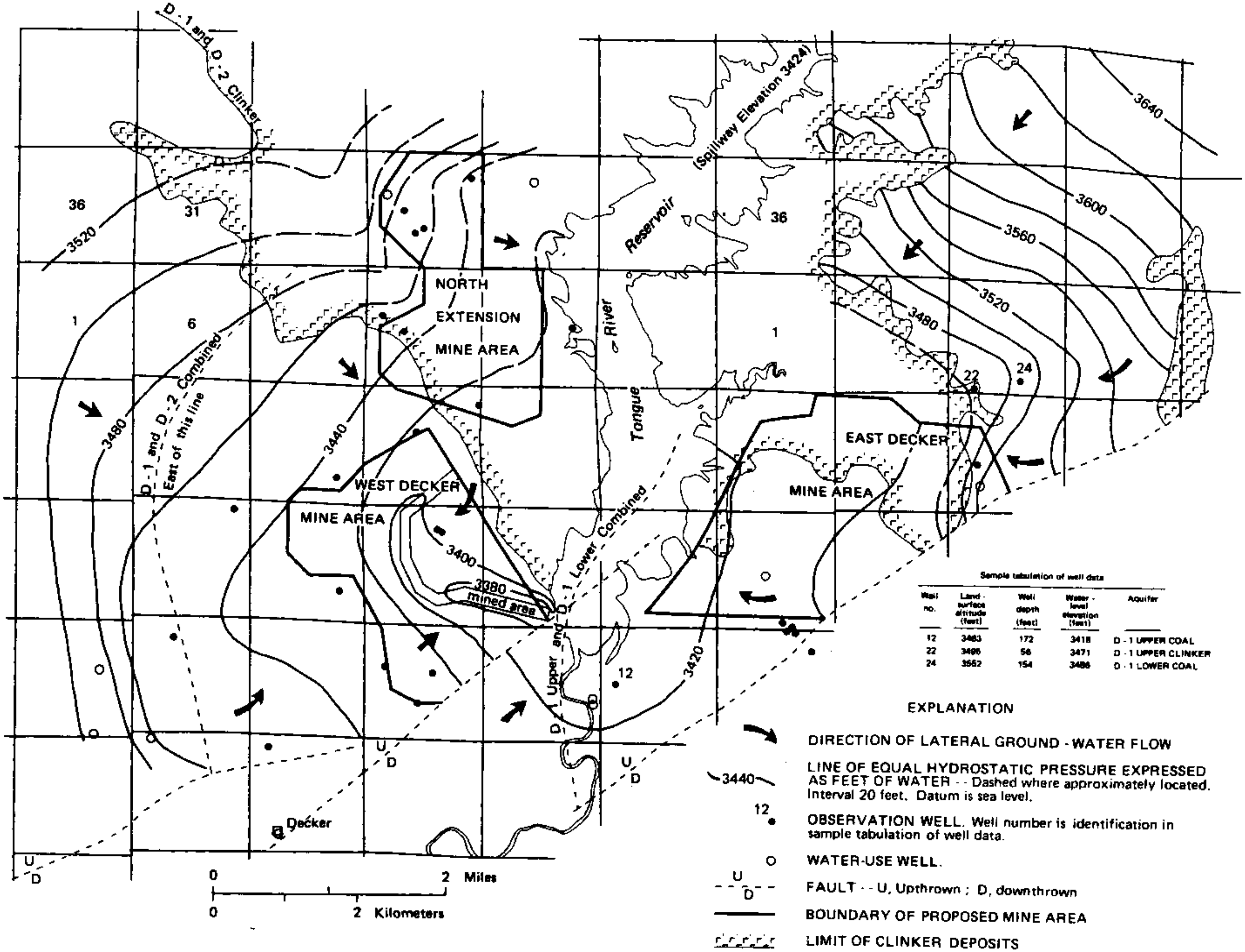
In the mine area, the pattern of ground-water flow toward the natural discharge area along the Tongue River valley has been modified by mine excavation. Removal of the aquifers and concurrent dewatering of the mine pit has produced a depression in the potentiometric surface about 50 feet lower than, and about a mile upgradient from, the natural discharge point. Consequently, ground-water gradients have steepened toward the mine cuts upgradient from the mine and have reversed direction downgradient from the mine. Between the Tongue River and the mine cut, ground water now flows from the river toward the mine.

Mining of the Dietz 1 coal bed began at the mine early in 1972. During the mining operation, water levels in observation wells declined according to their relative distances from the mined area and according to the changing geometry of the mine cut. The potentiometric surface for the Dietz 1 coal, based on water-level measurements in January 1975, showed large hydraulic gradients toward the mined area along its entire length, as shown in figure 4.1-1. The mine cut penetrates and receives water from the entire thickness of the aquifer, thereby creating a depression lower than the surrounding potentiometric surface and the nearby water table along the Tongue River.

Water levels in wells in the Dietz 2 coal also declined, even though the aquifer was not being mined. The water-level declines in these wells are a result of increased vertical leakage upward to the Dietz 1 coal.

Degree and extent of water-level declines presumably caused by the first 3 years of mining are shown in figure 4.1-2. Northwest of the mined area, water levels in the Dietz 1 coal had declined 10 feet or more within a distance of about 1.5 miles. Southwest of the mine, water-level declines were 10 feet or more within a distance of 1.75 miles. The area in which water levels declined 20 feet or more did not extend more than about 0.75 mile in any direction from the mine. East of the mine, water-level declines were much less extensive because of recharge induced from the Tongue River Reservoir and nearby alluvium and clinker.

Until early 1974, water levels declined at constant or increasing rates. These rates reflected the effect of increasing stress on the flow system as the mine area expanded. In early 1974, the rates of decline in all observation wells began to diminish. The moderation of decline rates indicated that, after 2 years of mining, the system had begun to approach a new equilibrium; however, the ground-water system will not fully attain equilibrium while the mine is in operation.



Sample tabulation of well data

Well no.	Land-surface altitude (feet)	Well depth (feet)	Water-level elevation (feet)	Aquifer
12	3463	172	3418	D-1 UPPER COAL
22	3496	56	3471	D-1 UPPER CLINKER
24	3562	154	3486	D-1 LOWER COAL

Figure 4.1-1.— Potentiometric surface of water in the Dietz coal aquifer (D-l), January 1975. (From Van Voast and Hedges, 1975, pl. 7.)

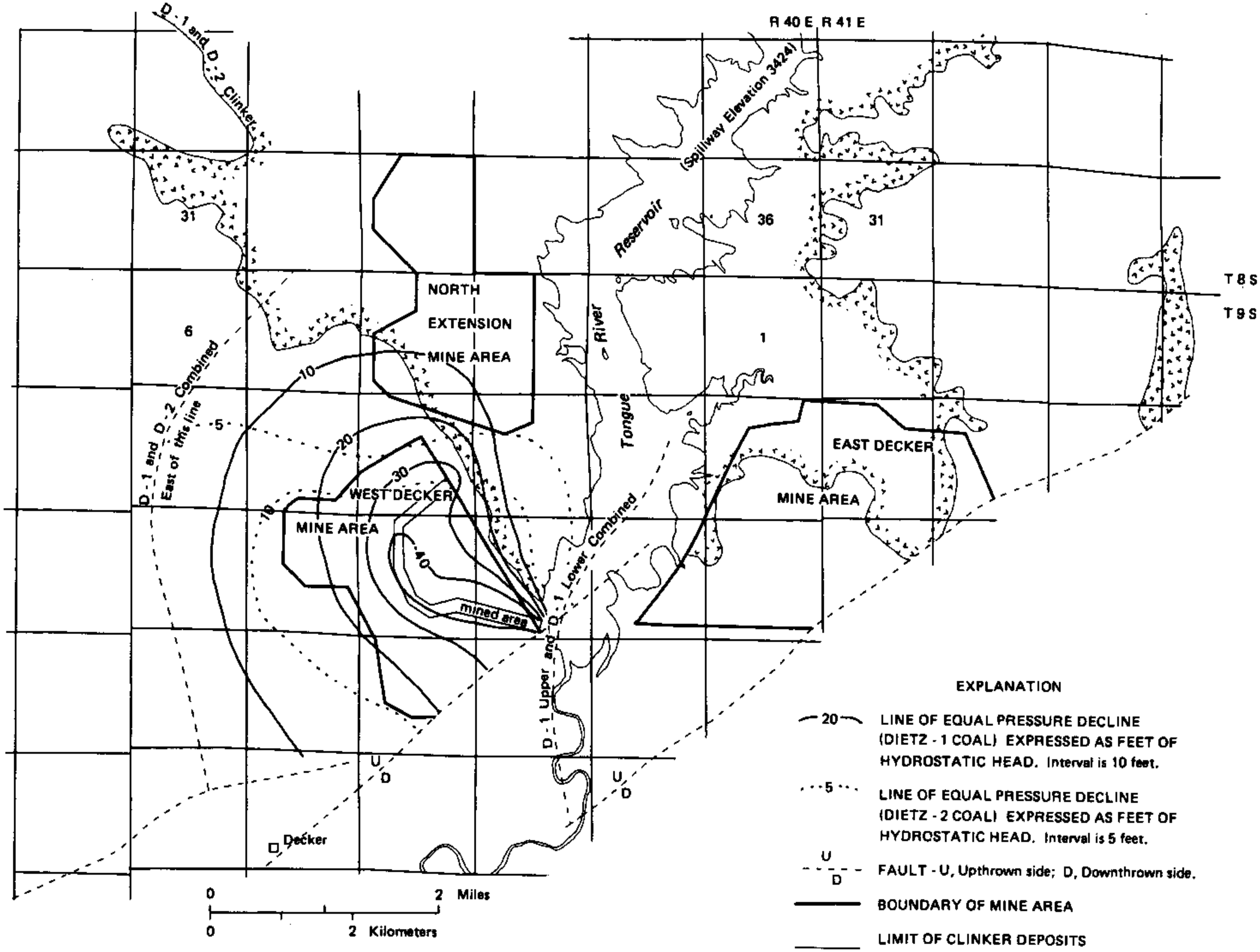


Figure 4.1-2.— Drawdown of water level in the Dietz coal aquifers after 3 years of mining. (From Van Voast and Hedges, 1975, pl. 9.)

Water levels in one of the wells farthest from the mined area (WR-15 fig. 3.2.3-1) illustrate that the potential area of hydrologic effect of mining extends beyond the existing observation-well network. In this well, constructed in mid-1974, the water level declined almost 3 feet in the first year of measurement. The well is more than 2 miles from the mined area. Similar water-level declines have been recorded in other wells similar distances from the mine (WR-16 and WR-17).

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.2 PREDICTING WATER-LEVEL DECLINES

GROUND-WATER MODELS PREDICT WATER-LEVEL DECLINES UNDER VARIOUS CONDITIONS

Ground-water models can predict water-level declines using various aquifer characteristics, mining plans, or boundary conditions.

Digital models can be used to simulate the effects of various mining conditions on ground-water systems having various aquifer materials and boundary conditions. A model (17) was used to simulate the water-level response in various aquifers under different mining conditions.

Dewatering of the excavation was simulated as an instantaneous removal of water to the bottom of mine cut. Except where noted, boundaries for each simulation were set at a sufficient distance to minimize boundary effects on water levels. The models produce a worst-case simulation of water-level declines because of the instantaneous removal of water. The models do not account for recharge by surface infiltration of rainfall, snowmelt, or stream loss.

The premise is to illustrate the effects of changes in head, hydraulic conductivity, storage coefficient, and mine-cut size, and the effects of hydrologic boundaries. Effects of changes in these parameters are illustrated by comparison with a base model, which depicts a homogeneous, isotropic, infinite aquifer, 10 feet thick and having a hydraulic conductivity of 0.5 ft/d and a storage coefficient of 1×10^{-4}. The initial potentiometric surface is placed 10 feet above the top of the aquifer. The aquifer simulated in the model represents the coal bed to be mined or the overburden above the target coal bed.

In reality, the aquifer system is probably anisotropic such that horizontal hydraulic conductivity is much larger than vertical hydraulic conductivity. Furthermore, the aquifer would become unconfined near the open pit and a storage coefficient larger than 1×10^{-4} would better represent the problem in the unconfined area. Both of these factors are possible sources of error to the model results. Incorporation of these assumptions into the model would probably result in drawdowns smaller than those indicated by this experiment.

The results of the models are illustrated in map and graphic forms. After 1 year of mining, water-level declines of more than 1 foot extend about 2 miles from the mine cut; after 20 years, the water-level declines of more than 1 foot extend about 8 miles from the mine cut (fig. 4.2-1).

The effects of changes in hydraulic conductivity, storage coefficient, aquifer thickness, depth of mine below the initial potentiometric surface, size of excavation, and aquifer thickness are illustrated in figure 4.2-2. Each curve illustrates the effect of modifying one parameter in the base model. The effect of each change can be determined by comparing each curve with curve 1. Curve 2 was developed by changing the hydraulic conductivity from 0.5 to 5 ft/d, curve 3 by changing the storage coefficient from 1×10^{-4} to 1×10^{-3}, curve 4 by placing the top of the

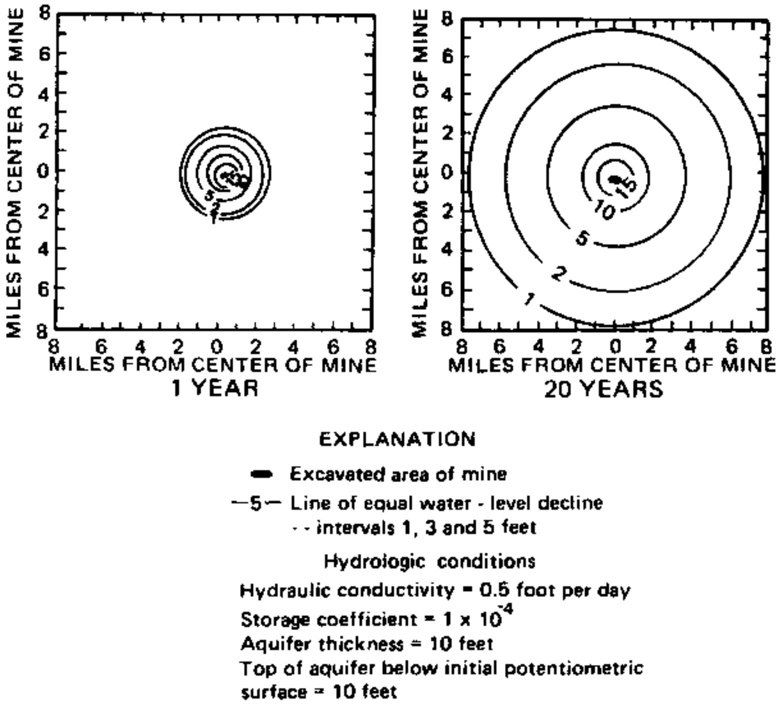
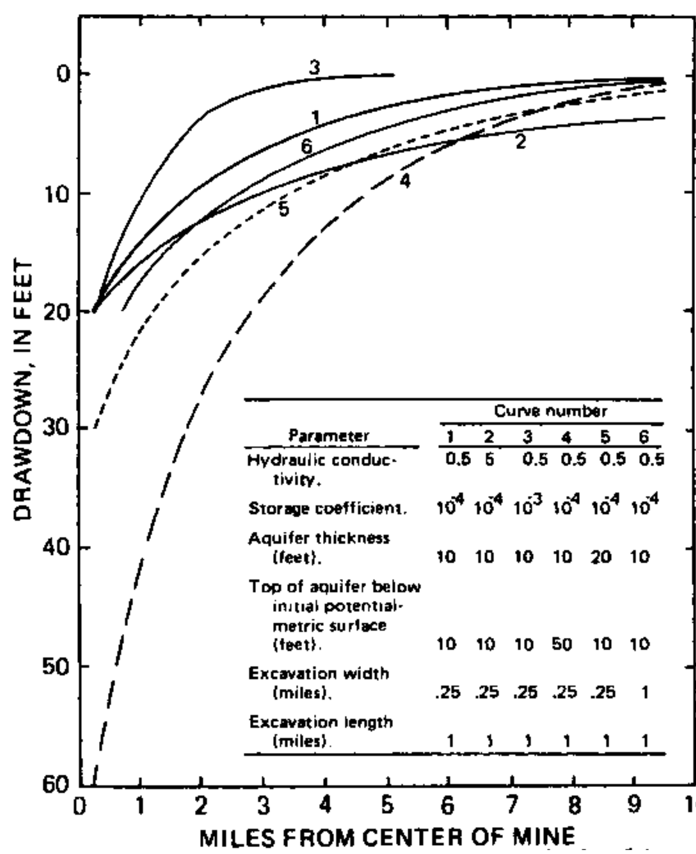


Figure 4.2-1.— Simulated water-level declines after 1 year and 20 years of mine dewatering.
(From Slagle and others, 1985, fig. 8.)



Parameter	Curve number 1	2	3	4	5	6
Hydraulic conductivity.	0.5	5	0.5	0.5	0.5	0.5
Storage coefficient.	10^{-4}	10^{-4}	10^{-3}	10^{-4}	10^{-4}	10^{-4}
Aquifer thickness (feet).	10	10	10	10	20	10
Top of aquifer below initial potentiometric surface (feet).	10	10	10	50	10	10
Excavation width (miles).	.25	.25	.25	.25	.25	1
Excavation length (miles).	1	1	1	1	1	1

Figure 4.2-2.— Simulated water-level declines with various aquifer characteristics.
(From Slagle and others, 1985, fig. 9.)

aquifer 50 feet below the initial potentiometric surface (instead of 10 feet), curve 5 by increasing the aquifer thickness from 10 to 20 feet, and curve 6 by increasing the excavation width from one-fourth to 1 mile.

The effects of a nearby surface-water body on water-level declines are depicted in figure 4.2-3. In this simulation, water levels along the boundary are maintained constant, allowing recharge from a lake or stream to limit water-level declines.

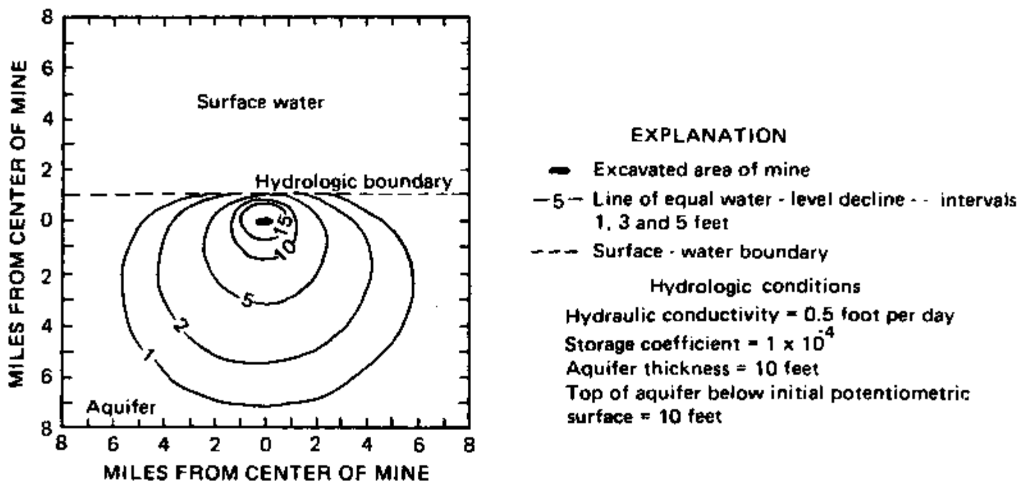


Figure 4.2-3.— Simulated water-level declines in an aquifer adjacent to a surface-water boundary. (From Slagle and others, 1985, fig. 11.)

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.3 IMPACTS OF WATER-LEVEL DECLINES

WATER-LEVEL DECLINES MAY AFFECT SPRINGS AND WELLS

About 50 wells and springs in the mine area could be affected by water-level declines.

Water-level declines can significantly affect the yield of wells and springs. In the worst case, if water levels declined below the bottom of the well, the well would become dry. Similarly, if the water table dropped below the discharge point of a spring, the spring would stop flowing. Under water-table conditions, a water-level decline would result in decreasing well yields (specific capacity), because the saturated thickness available to contribute water to the well would be less. Under confined conditions water-level declines would effectively increase pumping lifts and maximum well yield would be less.

In the mine area, about 50 wells and springs supply water for wildlife, agriculture, stock, domestic, industry, and public supply. Although total ground-water use probably does not exceed 30,000 gal/d, the wells and springs are vital to the economy and population of the area.

Springs in the area are used exclusively by livestock and wildlife. The springs shown in figure 3.2.1-1 are those identified as dependable sources of supply and do not include ephemeral springs that flow in response to seasonal high water levels in alluvium or clinker deposits. Because springs are a surface expression of the water table, even small water-level declines could affect them.

About two-thirds of the wells are used for watering stock. Generally, these wells are drilled to the shallowest source of ground water. These wells would be readily susceptible to impacts from mining.

Wells drilled for domestic, industrial, or public supplies generally are completed in coal aquifers to obtain good quality water. If the wells are in a coal bed to be mined, they are likely to be affected to some degree. Most of the coal beds contain water under confined conditions so only those wells near the mines where the coal beds would be dewatered would be significantly affected. Coal-bed wells a few miles from the mines might undergo water-level declines but their yield probably would not significantly decrease.

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.4 WATER QUALITY IN MINE SPOILS

SPOILS WATER CONTAINS MORE DISSOLVED CONSTITUENTS THAN NATIVE GROUND WATER

Dissolved constituents in water from resaturated mine spoils are more concentrated than those found in water from overburden sandstone aquifers.

When mine spoils are returned to the mine pit, the original structured system of aquifers is replaced with a heterogeneous mixture of rubble composed of waste coal, siltstone, sandstone, clinker, alluvium, soil, or any other material that was removed from the pit. Materials that had originally resided in the saturated zone where the potential for oxidation was slight now may lie in the unsaturated zone where oxidation can release soluble salts. The disruption of the natural system would result in significant differences in quality between water from the original aquifers and water from the mine spoils.

Observation wells drilled into resaturated mine spoils at the mine site have clearly shown changes in ground-water quality. Calcium, magnesium, and sulfate concentrations were substantially larger in mine-spoils waters than in water from coal aquifers (fig. 4.4-1). However, the mine-spoils water quality is similar to the water quality from sandstone aquifers in the overburden.

Water quality in wells drilled in mine spoils was extremely variable during the early period of resaturation. In 1975 and 1976, for example, dissolved-solids concentrations in one well fluctuated between 6,400 and 3,800 mg/L. Although data are not conclusive, the quality apparently has stabilized at the smaller concentration since the mine spoils have become saturated. Data indicate that during the early phase of resaturation, the first flush of water through the system may have leached much of the soluble minerals from the spoils.

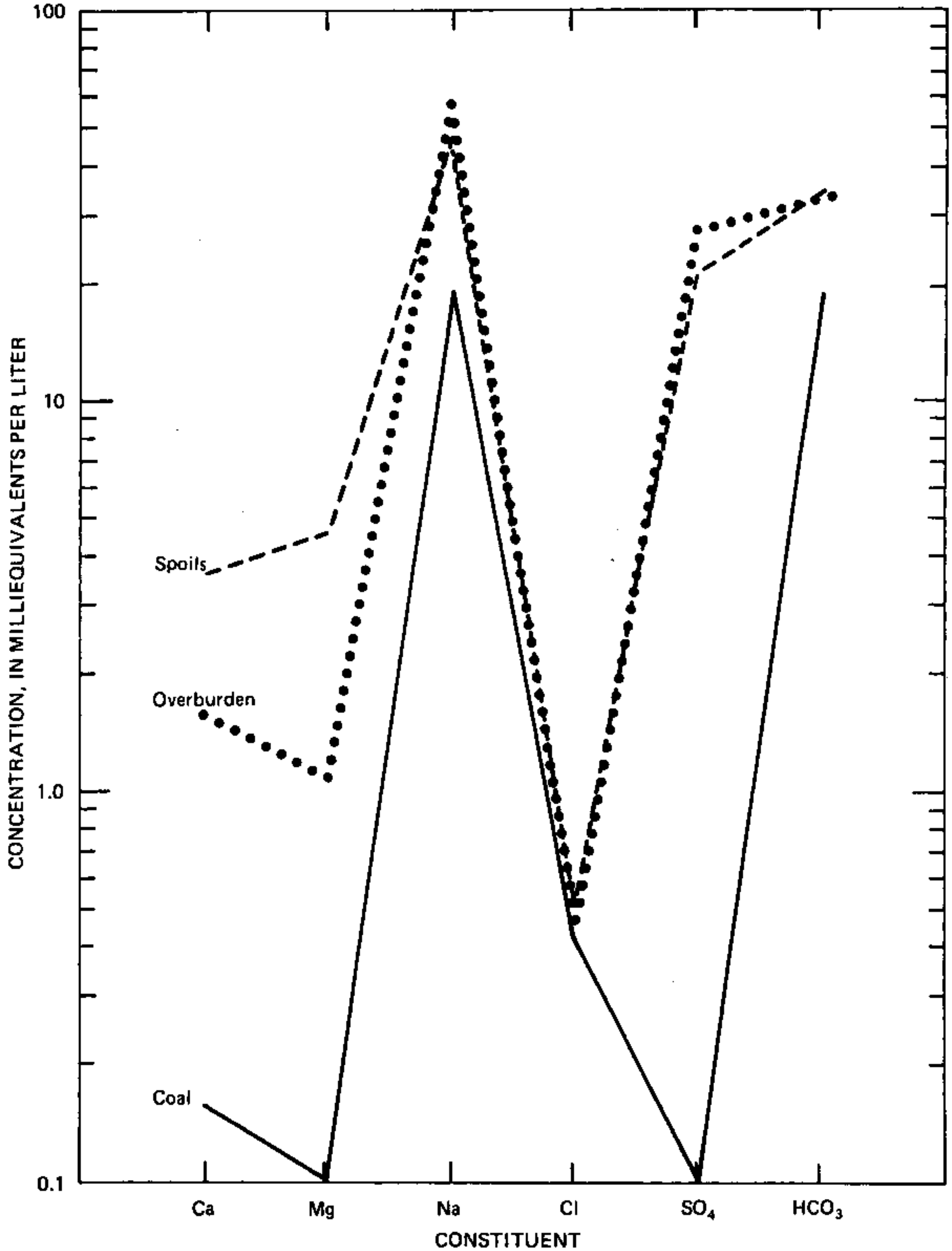


Figure 4.4-1.— Comparison of water quality in spoils and pre-mining aquifers. (From Van Voast, Hedges, and McDermott, 1978),

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.5 PREDICTING OFF-SITE GROUND-WATER QUALITY

AFTER GROUND-WATER FLOW PATTERNS RE-ESTABLISH, MINE-SPOILS WATER WILL MIGRATE DOWNGRADIENT

Predicting the ultimate ground-water-quality conditions in the vicinity of a reclaimed mine requires considerable speculation and simplifying assumptions.

During mining, ground-water flow patterns will generally be toward the mine cut as dewatering operations draw the water level down to the base of the mine (fig. 4.5-1). As the mine cut proceeds through the area, spoils replaced in earlier cuts will become saturated with ground water and the pattern of flow would continue to be toward the mine cut. Ultimately, after all mining has ceased and mine spoils have been resaturated, the original pattern of ground-water flow likely will be re-established. However, some variations will occur owing to differences in aquifer characteristics between mine spoils and the original aquifers and in the infiltration characteristics between the reclaimed surface and the original land surface.

The return of the original flow patterns will result in movement of mine-spoils water downgradient toward natural discharge areas. Any wells located downgradient from the reclaimed mine area and perforated in the shallow aquifers in contact with the spoils eventually will be affected by the mine-spoils water.

No data collected to date indicate what geochemical changes might occur as mine-spoils water enters natural aquifers. However, a prudent assumption is that mine-spoils waters would retain most of their dissolved solids after leaving the spoils. By using that assumption, the areas to be affected by migrating mine-spoils water can be predicted by outlining the downgradient path of ground water from the pre-mining water-level data. A rough estimate of travel time could also be made by calculating the volume rate exchange of water through the aquifer.

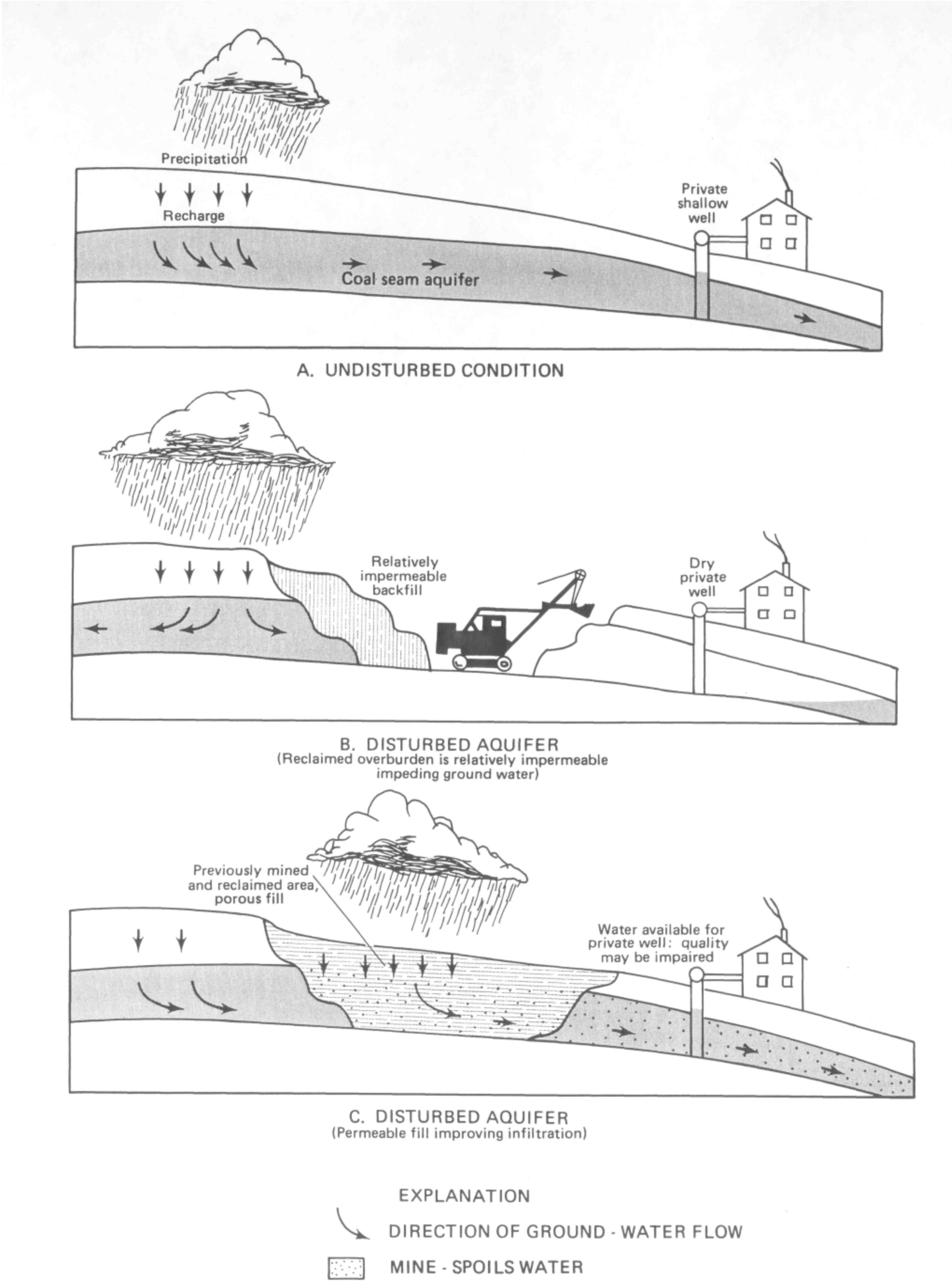


Figure 4.5-1.— Hypothetical migration of mine spoils water after reclamation.

4.6 MONITORING POST-MINING HYDROLOGIC CONDITIONS

AFTER MINING AND RECLAMATION HYDROLOGIC MONITORING WOULD SHOW CHANGES IN THE HYDROLOGIC SYSTEMS

Post-mining monitoring of ground-water levels, ground-water quality, and aquifer characteristics not only would show the ultimate affects of mining on hydrologic systems but also would serve as an aid in predicting hydrologic impacts in other areas to be mined.

A network of observation wells could be used to monitor changes in ground-water storage, quality, and flow patterns. Although mining is planned to continue in the area for at least 20 years, monitoring of hydrologic conditions during and following each phase of the operation would provide information useful in evaluating effects of mining and reclamation. Because of the long-term nature of the mining activity in the mine area, concurrent monitoring could provide data needed to evaluate the effectiveness of improved mining methods, various reclamation techniques, or other mitigating measures. The monitoring would also assist in predicting hydrologic impacts in other areas to be mined.

The network of wells shown in figure 4.6-1 could provide information on water-level changes in the various aquifer units in and near the mine areas. Additional wells outside the proposed mine boundaries as mining expands would be useful in showing water-level changes due to mine dewatering or mine spoil saturation. The frequency of water-level measurements would depend upon the status of mining and reclamation. As mine pits move through the proposed mining areas, frequency of monitoring could be increased in nearby wells and decreased in wells in which water levels have stabilized or have approached equilibrium.

As mine areas are reclaimed, replacement observation wells could be installed in mine spoils to monitor resaturation of the spoils material. Placement, density, and depth of the wells would depend upon the progression of mining and reclamation. Wells could be installed after surface reclamation activities have been completed and danger of damage to well casing and equipment has passed.

As mine spoils become resaturated, frequency of monitoring could be monthly or more frequently depending upon the rate of change in water levels. In some wells continuous recorders could be used to document the water-level rises. After the mine spoils have become saturated and water levels have stabilized, frequency could be reduced to quarterly.

Water samples could be collected from the observation wells installed in mine spoils to document water quality in the spoils. A few of the wells would need to be sampled monthly during the period of resaturation but most wells could be sampled annually to provide data on long-term variations in mine-spoils water.

Sample Table of Wells
West Decker Observation Wells

Well location	Decker number	Land surface altitude (feet)	Well depth (feet)	Water - level altitude (feet) April, 1975	Aquifer isolated for observation
9S 40E 08 DCAA	WR 3	3612	215	3431	D - 1 coal
9S 40E 09 BDDA$_1$	14	3598	192	3419	D - 1 coal
9S 40E 09 BDDA$_2$	2	3595	192	-	D - 1 coal discont. 12/20/72 - silt
9S 40E 09 BDDB	13	3592	247	3436	D - 2 coal
9S 40E 16 ABCA	1	3498	104	3404	D - 1 coal
9S 40E 16 ABCD$_1$	6	3499	135	3406	D - 1 coal
9S 40E 16 ABCD$_2$	7	3498	207	3445	D - 2 coal
9S 40E 17 DACB	4	3585	220	3428	D - 1 coal
9S 40E 17 DACC	12	3486	230	3427	D - 1 coal
9S 40E 18 ABAD	16	3640	237	3451	D - 1 & 2 coal combined
9S 40E 19 BAC	15	3685	390	3445	D - 1 & 2 coal combined
9S 40E 21 ACCA$_1$	8	3537	165	3426	D - 1 coal
9S 40E 21 ACCA$_2$	9	3537	255	3458	D - 2 coal
9S 40E 21 BCAC	11	3575	210	3429	D - 1 coal
9S 40E 21 BCAD	5	3574	200	-	D - 1 coal discont. 9/15/73 - silt
9S 40E 21 CADA	10	3537	169	3426	D - 1 coal
9S 40E 29 BBAC	17	3570	300	3455	D - 1 & 2 coal combined

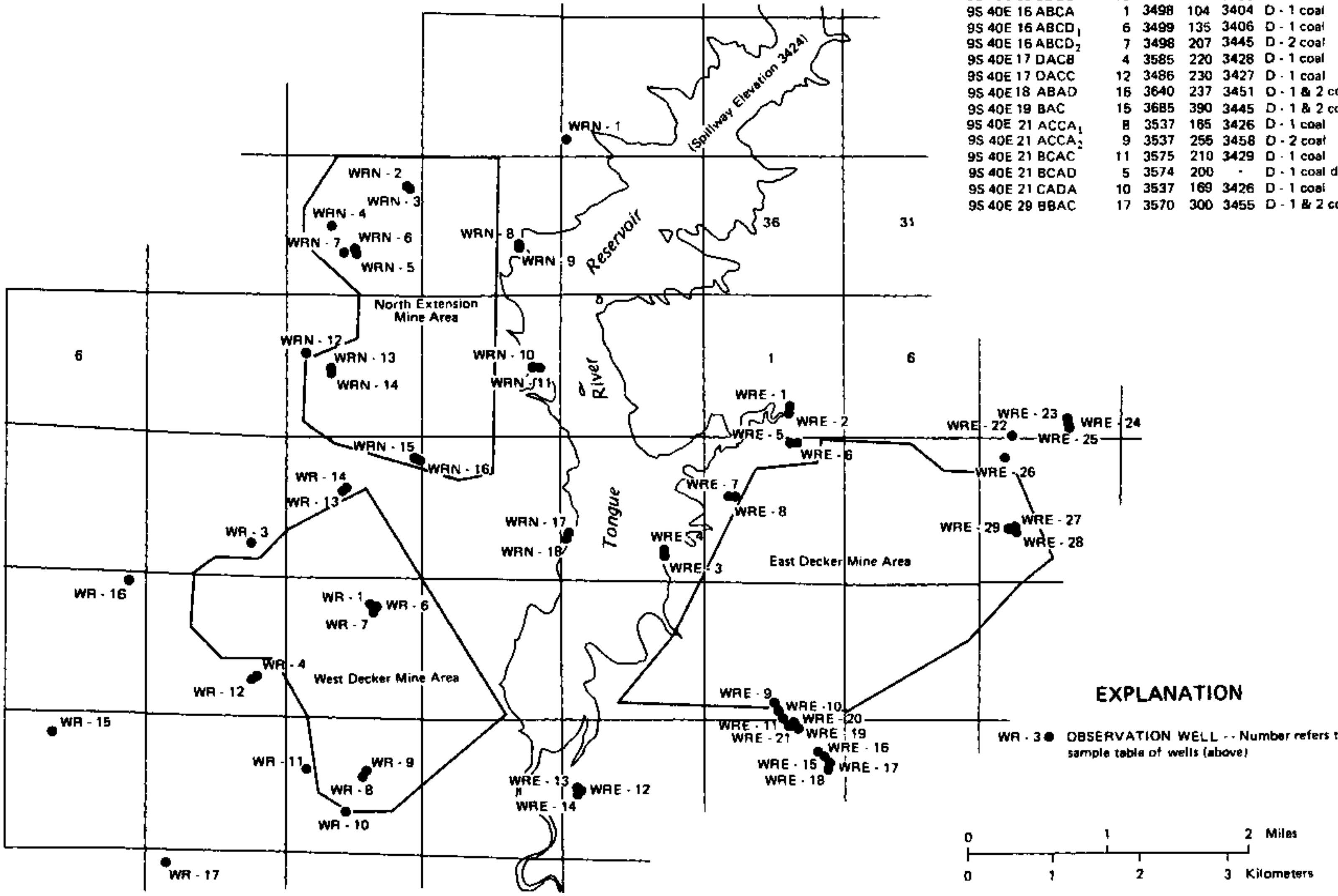


Figure 4.6-1.— Post-mining network of observation wells which could be used for long-term monitoring. (From Van Voast and Hedges, 1975, pl. 3.)

Off-site effects of mining could be monitored by observation wells down-gradient from the mine areas. Although ground-water flow would be toward pits during the mining operation, the original flow pattern probably would be reestablished after mining had ceased. Ground-water samples collected from the downgradient wells would provide data on migration of mine-spoils water into and through the undisturbed aquifers.

Selected observation wells in reclaimed spoils could provide information on aquifer characteristics of the spoils material. When water samples are collected, observations of drawdown and recovery of water levels in the pumped well and any nearby observation wells could provide information on aquifer properties including transmissivity and storage coefficient. Any changes in these properties over time as a result of compaction, piping, or readjustment of compaction , piping, or readjustment of spoil material would be observed from periodic repetition of the aquifer tests.

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