CHANGES IN GROUND-WATER QUALITY RESULTING FROM SURFACE COAL MINING OF A SMALL WATERSHED IN JEFFERSON COUNTY, OHIO

By Janet Hren

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CONVERSION FACTORS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)

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ABSTRACT

Two samples were collected from each of six wells in a small watershed in Jefferson County, Ohio, in 1984. The watershed was mined and reclamation begun in 1980. Data collected from 1976 through 1982 indicate that ground-water quality was still changing at that time. The purpose of this study was to determine to what extent ground-water quality continued to change 4 years after mining.

The upper saturated zone was destroyed by mining and replaced by spoils material during reclamation. A new saturated zone then formed in the spoils material. The premining median concentrations of sulfate, manganese, and dissolved solids in the upper saturated zone were 84 milligrams per liter (mg/L), 30 micrograms per liter (µg/L), and 335 mg/L, respectively. The postmining median concentrations of these constituents in the upper-zone wells disturbed by mining were 360 mg/L, 595 µg/L, and 814 mg/L, respectively. Concentrations of these constituents were still increasing in 1984 in the upper saturated zone. In the area not disturbed by mining, concentrations have remained nearly at premining levels.

The premining median concentrations of sulfate, manganese, and dissolved solids in the middle saturated zone were 47 mg/L, 10 µg/L, and 405 mg/L, respectively. The postmining median concentrations of these constituents were 390 mg/L, 490 µg/L, and 959 mg/L, respectively. In the middle saturated zone, concentrations of these constituents also were still increasing in 1984, probably due to mixing with water of the upper saturated zone.

INTRODUCTION

In 1976 the U.S. Bureau of Mines sponsored a multi-agency study to assess the effects of surface coal mining on the hydrology of small watersheds in eastern Ohio (Hamon and others, 1977). The role of the U.S. Geological Survey was to (1) describe the ground-water hydrology of the watersheds, and (2) document ground-water quality and flow characteristics during premining and postmining periods. Watershed J11, in Jefferson County (fig. 1), was one of the areas studied. The J11 watershed was mined and reclamation begun in 1980. The geology, hydrology, and water quality before, during, and after mining were described by Razem (1984). At the end of the data-collection period (1976 through 1982) ground-water quality and water levels had not restabilized.

The purpose of this study is to resume the evaluation of the impact of surface coal mining and reclamation on the ground-water quality in the study watershed. Along with the data of Razem (1984), two additional samples collected from each of six wells and one sample from two seeps in 1984 were used to evaluate changes in the ground-water quality.

HYDROGEOLOGIC DESCRIPTION OF WATERSHED

Premining Conditions

The J11 watershed is in the unglaciated Appalachian Plateau physiographic province (Fenneman, 1938) in the eastern Ohio coal region. Before mining, the area was a 29-acre, primarily pasture watershed. It was drained by a continuous main stream having a well-developed channel and several intermittent tributaries with poorly developed channels. Flow to the stream was maintained by discharge from a saturated zone perched on a shaley clay bed underlying the Waynesburg No. 11 coal bed of the Pennsylvanian Monongahela Formation (fig. 2). A lower saturated zone was

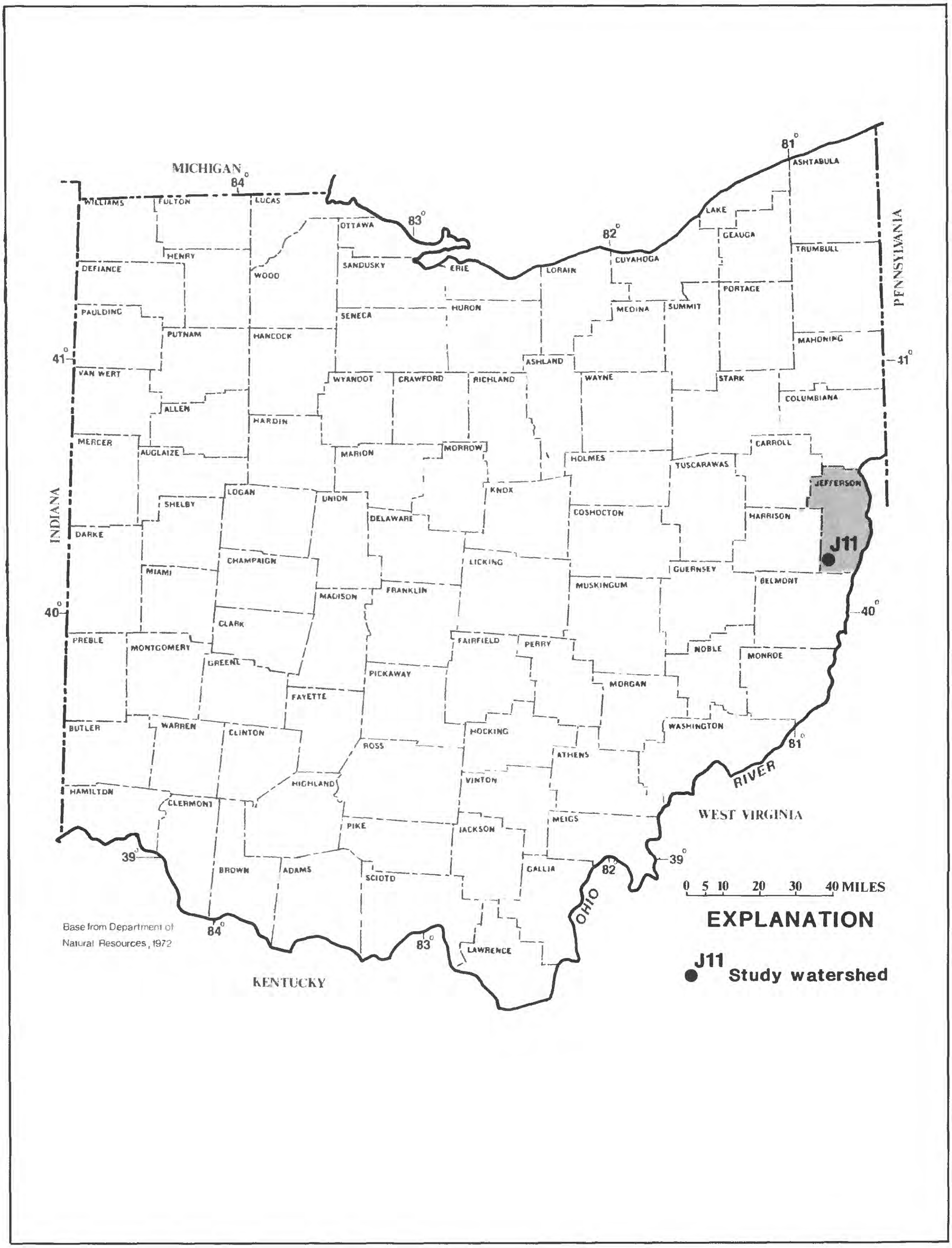
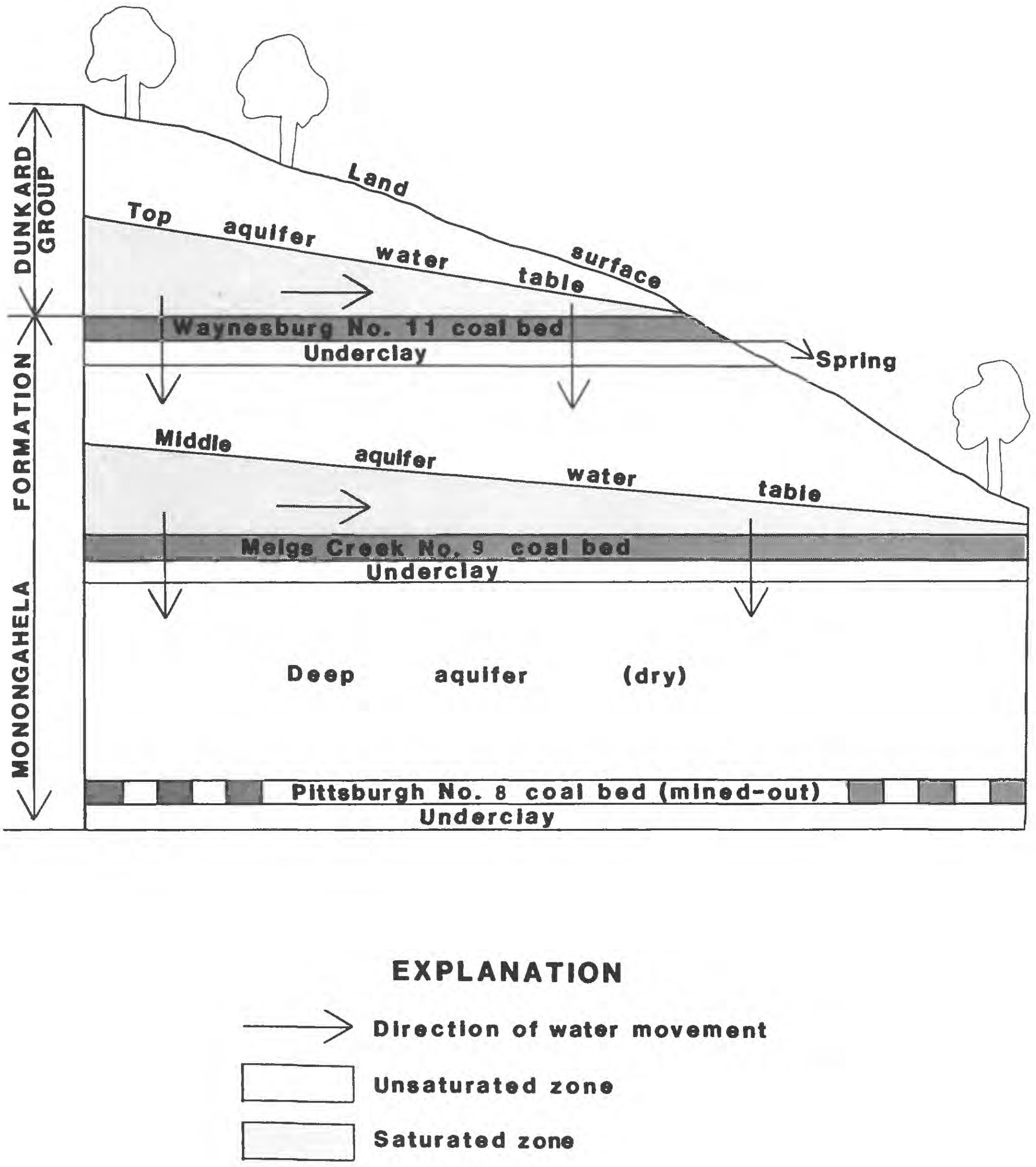


Figure 1.--Location of the study watershed.



From Razem (1984)

Figure 2.--Schematic section illustrating premining ground-water occurrence and flow at watershed J11.

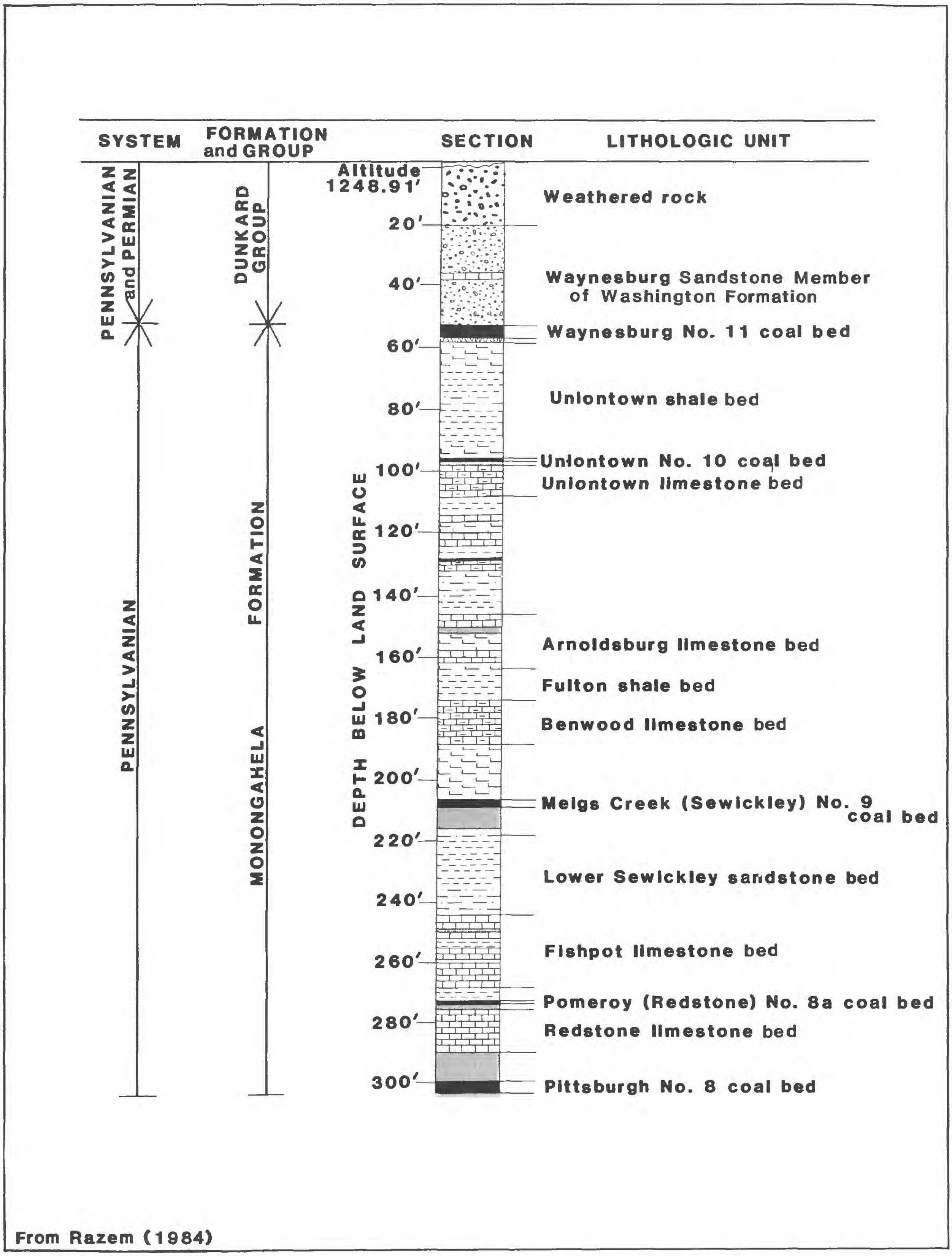
perched above an underclay beneath the Meigs Creek (Sewickley) No. 9 coal bed of the Monongahela Formation. A third, much deeper saturated zone perhaps occurred above a clay underlying the Pittsburgh No. 8 coal bed, but this coal has been mined by underground methods and the zone is now dry. Stratigraphy of the J11 watershed is shown in figure 3. Detailed description of the geology and soils is given by U.S. Bureau of Mines (1983) and Razem (1984).

Nine observation wells were installed in the watershed in April and May 1976. Four wells penetrated into the top saturated zone, three into the middle zone, and two into the deepest zone (fig. 4). Each well was cased such that the open interval spanned only one of the three zones.

In the well-numbering system, the prefix "W" refers to premining, the first number is the well-identification number, and the second number refers to the zone of completion: 1 = top, 2 = middle, and 3 = deep. The prefix "P" in the well name refers to postmining.

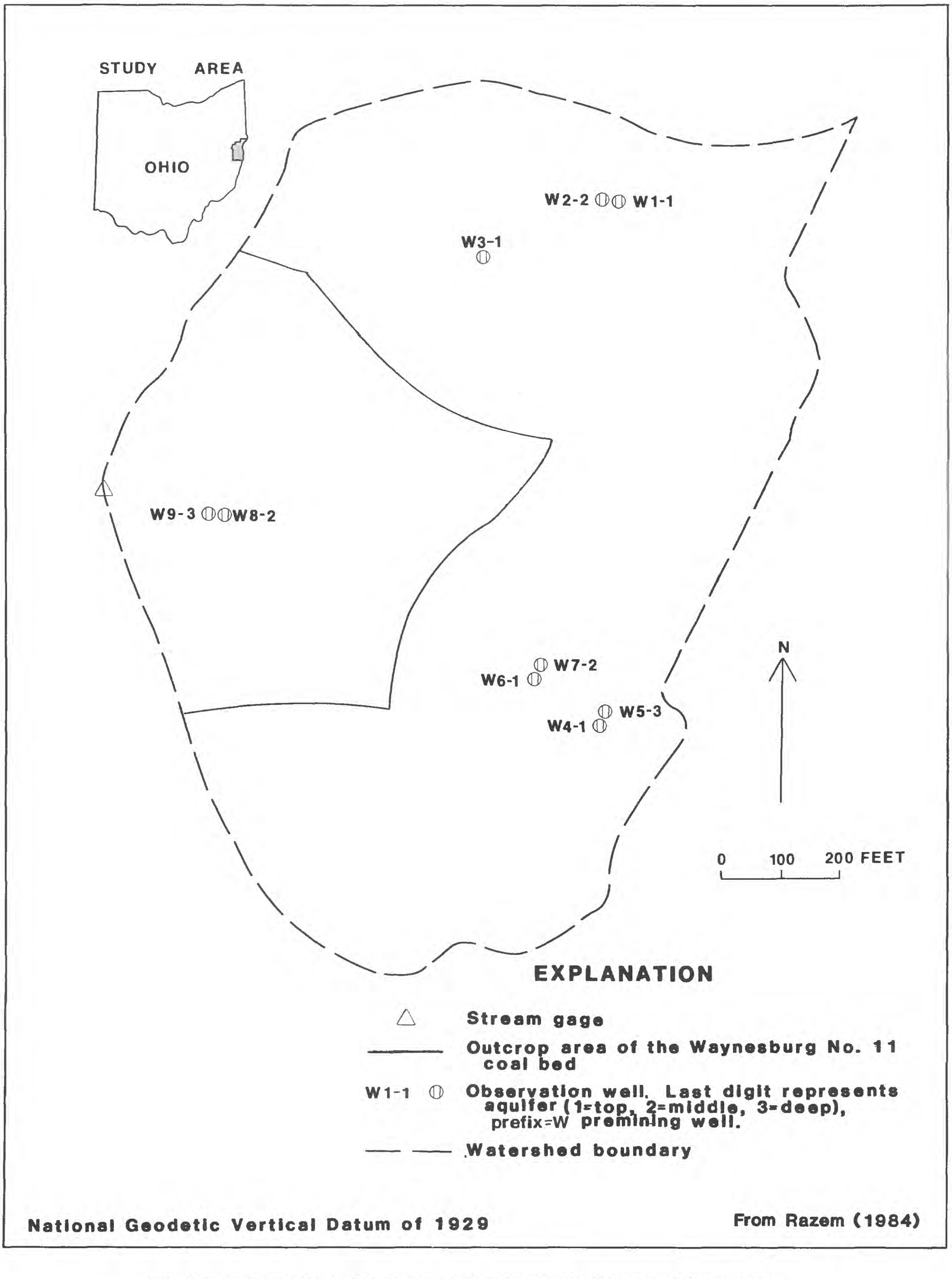
Postmining Conditions

The J11 watershed was mined from May through October 1980. The upper saturated zone was not disturbed until the end of July. Mining and reclamation involved stripping the overburden, removing the Waynesburg No. 11 coal bed, and replacing the overburden to approximate premining configuration. Topsoil was spread, diversion terraces were built for erosion-control purposes, and seed, fertilizer, and mulch applied. Modifications were made to the erosion-control systems during the 2 years following mining. Final reclamation was completed with the removal of the diversion terraces in June 1982.



From Razem (1984)

Figure 3.--Stratigraphic column for watershed J11.



National Geodetic Vertical Datum of 1929

From Razem (1984)

Figure 4.--Premining locations of observation wells and coal outcrop.

Mining and reclamation affected 94 percent of the original watershed. The final drainage area is 32 acres. The top saturated zone was nearly all destroyed during mining. Wells W1-1, W2-2, and W3-1, removed during mining, were redrilled in the same locations after the area was regraded. An additional well, P10-1, also was installed in the spoils material (fig. 5). Wells W4-1 and W6-1, located behind the highwall, were not destroyed by mining, but water levels in these wells dropped immediately after mining began (Razem, 1984).

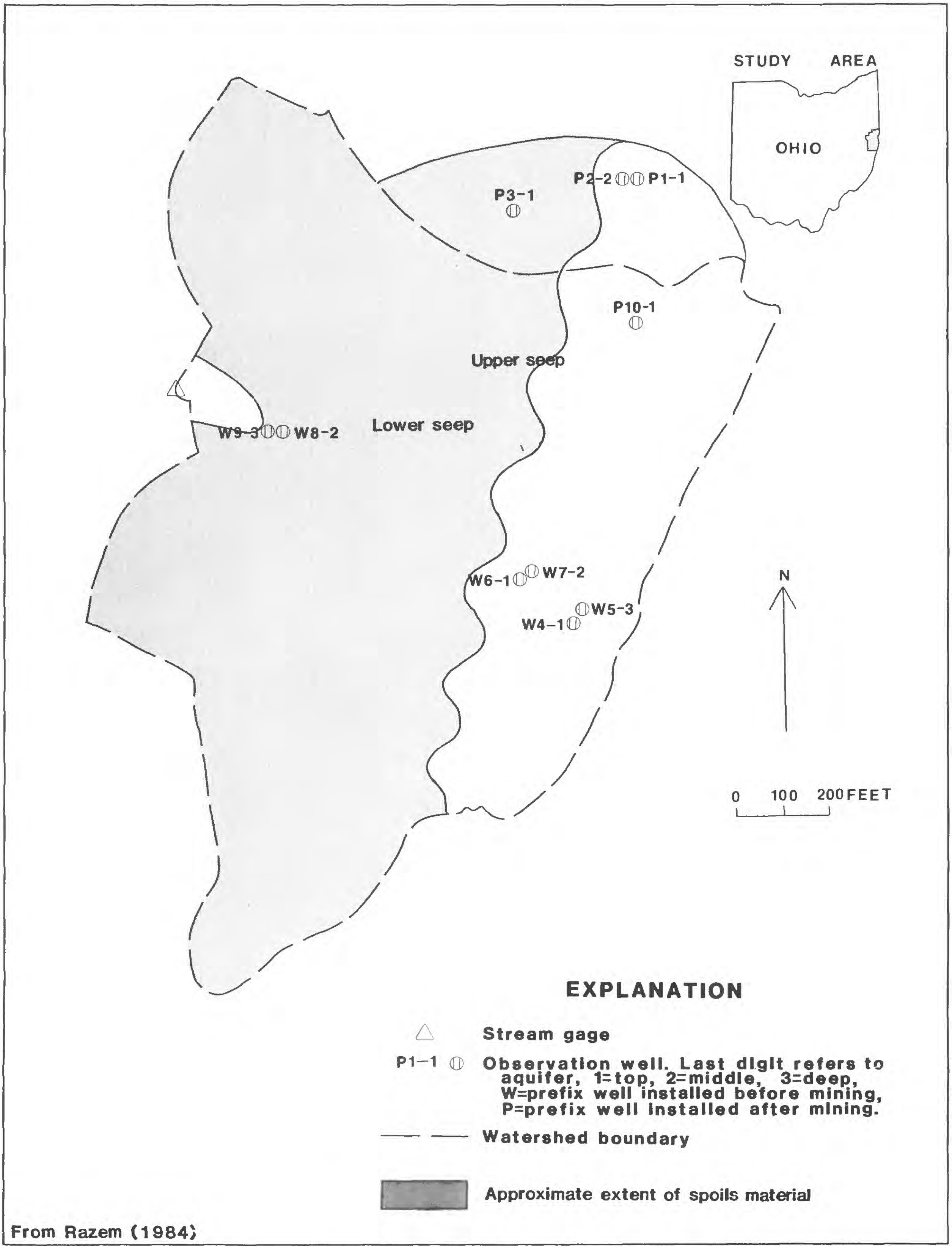
Base flow to the stream stopped entirely. The middle saturated zone below the Waynesburg No. 11 coal bed was undisturbed. However, some areas downslope (well W8-2) from the mined coal outcrop were covered with a layer of spoils material.

GROUND-WATER QUALITY

Premining Conditions

Ground-water samples were collected from wells in the upper and middle saturated zones from 1976 until mining began in July 1980. Wells W5-3 and W9-3, which penetrate into the deep zone, were dry during the entire study. Sample collection and analytical procedures are described by Razem (1984).

A summary of the premining water-quality data is shown in tables 1 through 6. Differences in premining concentrations of sulfate, manganese, and dissolved solids in the upper saturated zone are shown in figures 6 through 8, respectively, and in figures 9 through 11, respectively, for the middle saturated zone. Premining differences in the ground-water quality were a result of local geology, flow paths, and seasonal variations in water quality. In the upper saturated zone the water types were calcium bicarbonate and calcium sulfate. The middle saturated zone contained water of calcium bicarbonate and sodium bicarbonate types.



From Razem (1984)

Figure 5.--Postreclamation locations of observation wells and seeps.

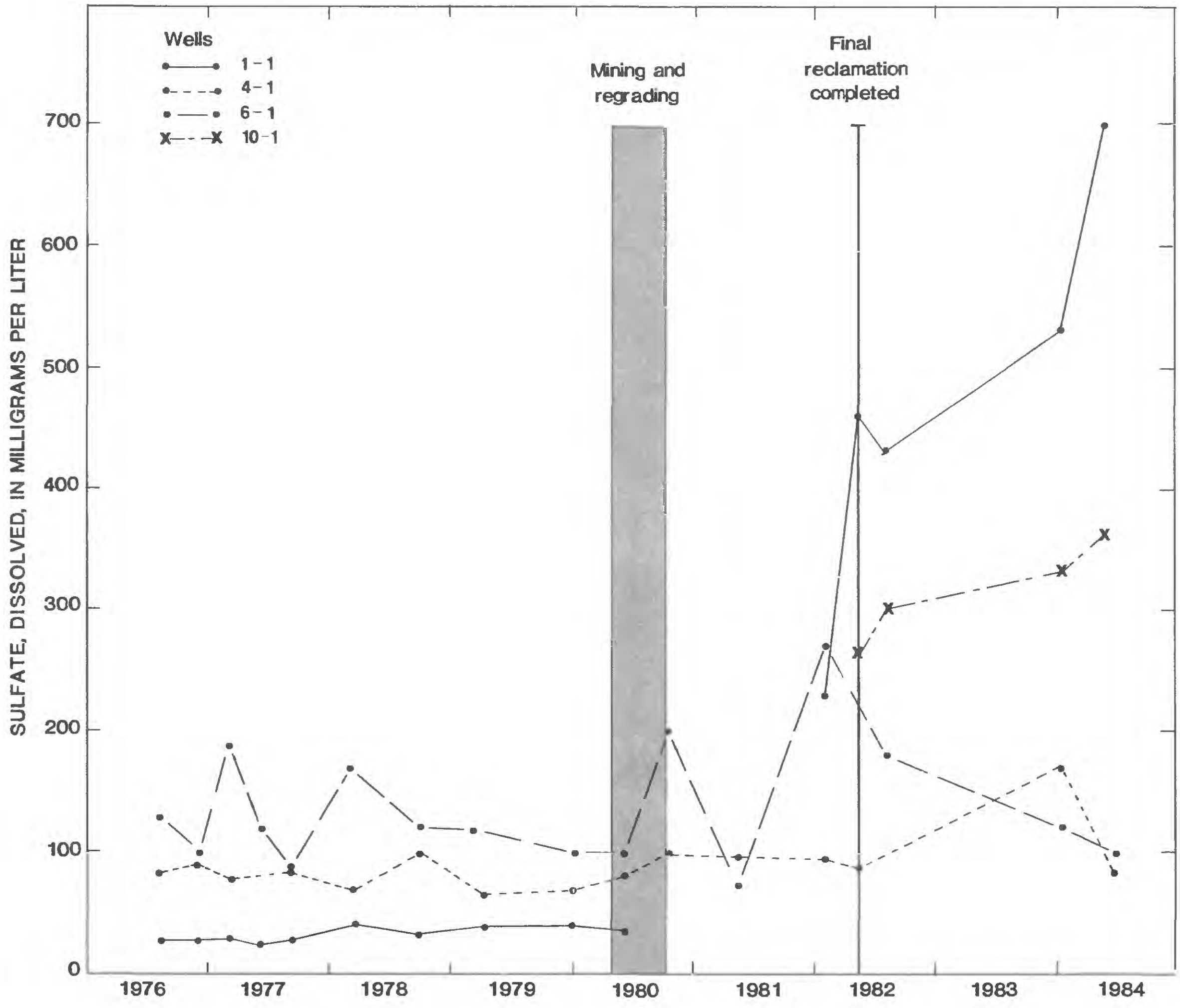


Figure 6.—Variation in concentrations of dissolved sulfate in the top-aquifer wells.

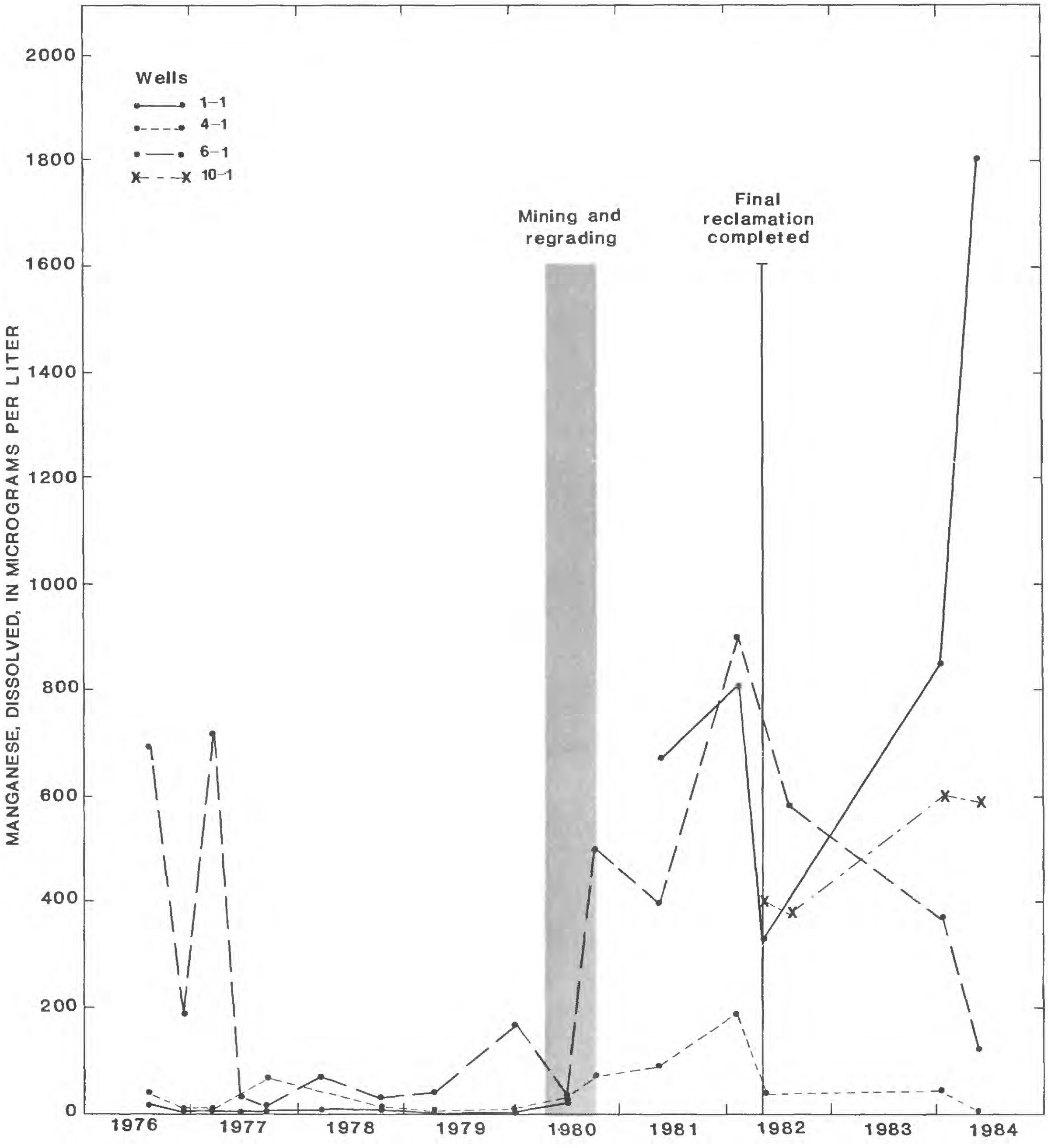


Figure 7.—Variation in concentrations of dissolved manganese in the top-aquifer wells.

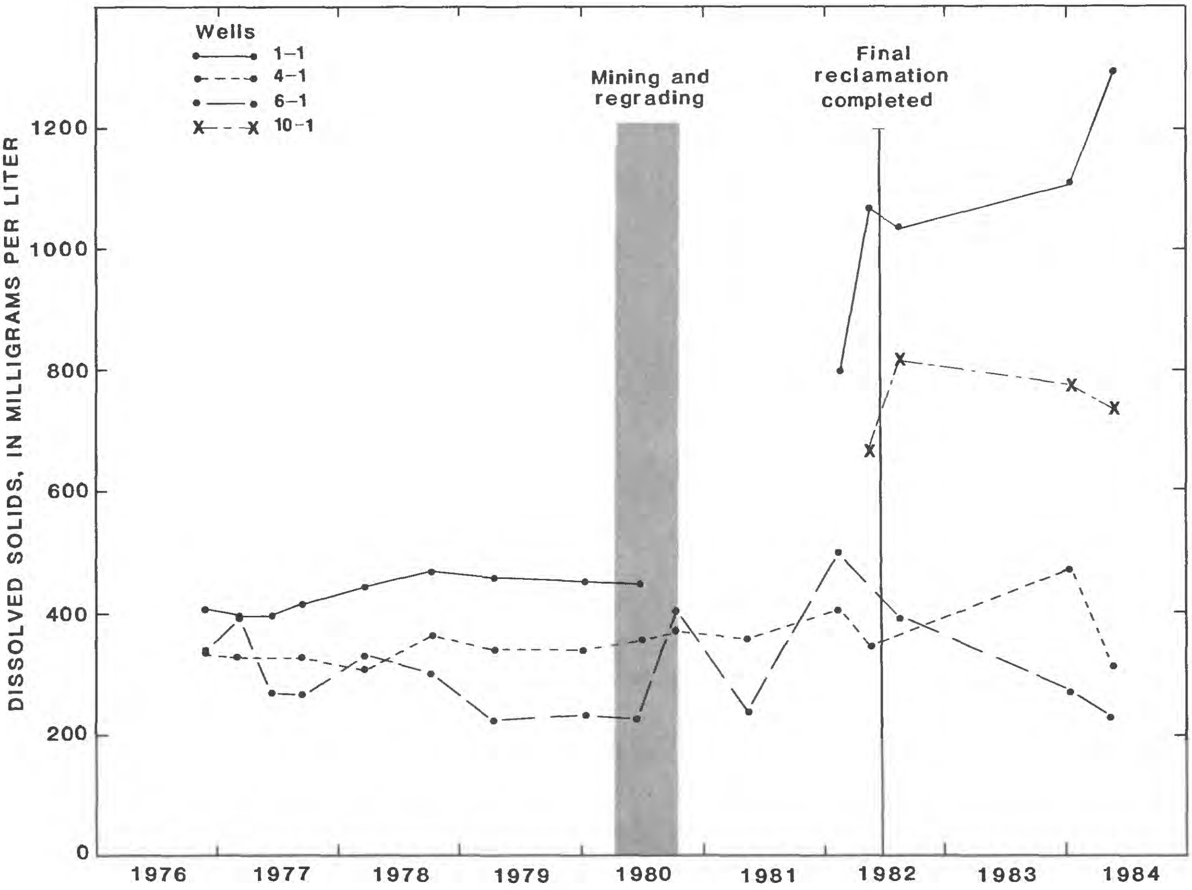


Figure 8.--Variation in concentrations of dissolved solids in the top-aquifer wells.

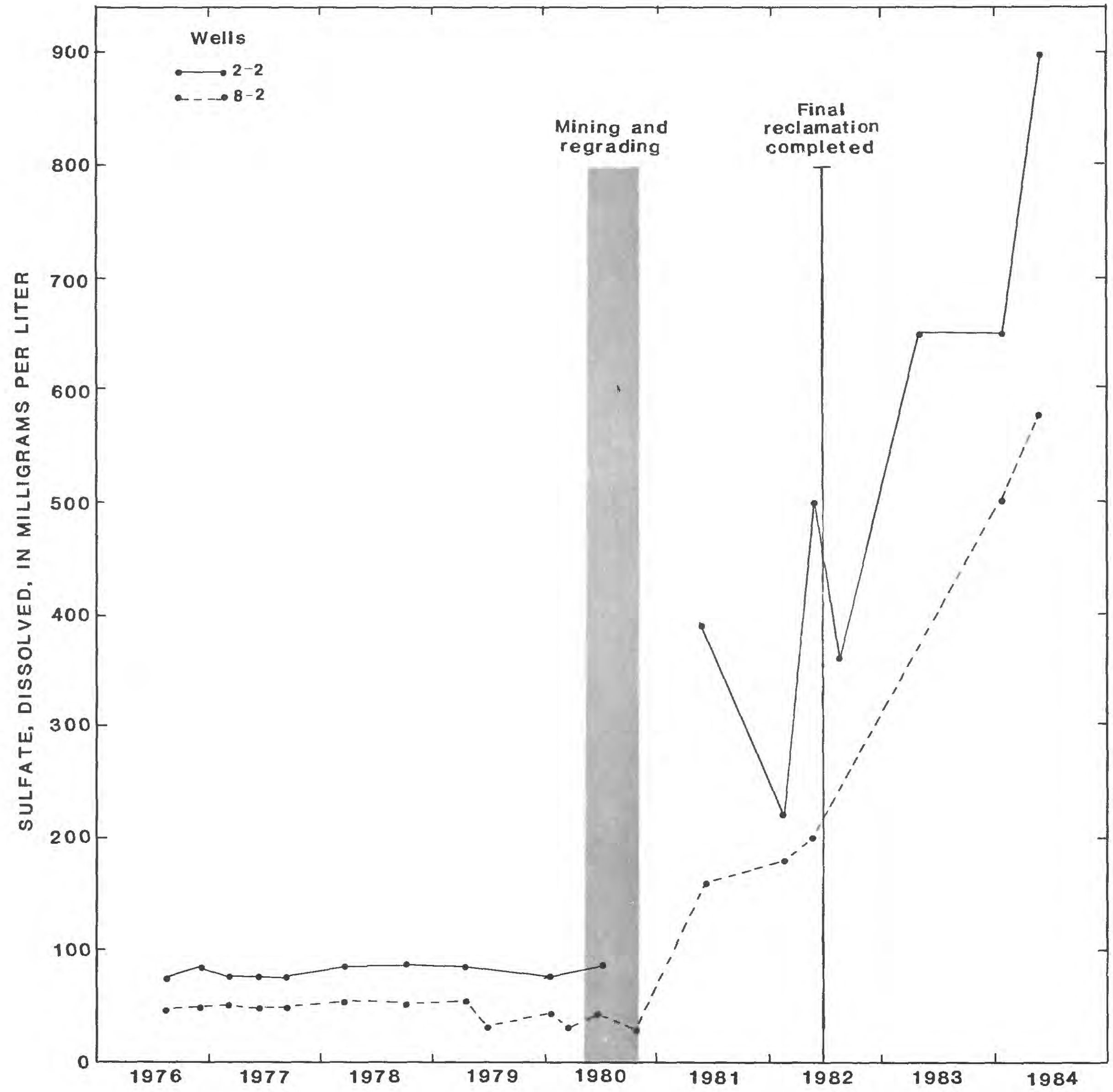


Figure 9.--Variation in concentrations of dissolved sulfate in the middle-aquifer wells.

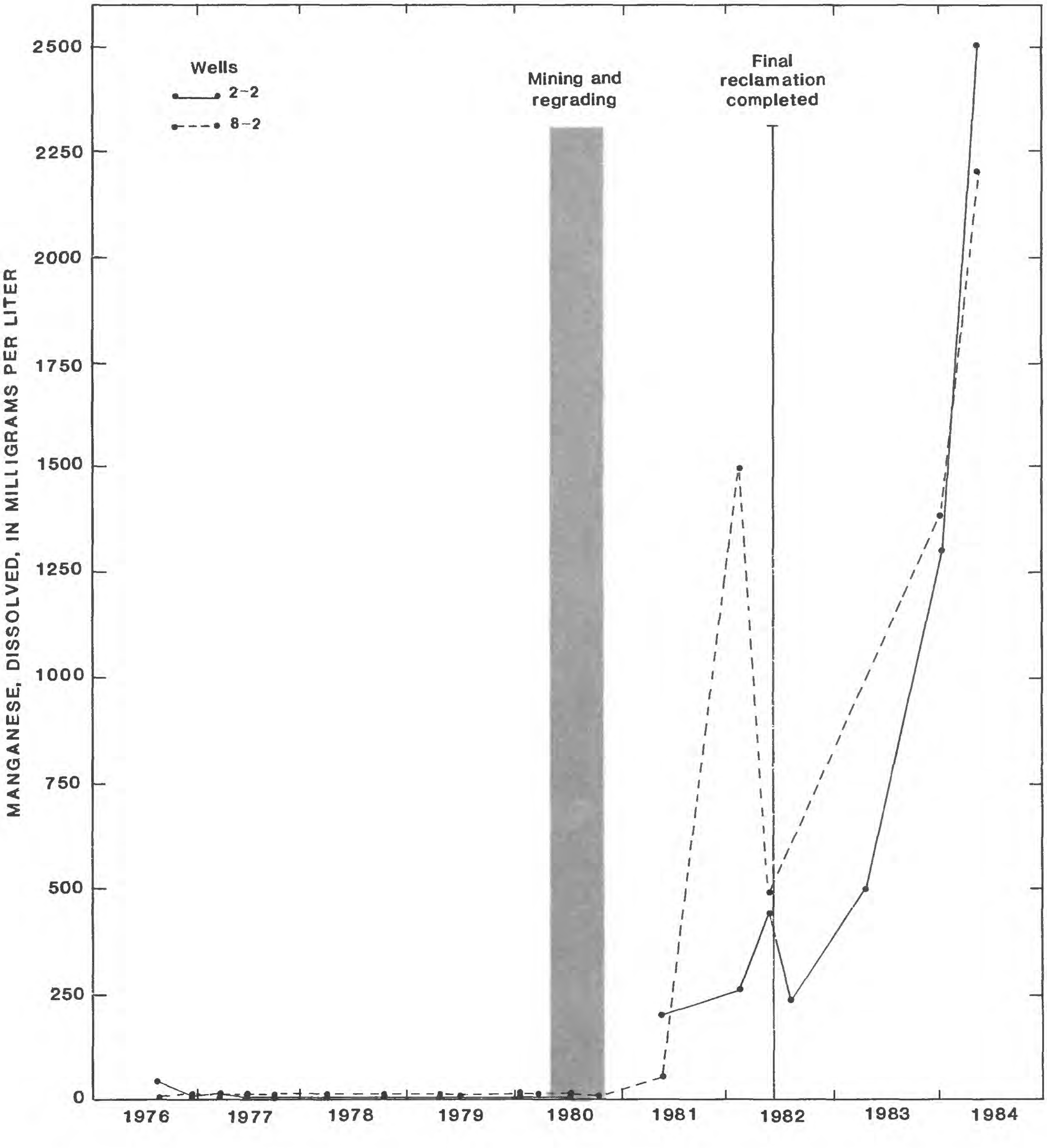


Figure 10.--Variation in concentrations of dissolved manganese in the middle-aquifer wells.

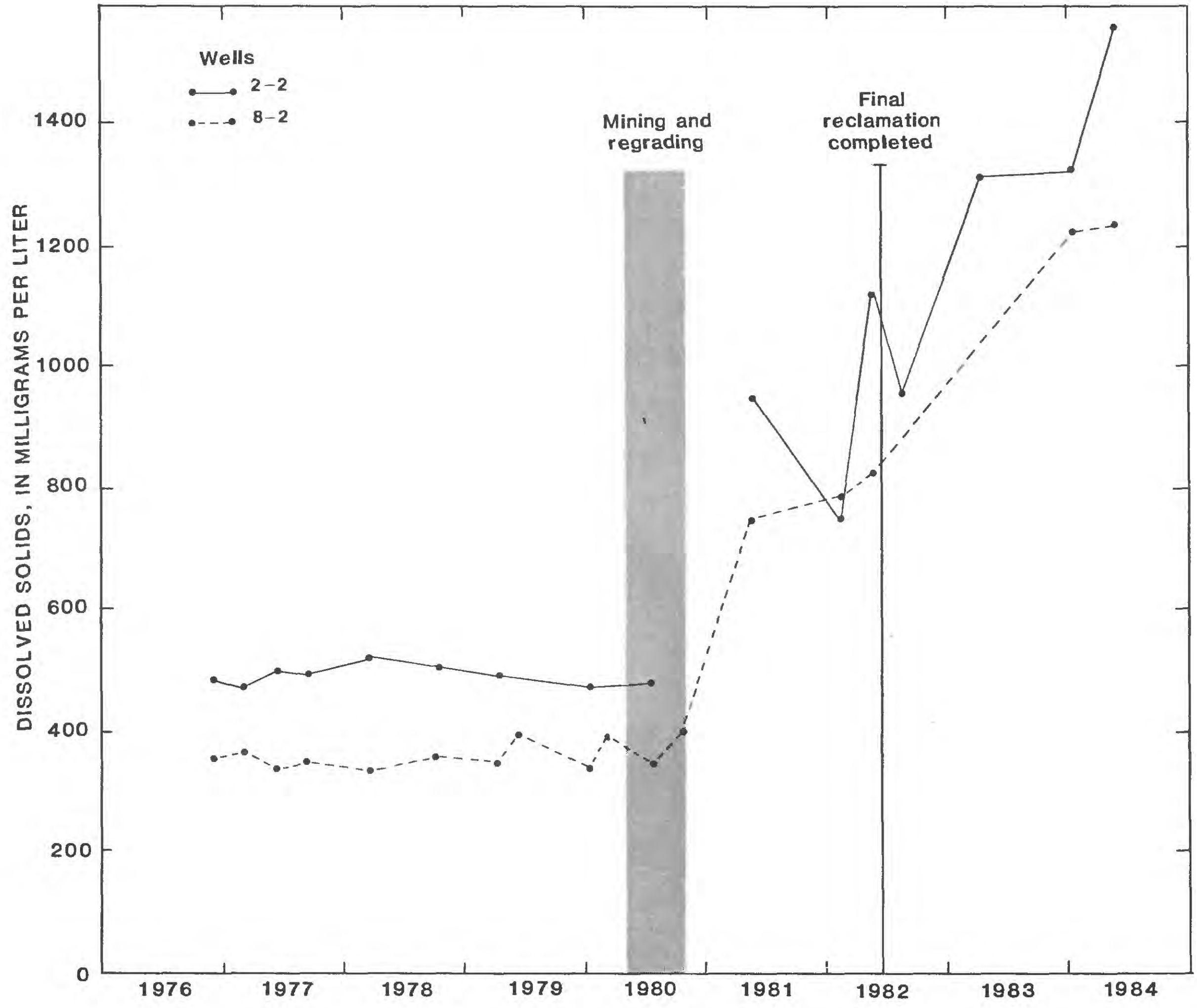


Figure 11.--Variation in concentrations of dissolved solids in the middle-aquifer wells.

Postmining Conditions

Periodic sampling of the wells continued through the active mining and reclamation phase until August 1982. Well P2-2 was sampled again in 1983, and all wells except W7-2 and P3-1 were sampled twice in 1984. A 100-foot drop in the water level in well W7-2 made it impossible to sample with the methods used previously; well P3-1 was either dry or did not contain enough water to yield a sample.

Postmining water-quality data are shown in tables 1 through 6. Razem (1984) reported that the postmining water type in the upper zone was calcium sulfate except at well W4-1, which was calcium bicarbonate. Median concentrations of all constituents and properties, except pH, increased in the upper zone disturbed by mining (wells P1-1 and P10-1).

The increases of median concentrations of constituents in the top aquifer (spoils) result from more surface area along mineral-water contacts, which allows for more mineral dissolution. Dissolution of limestones and carbonate cements caused the rise in calcium, magnesium, and bicarbonate. Manganese is derived from oxides and hydroxides in the soil and rock; sulfates and iron are derived from reduced minerals, particularly pyrite. The introduction of oxygen and its contact with reduced minerals (pyrite), will cause dissolution of these minerals to yield iron, sulfates, and acidity.

Median concentrations of chloride, sulfate, iron, and manganese more than doubled over the premining median concentrations. The only median concentration that exceeded U.S. Environmental Protection Agency (1976) limits for domestic water supplies was that for manganese, but concentrations of sulfate and iron exceeded these standards in at least one sample. Variations in sulfate, manganese, and dissolved solids at the upper-zone wells are shown in figures 5 through 7, respectively. Samples taken in 1984 indicate that these concentrations still were increasing in the upper saturated zone in the area destroyed by mining (wells P1-1 and P10-1). Concentrations in wells not disturbed by mining (W4-1 and W6-1) have remained at premining levels.

In well P1-1 calcium concentrations increased but alkalinity (as calcium carbonate) showed only a short-term increase (fig. 12). This indicates that the excess carbonate is neutralizing most of the acid produced, since sulfate concentrations increased significantly (fig. 6), but the pH decreased only slightly.

Chloride concentrations also increased dramatically in well P1-1, but as indicated in figure 13, the sodium to chloride ratio was approximately 0.4. This indicates that sodium and chloride concentrations increased, but chloride increased at a greater rate than sodium. The source of the excess chloride is possibly calcium chloride or magnesium chloride salts derived from the mine-spoil materials.

Water in the middle saturated zone is a calcium bicarbonate type (well W8-2) and a calcium sulfate type (well P2-2). Median concentrations of all constituents and properties, except pH, total organic carbon, and sodium, increased in the middle zone due to mixing with waters of the upper zone. Water levels in well P2-2 rose approximately 20 feet to the same level as in well P1-1; this, along with similarities in water quality, indicates that there is now only one saturated zone in this area. Razem (1984) believed that the underclay was removed or pierced during the mining, allowing the two zones to mix. In the middle zone, median concentrations of specific conductance, calcium, magnesium, chloride, sulfate, iron, manganese, and zinc more than doubled over premining median concentrations. The median concentrations of manganese and sulfate exceeded U.S. Environmental Protection Agency (1976) limits for domestic water supplies, while concentrations of iron exceeded the standard on at least one occasion.

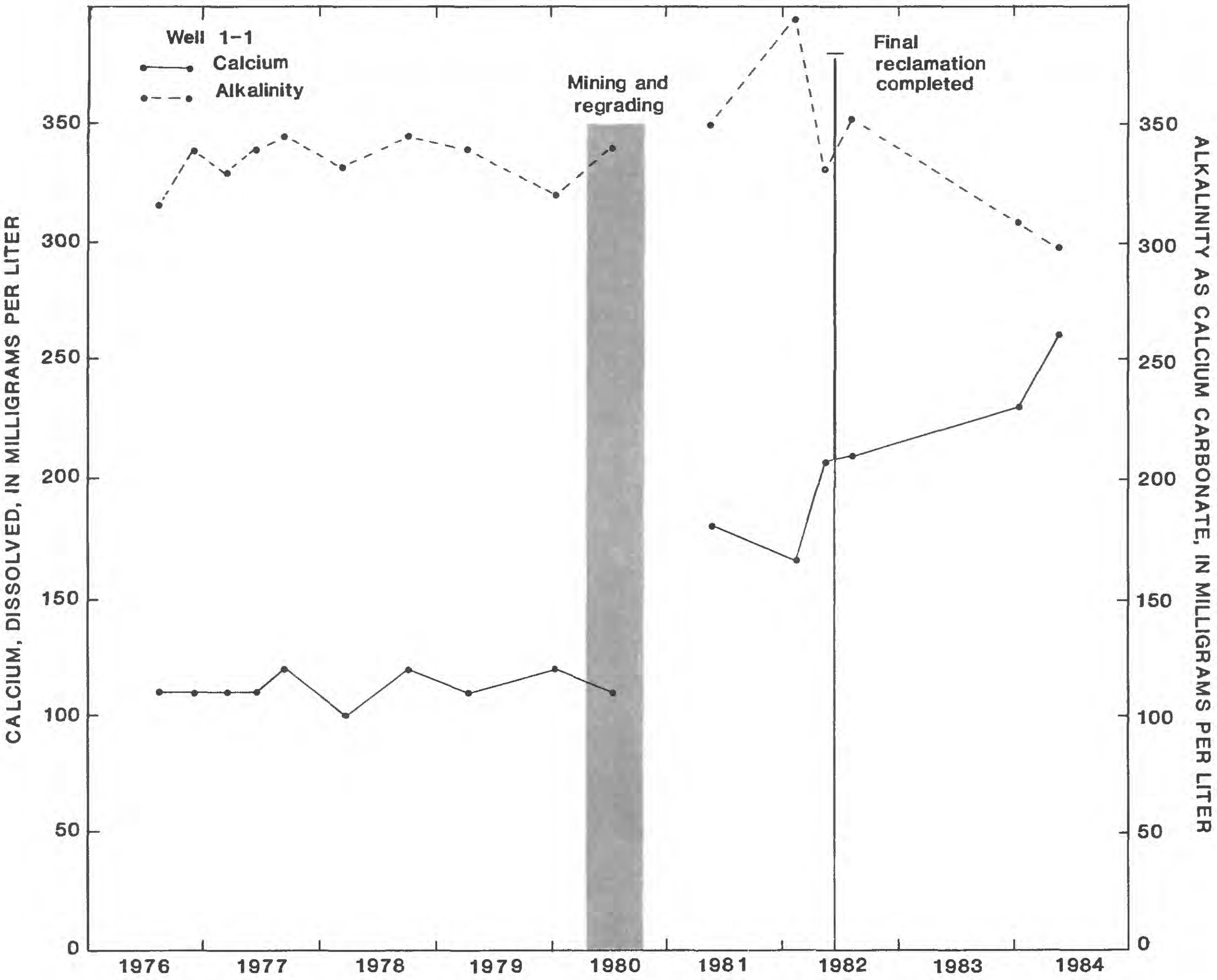


Figure 12.-- Variation in concentration of dissolved calcium and alkalinity in well 1-1.

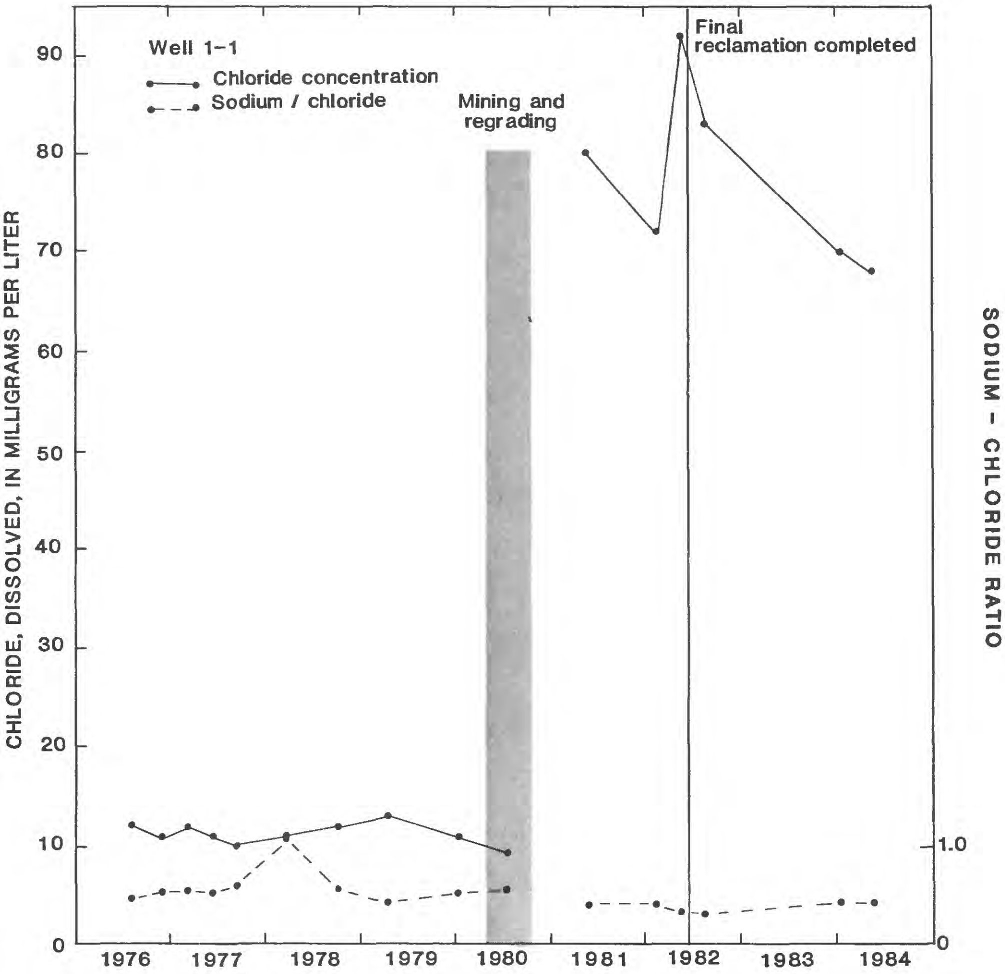


Figure 13.— Variation in concentrations of dissolved chloride and in the sodium-to-chloride ratio in well 1-1.

Figures 8 through 10 show the variations in concentrations of sulfate, manganese, and dissolved solids, respectively, at middle-zone wells P2-2 and W8-2. Chloride and calcium concentrations at well P2-2 follow a pattern similar to well P1-1, again indicating that the two zones are connected (figs. 14 and 15). Concentrations of most constituents also increased at well W8-2, but at a slower rate than well P2-2. This is due to the time required for water to travel from the area around well P2-2 to well W8-2.

In May 1984, two seeps were found saturating the surface and flowing overland to the stream channel. The upper seep was located at about the elevation of the now-removed Waynesburg No. 11 coal bed, and the lower seep was a short distance above the toe of the graded spoil (fig. 5). The seeps had an oily bacteria-related film on the water surface and iron hydroxide deposits on the ground. Vegetation in the area of the seeps had been killed. Water from both seeps was a calcium sulfate type and high in manganese. Concentrations of selected constituents are shown in table 7. Generally, concentrations of most constituents were much higher in the seeps than in the wells sampled, probably because the seeps are downgradient in the flow system.

A continued evaluation of the J11 watershed is currently being conducted by the U.S. Geological Survey (R. L. Jones, U.S. Geological Survey, oral commun., 1986). As part of this project, ground-water quality data will be collected semiannually from four wells in the watershed from 1986 to 1989. This project will provide the data necessary for a better understanding of the long-term impacts of surface mining on ground-water quality.

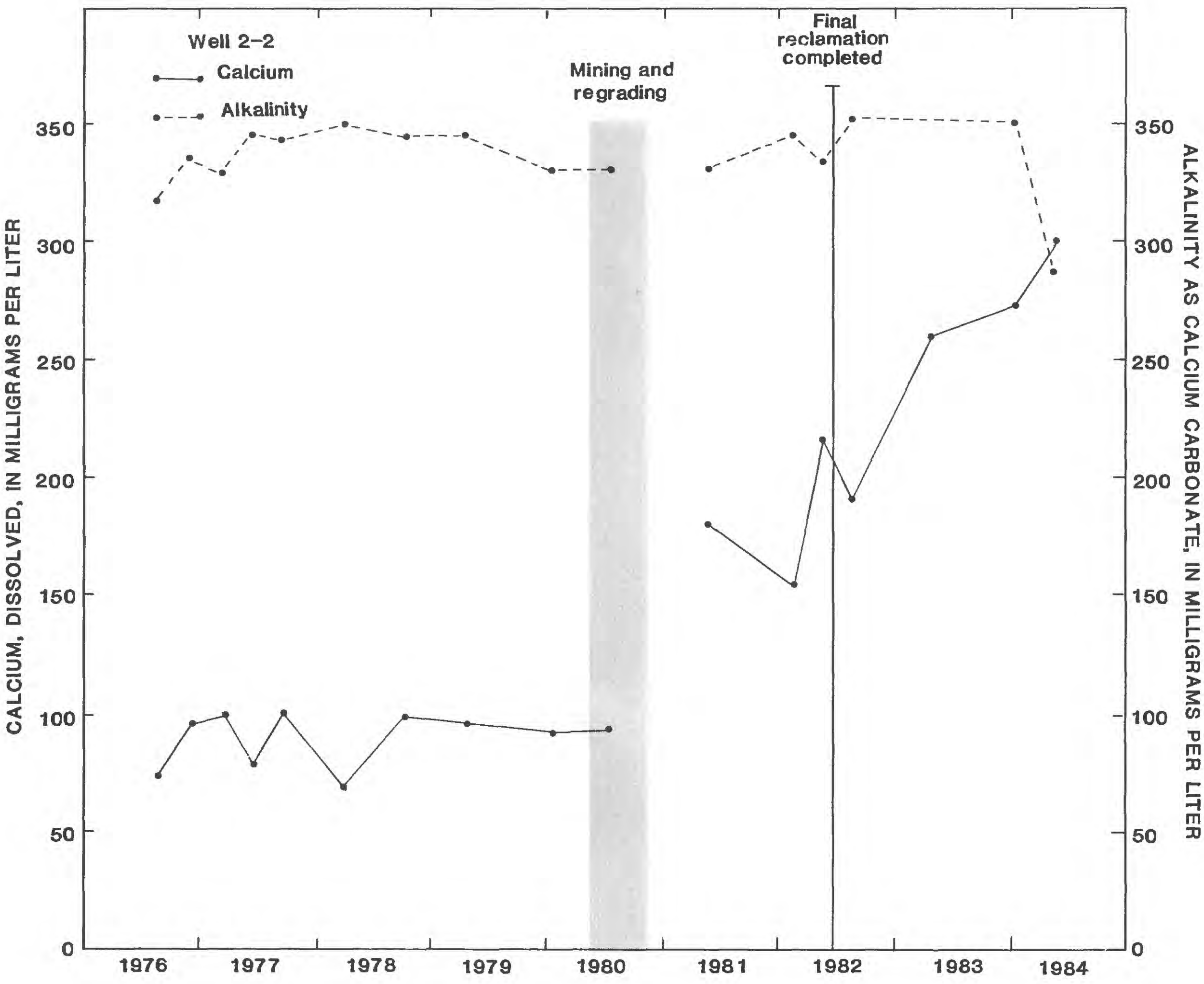


Figure 14.— Variation in concentrations of dissolved calcium and alkalinity in well 2-2.

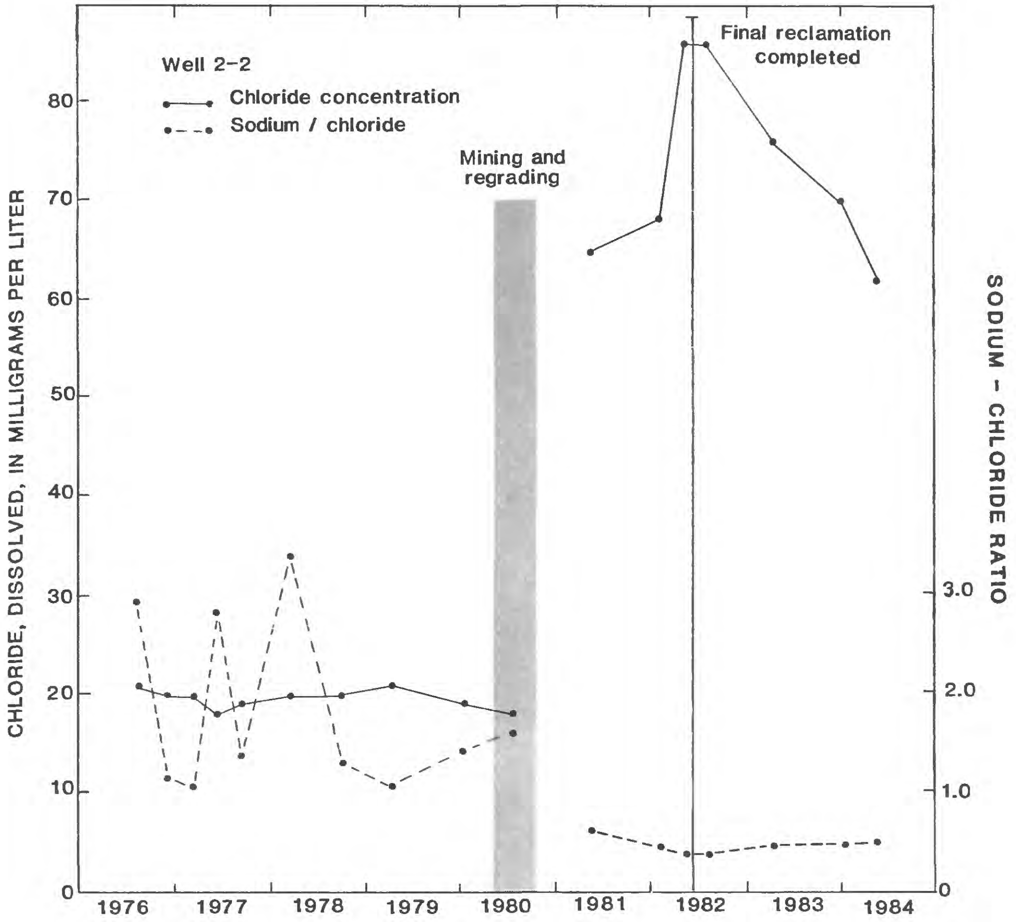


Figure 15.— Variation in concentrations of dissolved chloride and in the sodium-to-chloride ratio in well 2-2.

Results indicate that the ground water at watershed J11 was still becoming more mineralized in the upper and middle saturated zones through 1984. This results from the mining operation, which broke the bedrock and exposed materials susceptible to solution. Long-term impacts of surface mining on ground-water quality are not known. Some key hydrologic parameters necessary to evaluate long-term impacts are incompletely understood and include:

1. Time required for reestablishment of a dynamic equilibrium,
2. Changes in ground-water quality, and
3. Transient versus permanent changes in ground-water quality and quantity conditions.

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SUMMARY

The J11 watershed was mined and reclamation begun in 1980. Water-quality data were obtained on nine wells from 1976 through 1982 (Razem, 1984). At the end of that time, ground-water quality and levels had not equilibrated following mining and reclamation. Two additional samples were collected from each of six postmining wells in 1984. These data along with those of Razem (1984) were used to determine to what extent ground-water quality was still changing 4 years after mining.

The upper aquifer was destroyed by mining and replaced by spoils during reclamation. A new saturated zone then formed in the spoils material. The premining median concentrations of sulfate, manganese, and dissolved solids in the upper saturated zone were 84 mg/L, 30 µg/L, and 335 mg/L, respectively. The postmining median concentrations of these constituents in the upper-zone wells disturbed by mining (wells P1-1 and P10-1) were 360 mg/L, 595 µg/L, and 814 mg/L, respectively. Concentrations of these constituents were still increasing in 1984 in the upper saturated zone disturbed by mining. In the area not disturbed by mining these concentrations have remained at nearly premining levels.

The premining median concentrations of sulfate, manganese, and dissolved solids in the middle saturated zone were 47 mg/L, 10 µg/L, and 405 mg/L, respectively. The postmining median concentrations of these constituents (wells 8-2 and 2-2) were 390 mg/L, 490 µg/L, and 959 mg/L, respectively. In the middle saturated zone, concentrations of these constituents also were still increasing in 1984, probably due to mixing with water of the upper zone.

DATA TABLES

Table 1.--Chemical analyses of ground water collected from well

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens

Constituent or property	Sampling date, premining period						
	1976		1977			1978	
	8/17	12/2	3/9	6/14	9/20	3/29	10/4
Temperature (°C)	14.0	8.0	12.5	13.0	14.0	11.5	12.5
Specific conductance (µS/cm)	830	720	725	730	740	750	760
Oxygen, dissolved (mg/L)	--	--	--	--	--	--	--
pH	7.6	7.3	7.3	7.3	7.3	7.3	7.2
Alkalinity (mg/L as $CaCO_3$)	316	339	329	339	346	332	344
Bicarbonate (mg/L)	385	413	401	413	422	405	420
Total organic carbon (mg/L)	4.5	2.9	7.5	5.4	7.8	--	--
Phosphorus, dissolved (mg/L)	--	--	--	--	--	<.01	<.01
Calcium, dissolved (mg/L)	110	110	110	110	120	99	120
Magnesium, dissolved (mg/L)	31	31	30	29	31	27	31
Sodium, dissolved (mg/L)	5.8	5.7	6.3	5.6	6.0	12	6.7
Potassium, dissolved (mg/L)	1.7	1.8	1.7	1.6	1.7	1.7	1.6
Chloride, dissolved (mg/L)	12	11	12	11	10	11	12
Sulfate, dissolved (mg/L)	28	28	29	24	28	40	32
Fluoride, dissolved (mg/L)	.1	.1	.1	.1	.2	.1	.1
Silica, dissolved (mg/L)	--	10	12	11	11	12	11
Iron, dissolved (µg/L)	<10	40	30	<10	10	60	<10
Manganese, dissolved (µg/L)	20	<10	<10	<10	<10	1400	<10
Strontium, dissolved (µg/L)	--	--	--	--	--	--	470
Zinc, dissolved (µg/L)	--	--	--	--	--	--	30
Aluminum, dissolved (µg/L)	--	--	--	--	--	--	20
Hydrogen sulfide, dissolved (mg/L)	.0	.0	.2	.0	.0	.0	.0
Dissolved solids (mg/L)	--	402	399	396	416	445	471

Wl-1 (premining) and Pl-1 (postmining), August 1976 through May 1984

per centimeter at 25° Celsius. Dash indicates data are not available]

Sampling date, postmining period								
1979	1980		1981	1982			1984	
4/17	1/16	7/8	5/27	2/17	5/19	8/3	1/17	5/31
11.0	9.5	14.5	17.0	11.0	14.5	14.0	11.0	14.0
810	730	770	1310	1210	1500	1400	1500	1760
--	--	--	--	--	--	--	2.7	.0
7.5	6.5	7.0	6.9	6.8	7.0	7.0	6.8	6.8
340	320	340	349	394	328	353	308	298
414	392	417	426	480	400	430	376	363
--	--	--	8.8	26	1.3	1.8	1.3	.2
.01	.01	.01	<.01	.04	<.01	--	.03	<.01
110	120	110	180	165	208	210	230	260
27	28	27	57	49	61	57	63	74
5.4	5.7	5.4	32	30	31	28	30	29
1.3	1.3	1.4	--	3.4	3.6	3.4	3.4	3.5
13	11	9.5	80	73	92	87	70	68
38	38	33	--	230	460	430	530	700
.1	.1	.1	.1	.2	.1	.2	.1	.2
11	11	10	--	11	11	11	12	12
50	10	20	--	11	200	67	59	46
3	3	20	670	810	330	410	850	2000
410	440	390	930	760	1000	970	830	930
<20	30	40	--	--	--	--	46	9
20	0	20	--	--	--	--	40	<100
.0	.0	.0	.0	.0	.0	.0	.0	.0
459	452	447	--	801	1070	1040	1110	1290

Table 2.--Chemical analyses of ground water

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm,

Constituent or property	Sampling date, premining period						
	1976		1977		1978		1979
	8/17	12/1	3/8	9/20	3/28	10/4	4/17
Temperature (°C)----	13.0	4.0	12.0	14.0	13.0	12.0	12.0
Specific conductance (µS/cm)-----------	550	530	525	560	525	600	622
Oxygen, dissolved (mg/L)------------	--	--	--	--	--	--	--
pH------------------	7.4	7.1	6.8	7.0	7.0	7.2	7.6
Alkalinity (mg/L as $CaCO_3$)------------	171	180	157	176	118	181	148
Bicarbonate (mg/L)--	208	219	192	214	144	221	180
Total organic carbon (mg/L)------------	4.5	4.6	8.1	7.6	--	--	--
Phosphorus, dissolved (mg/L)-----	--	--	--	--	<.01	.02	.01
Calcium, dissolved (mg/L)------------	80	77	81	80	68	88	84
Magnesium, dissolved (mg/L)------------	16	17	16	16	13	17	15
Sodium, dissolved (mg/L)------------	11	10	12	10	11	11	11
Potassium, dissolved (mg/L)------------	1.5	1.5	1.6	1.7	1.4	2.4	1.3
Chloride, dissolved (mg/L)------------	21	18	33	17	43	26	48
Sulfate, dissolved (mg/L)------------	83	89	78	84	68	100	65
Fluoride, dissolved (mg/L)------------	.1	.1	.1	.1	.1	.1	.1
Silica, dissolved (mg/L)------------	--	14	15	15	15	13	13
Iron, dissolved (µg/L)------------	<10	60	<10	80	90	740	<10
Manganese, dissolved (µg/L)------------	40	<10	<10	70	<10	<10	3
Strontium, dissolved (µg/L)------------	--	--	--	--	--	420	230
Zinc, dissolved (µg/L)------------	--	--	--	--	--	30	20
Aluminum, dissolved (µg/L)------------	--	--	--	--	--	10	20
Hydrogen sulfide, dissolved (mg/L)--	--	--	--	--	--	--	--
Dissolved solids (mg/L)------------	--	335	331	329	308	369	339

collected from well W4-1, August 1976 through May 1984

microsiemens per centimeter at 25° Celsius. Dash indicates data are not available]

Sampling date, postmining period							
1980		1980	1981	1982		1984	
1/15	7/9	10/17	5/28	2/3	5/19	1/17	5/31
10.0	14.5	14.5	12.5	10.0	14.5	10.5	11.9
675	550	644	624	697	575	550	525
--	--	--	--	.0	--	--	--
6.6	6.7	6.7	6.7	6.6	7.1	7.1	7.1
170	220	156	168	195	197	220	180
206	264	190	205	238	240	268	219
--	--	2.2	1.2	9.9	1.2	1.4	.8
.00	.00	.01	<.01	6.8	.14	.01	<.01
85	90	84	80	79	78	110	75
15	16	16	15	18	15	22	15
12	9.4	13	12	15	9.8	13	7
1.3	1.6	1.5	1.5	3.6	1.7	1.7	1.7
38	15	41	37	44	21	22	19
67	79	98	95	94	84	170	80
.1	.1	.0	.1	<.1	.1	.3	.1
11	14	14	14	16	13	12	14
20	70	730	80	4300	2500	390	26
4	30	70	90	190	39	46	7
320	280	330	250	310	270	380	250
60	30	30	--	--	--	110	38
10	10	20	--	--	--	80	100
--	--	--	--	--	--	.0	--
348	358	363	356	405	345	471	309

Table 3.--Chemical analyses of ground water collected

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens

Constituent or property	Sampling date, premining period						
	1976		1977			1978	
	8/17	12/2	3/9	6/14	9/20	3/28	10/4
Temperature (°C)	11.0	5.5	11.0	11.5	13.0	14.5	12.0
Specific conductance (µS/cm)	480	555	595	435	450	520	475
Oxygen, dissolved (mg/L)	--	--	--	--	--	--	--
pH	7.7	7.2	6.9	7.2	7.3	6.8	7.5
Alkalinity (mg/L as $CaCO_3$)	69	101	84	69	105	56	98
Bicarbonate (mg/L)	84	123	102	84	128	68	120
Total organic carbon (mg/L)	3.0	4.2	7.3	6.1	8.1	--	--
Phosphorus, dissolved (mg/L)	--	--	--	--	--	<.01	<.01
Calcium, dissolved (mg/L)	69	81	90	59	65	73	68
Magnesium, dissolved (mg/L)	9.3	12	16	11	9.3	15	11
Sodium, dissolved (mg/L)	7.7	8.7	8.5	6.6	7.8	6.7	9.4
Potassium, dissolved (mg/L)	1.6	2.1	2.2	1.6	1.6	1.6	1.6
Chloride, dissolved (mg/L)	26	55	21	9.5	15	9.8	18
Sulfate, dissolved (mg/L)	130	100	190	120	85	170	120
Fluoride, dissolved (mg/L)	.1	.1	.1	.2	.1	.2	.2
Silica, dissolved (mg/L)	--	17	19	18	19	18	15
Iron, dissolved (µg/L)	30	40	30	<10	<10	<10	<10
Manganese, dissolved (µg/L)	690	190	720	30	<10	70	30
Strontium, dissolved (µg/L)	--	--	--	--	--	--	330
Zinc, dissolved (µg/L)	--	--	--	--	--	--	40
Aluminum, dissolved (µg/L)	--	--	--	--	--	--	33
Hydrogen sulfide, dissolved (mg/L)	.0	.0	.3	--	--	--	--
Dissolved solids (mg/L)	--	339	398	267	266	330	303

from well W6-1, August 1976 through May 1984

per centimeter at 25° Celsius. Dash indicates data are not available]

			Sampling date, postmining period					
1979	1980		1980	1981	1982		1984	
4/17	1/16	7/9	10/17	5/28	2/3	8/5	1/17	5/31
11.0	9.5	14.5	14.5	13.0	10.0	14.0	11.0	11.5
320	335	357	650	374	736	620	380	287
--	--	--	--	--	4.9	--	1.5	1.8
6.8	6.9	6.7	6.7	6.8	6.9	7.1	7.2	6.9
16	46	54	84	100	72	80	92	74
20	56	66	102	122	88	98	112	90
--	--	--	1.5	4.8	3.8	7.8	.9	.3
<.01	0	.01	.01	.01	<.01	--	.04	<.01
40	54	47	89	53	107	100	65	44
12	9.1	9.5	14	8.9	19	16	11	9.3
6.0	6.0	6.2	9.1	8.0	12	9.7	8.0	6.1
1.2	1.0	1.2	1.8	1.4	1.8	1.4	1.3	1.1
7.5	10	9.9	19	12	22	14	10	6.9
120	100	99	200	71	270	180	120	98
.2	.2	.2	.0	.1	.1	.1	.2	.2
19	19	17	20	20	18	19	19	17
20	30	60	410	40	490	150	130	36
40	170	30	500	400	910	580	370	120
150	200	180	470	300	640	510	290	180
20	30	20	80	--	--	--	27	45
30	0	10	10	--	--	--	30	<100
.2	--	--	.3	.0	.6	.7	.0	--
223	231	226	405	236	496	390	270	226

Table 4.--Chemical analyses of ground water collected from well P10-1, May 1982-May 1984

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25° Celsius. Dash indicates data are not available.]

Constituent or property	Sampling date, postmining period			
	1982		1984	
	5/18	8/3	1/17	5/31
Temperature (°C)	13.5	14.0	11.0	13.3
Specific conductance (µS/cm)	1050	1150	1100	1170
Oxygen, dissolved (mg/L)	--	--	.8	.0
pH	6.8	6.9	6.7	7.0
Alkalinity (mg/L as $CaCO_3$)	262	336	270	274
Bicarbonate (mg/L)	320	410	329	334
Total organic carbon (mg/L)	5.4	2.8	1.0	.5
Phosphorus, dissolved (mg/L)	.01	--	.01	.02
Calcium, dissolved (mg/L)	139	180	170	160

Magnesium, dissolved (mg/L)	34	43	45	46
Sodium, dissolved (mg/L)	16	20	20	18
Potassium, dissolved (mg/L)	2.9	2.5	2.7	2.7
Chloride, dissolved (mg/L)	42	53	46	42
Sulfate, dissolved (mg/L)	260	300	330	360
Fluoride, dissolved (mg/L)	.2	.2	.2	.2
Silica, dissolved (mg/L)	11	12	11	12
Iron, dissolved (µg/L)	26	32	99	48
Manganese, dissolved (µg/L)	400	380	600	590
Strontium, dissolved (µg/L)	460	600	580	600
Zinc, dissolved (µg/L)	--	--	34	7
Aluminum, dissolved (µg/L)	--	--	10	<100
Hydrogen sulfide, dissolved (mg/L)	.0	.0	.0	--
Dissolved solids (mg/L)	670	814	776	737

Table 5.--Chemical analyses of ground water collected from well

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm,

Constituent or property	Sampling date, premining period							
	1976		1977			1978		1979
	8/16	12/2	3/9	6/14	9/20	3/29	10/4	4/17
Temperature (°C)----	13.0	9.0	12.0	12.0	13.0	13.0	12.5	11.0
Specific conductance (µS/cm)-----------	760	760	750	817	805	825	890	840
Oxygen, dissolved (mg/L)-------------	--	--	--	--	--	--	--	--
pH------------------	8.2	7.2	7.2	7.2	7.1	7.2	7.1	7.2
Alkalinity (mg/L as $CaCO_3$)------------	317	335	328	346	343	350	344	346
Bicarbonate (mg/L)--	386	409	400	422	418	427	419	422
Total organic carbon (mg/L)------------	4.5	2.9	7.6	5.1	7.9	--	--	--
Phosphorus, dissolved (mg/L)-----	--	--	--	--	--	<.01	<.01	<.01
Calcium, dissolved (mg/L)------------	73	93	99	78	100	68	98	93
Magnesium, dissolved (mg/L)------------	25	32	33	28	33	25	34	31
Sodium, dissolved (mg/L)------------	62	29	27	65	33	85	33	28
Potassium, dissolved (mg/L)------------	2.5	2.4	2.4	2.5	2.4	2.7	2.4	2.3
Chloride, dissolved (mg/L)------------	21	25	25	23	24	25	25	26
Sulfate, dissolved (mg/L)------------	76	85	77	78	77	85	87	85
Fluoride, dissolved (mg/L)------------	.3	.2	.2	.2	.2	.2	.2	.2
Silica, dissolved (mg/L)------------	--	16	18	16	18	16	17	16
Iron, dissolved (µg/L)------------	<10	40	<10	<10	<10	<10	20	<10
Manganese, dissolved (µg/L)------------	40	<10	20	<10	<10	<10	<10	7
Strontium, dissolved (µg/L)------------	--	--	--	--	--	--	1900	1500
Zinc, dissolved (µg/L)------------	--	--	--	--	--	--	<20	<20
Aluminum, dissolved (µg/L)------------	--	--	--	--	--	--	10	20
Hydrogen sulfide, dissolved (mg/L)--	.0	.0	.2	.0	.0	.0	.0	.0
Dissolved solids (mg/L)------------	--	484	479	499	494	519	506	492

W2-2 (premining) and well P2-2 (postmining), August 1976 through May 1984

microsiemens per centimeter at 25° Celsius. Dash indicates data are not available]

Sampling date, postmining period								
1980		1981	1982			1983	1984	
1/16	7/8	5/27	2/17	5/19	8/4	4/28	1/17	5/31
10.0	14.0	14.0	--	14.0	15.0	14.0	11.0	13.5
750	830	1410	1240	1600	1140	1710	1700	2070
--	--	--	--	--	--	9.7	5.8	--
6.8	6.8	7.0	6.8	7.0	7.0	7.0	7.2	6.4
330	330	333	344	336	353	--	350	287
400	400	:06	420	410	430	420	427	350
--	--	1.8	5.2	1.2	1.2	1.0	1.3	.6
.01	.00	--	--	--	--	<.01	.01	<.01
89	89	180	156	216	190	260	270	300
31	28	58	51	66	55	77	81	92
34	37	40	32	31	32	33	33	31
2.2	2.4	3.5	3.4	3.5	3.0	3.6	3.5	3.9
24	23	65	68	86	86	76	70	62
76	86	390	220	500	360	650	650	900
.3	.3	.2	.2	.1	.2	.1	.2	.1
17	15	13	12	12	13	13	14	15
50	10	40	1500	220	1300	340	3700	900
10	8	200	260	440	240	500	1300	2500
1500	1700	1900	1700	2000	2000	2100	2200	2000
30	80	--	--	--	--	--	68	30
10	30	--	--	--	--	100	280	<100
.0	.0	.0	.0	.0	.0	.0	.0	--
473	481	959	754	1120	955	1310	1320	1560

Table 6.--Chemical analyses of ground water collected

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens

Constituent or property	Sampling date, premining period								
	1976		1977			1978		1979	
	8/17	12/2	3/9	6/14	9/20	3/28	10/4	4/17	6/28
Temperature (°C)----	12.5	9.5	11.5	12.0	13.0	12.0	12.0	12.0	14.5
Specific conductance (µS/cm)-----------	600	570	590	580	605	590	580	625	680
Oxygen, dissolved (mg/L)-------------	--	--	--	--	--	--	--	--	--
pH------------------	7.9	7.6	7.5	7.4	7.3	7.6	7.5	7.6	7.6
Alkalinity (mg/L as $CaCO_3$)------------	262	274	264	254	264	254	267	272	328
Bicarbonate (mg/l)--	320	334	322	310	322	310	326	332	400
Total organic carbon (mg/L)------------	3.1	4.5	7.2	5.4	6.2	--	--	--	--
Phosphorus, dissolved (mg/L)-----	--	--	--	--	--	<.01	<.01	<.01	.0
Calcium, dissolved (mg/L)------------	57	46	34	61	61	55	68	74	32
Magnesium, dissolved (mg/L)------------	23	20	15	23	24	22	26	25	13
Sodium, dissolved (mg/L)------------	39	58	85	33	33	32	27	11	99
Potassium, dissolved (mg/L)------------	2.0	2.2	2.2	1.9	2.0	2.1	1.7	1.7	1.8
Chloride, dissolved (mg/L)------------	10	12	11	10	14	9.3	12	9.3	12
Sulfate, dissolved (mg/L)------------	44	47	50	47	47	52	51	55	29
Fluoride, dissolved (mg/L)------------	.4	.2	.2	.2	.1	.2	.2	.2	1.2
Silica, dissolved (mg/L)------------	--	11	11	11	12	11	11	11	9.4
Iron, dissolved (µg/L)------------	<10	30	<10	<10	<10	40	<10	<10	<10
Manganese, dissolved (µg/L)------------	<10	<10	<10	<10	<10	<10	<10	1	3
Strontium, dissolved (µg/L)------------	1400	1600	1100	1200	1100	--	--	--	--
Zinc, dissolved (µg/L)------------	--	--	--	--	--	--	ND	ND	--
Aluminum, dissolved (µg/L)------------	--	--	--	--	--	--	30	30	--
Hydrogen sulfide, dissolved (mg/L)--	.0	.0	.2	.0	.0	.0	.0	.0	--
Dissolved solids (mg/L)------------	--	361	367	340	352	338	361	354	395

from well W8-2, August 1976 through May 1984

per centimeter at 25° Celsius. Dash indicates data are not available]

			Sampling date, postmining period					
1980			1980	1981	1982		1984	
1/16	3/12	7/9	10/17	5/28	2/18	5/18	1/16	5/30
10.0	11.0	13.0	11.5	13.0	--	12.5	11.0	12.0
580	680	475	702	1090	1230	1250	1750	1780
--	--	--	--	--	--	--	--	--
6.9	7.4	7.1	7.8	7.1	6.9	7.1	7.0	6.8
270	320	290	339	540	558	591	560	553
324	390	348	413	658	680	720	683	674
--	3.4	--	1.0	2.0	1.6	--	2.6	1.7
.01	.00	.00	.01	<.01	.04	.06	.04	<.01
71	39	68	29	160	172	178	250	250
26	14	23	11	52	56	56	79	83
16	95	26	110	14	11	14	37	33
1.6	1.5	1.6	1.8	2.2	2.2	2.2	2.7	2.8
10	14	11	12	15	12	2.4	18	19
43	28	42	25	160	180	200	500	580
.2	1.2	.4	1.3	.1	.1	.1	15	.2
11	10	10	9.3	15	14	14	.2	15
0	20	10	20	<10	11	16	4	33
5	10	5	5	50	1500	490	1400	2200
--	--	--	--	--	--	--	3000	3000
30	--	10	0	--	--	--	70	44
0	--	20	20	--	--	--	10	100
.0	.0	.0	.0	.0	<.1	.0	.0	.0
341	395	355	404	744	786	824	1220	1230

Table 7.--Chemical analyses of ground water collected from seeps, May 1984

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C]

Constituent or property	Upper seep	Lower seep
Temperature (°C)	13.0	11.0
Specific conductance (µS/cm)	1,980	2,390
pH	6.4	4.2
Total organic carbon (mg/L)	.6	240
Phosphorus, dissolved (mg/L)	<.01	<.01
Calcium, dissolved (mg/L)	240	240
Magnesium, dissolved (mg/L)	100	130
Sodium, dissolved (mg/L)	23	17
Potassium, dissolved (mg/L)	4.3	7.3
Chloride, dissolved (mg/L)	53	34
Sulfate, dissolved (mg/L)	920	1,500
Fluoride, dissolved (mg/L)	.2	.6
Silica, dissolved (mg/L)	14	30
Iron, dissolved (µg/L)	390	63,000
Manganese, dissolved (µg/L)	13,000	63,000
Strontium, dissolved (µg/L)	780	1,000
Zinc, dissolved (µg/L)	110	810
Aluminum, dissolved (µg/L)	100	7,200
Dissolved solids (mg/L)	1,470	--

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