GROUND-WATER MOVEMENT AND EFFECTS OF COAL STRIP MINING ON WATER QUALITY OF HIGH-WALL LAKES AND AQUIFERS IN THE MACON-HUNTSVILLE AREA, NORTH-CENTRAL MISSOURI

By Dennis C. Hall and Robert E. Davis

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Donald Paul Hodel, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
1400 Independence Road
Mail Stop 200
Rolla, Missouri 65401

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch	25.40 0.02540	millimeter meter
inch per hour	0.007056	millimeter per second
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
mile	1.609	kilometer
square mile	2.590	square kilometer
foot squared per day	0.09290	meter squared per day
gallon	3.785 0.003785	liter or cubic decimeter cubic meter
ton	0.9072	megagram or metric ton
gallon per minute	0.06309	liter per second

Temperature in degree Celsius (°C) may be converted to degree Fahrenheit (°F) as follows: F = 9/5 °C + 32.

Temperature in degree Fahrenheit (°F) may be converted to degree Celsius (°C) as follows: °C = 5/9 (°F-32).

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ABSTRACT

Glacial drift and Pennsylvanian bedrock were mixed together forming spoil during prereclamation strip mining for coal in north-central Missouri. This restructuring of the land increases the porosity of the material, and increases aqueous concentrations of many dissolved constituents. Median sodium and bicarbonate concentrations were slightly greater, calcium 5 times greater, magnesium 6 times greater, manganese 15 times greater, iron 19 times greater, and sulfate 24 times greater in water from spoil than in water from glacial drift. Median potassium concentrations were slightly greater, and chloride concentrations were two times greater in water from glacial drift than in water from spoil. Water types in glacial drift and bedrock were mostly sodium bicarbonate and calcium bicarbonate; in spoil and lakes in the spoil, the water types were mostly calcium sulfate. Median pH values in water from spoil were 6.6, as compared to 7.4 in water from glacial drift and 9.0 in water from bedrock. Neutralization of acid by carbonate rocks causes the moderate pH values in water from spoil; a carbonate system closed to the atmosphere may result in alkaline pH values in bedrock.

Alluvium, glacial drift, bedrock, and spoil are aquifers in the study area. Transmissivities generally are greatest for spoil, and decrease in the following order: alluvium, glacial drift, and bedrock.

Recharge to spoil is from precipitation, lateral flow from glacial drift, and lateral and vertical flow from bedrock. Precipitation probably is the major source of recharge, both directly by infiltration and indirectly as inflow from lakes. The rate of recharge to the aquifers is unknown, but probably is small. Ground-water discharge from the glacial drift, bedrock, and spoil is to alluvium, which generally discharges to streams.

The potentiometric surface in the shallow aquifers generally conformed to the topography. The direction of flow generally was from high-wall lakes in the spoil toward East Fork Little Chariton River or South Fork Claybank Creek.

Significant differences (95-percent confidence level) in values and concentrations of aqueous constituents between spoil areas mined at different times (1940, 1952, and 1968) were obtained for pH, calcium, magnesium, manganese, sulfate, chloride, and dissolved solids, but not for iron. These differences are attributed to local variations in the geohydrologic system rather than spoil age. The changes in water quality occurred in fewer than 12 years and have persisted for more than 40 years.

Water from high-wall lakes, glacial drift, bedrock, and spoil was saturated with respect to calcite, dolomite, and quartz, but only water from spoil was saturated with respect to gypsum. The difference can be attributed either to dissolution of freshly exposed gypsum or to oxidation of freshly exposed pyrite, or both, in spoil. The exposure of the minerals probably results from disturbance of the drift and bedrock overburden during mining.

The general chemical processes that occur as water moves into spoil are dissolution and precipitation of calcite, dissolution of dolomite, consumption of oxygen gas, consumption and release of carbon dioxide gas, dissolution of pyrite and gypsum, precipitation of goethite (or iron hydroxide), and release of sodium ions by ion exchange. When all the pyrite has been consumed through oxidation, the quality of water in the spoil probably will begin to improve. How long this might take is not known.

INTRODUCTION

Strip mining of coal has a significant effect on the near-surface environment because overburden, the material above the coal, is removed successively in furrows or strips. After the first strip cut, the broken and mixed overburden from successive cuts is placed into the previous cut forming spoil. The last cut is left open and eventually may fill with water, forming a high-wall lake. Strip mining can alter both the hydraulic and geochemical characteristics of hydrologic systems in the mined area.

To administer coal-mining regulations, State and Federal agencies need to assess the probable effects of strip mining on the movement and quality of ground water. However, to date (1984), information about the effects has been insufficient to make these assessments.

Purpose and Scope

The purpose of this study was to describe the ground-water hydrology and general geochemical processes affecting ground-water quality in the Macon-Huntsville area of north-central Missouri (fig. 1). Specifically, the objectives were to determine the ground-water conditions in the area and the effects of strip mining of coal with a substantial sulfur content in a humid climate on water quality of high-wall lakes and aquifers.

An extensive data-collection program was begun during 1980 to provide hydrologic and geochemical information for the study. Existing wells in the study area were inventoried. In addition, 15 observation wells were installed in or near mine spoil emplaced during 1940 (fig. 2), 1952 (fig. 3), and 1968 (fig. 4) in southern Macon County. Cuttings were collected during drilling and were analyzed for physical properties and mineralogy. Water levels in the observation wells were measured monthly, and several sets of water samples were collected from the wells for on-site and laboratory chemical analysis. Staff gages were installed in nine lakes in spoil to determine the relationship between the lakes and ground water in the spoil. Samples of water from the lakes were collected and analyzed for specific conductance, pH, temperature, and carbonate and bicarbonate concentrations (see "Supplemental Data" section at the back of the report for data collected during the study).

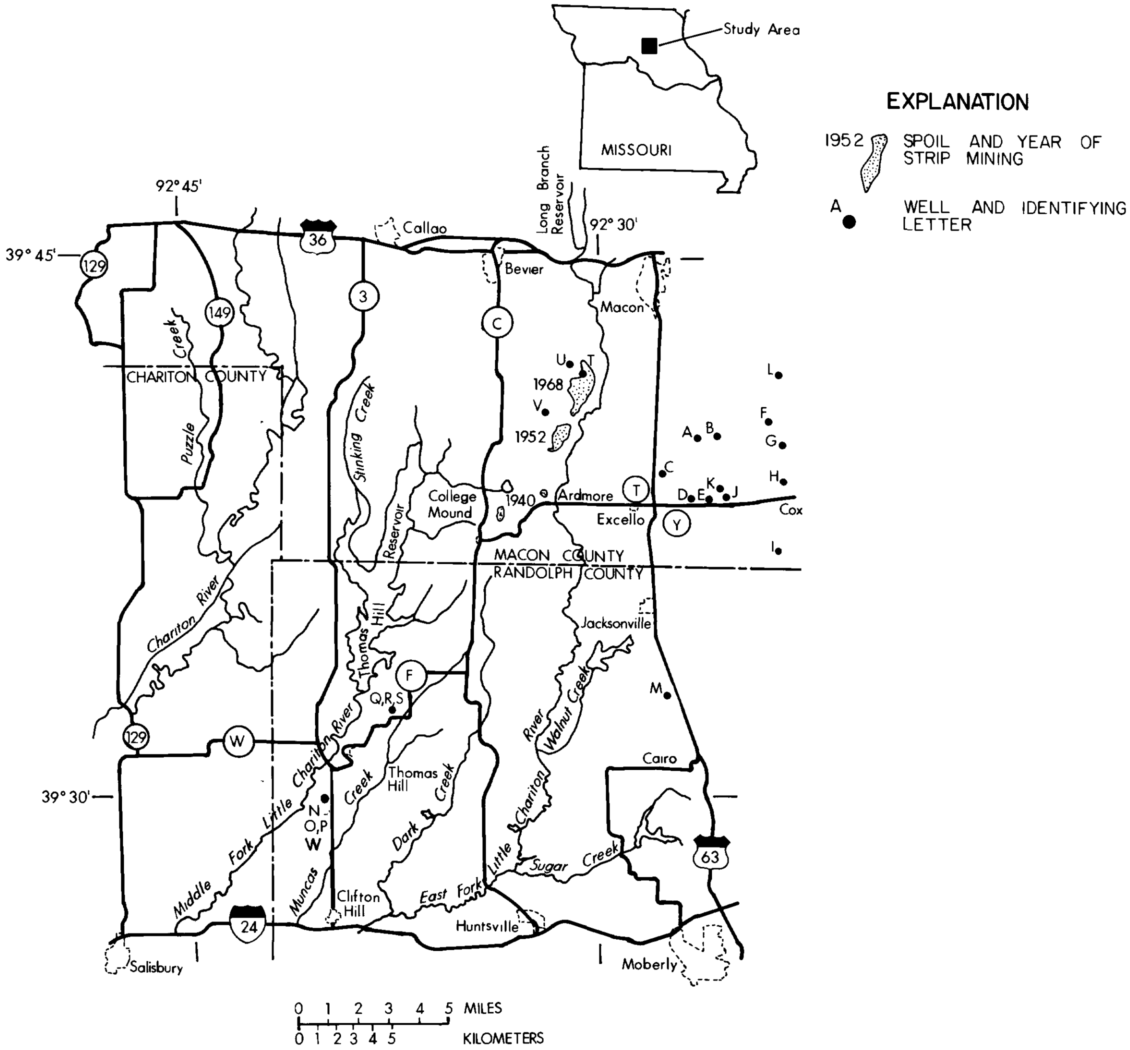

Figure 1.--Location of study area, spoil areas, and wells outside of spoil areas.

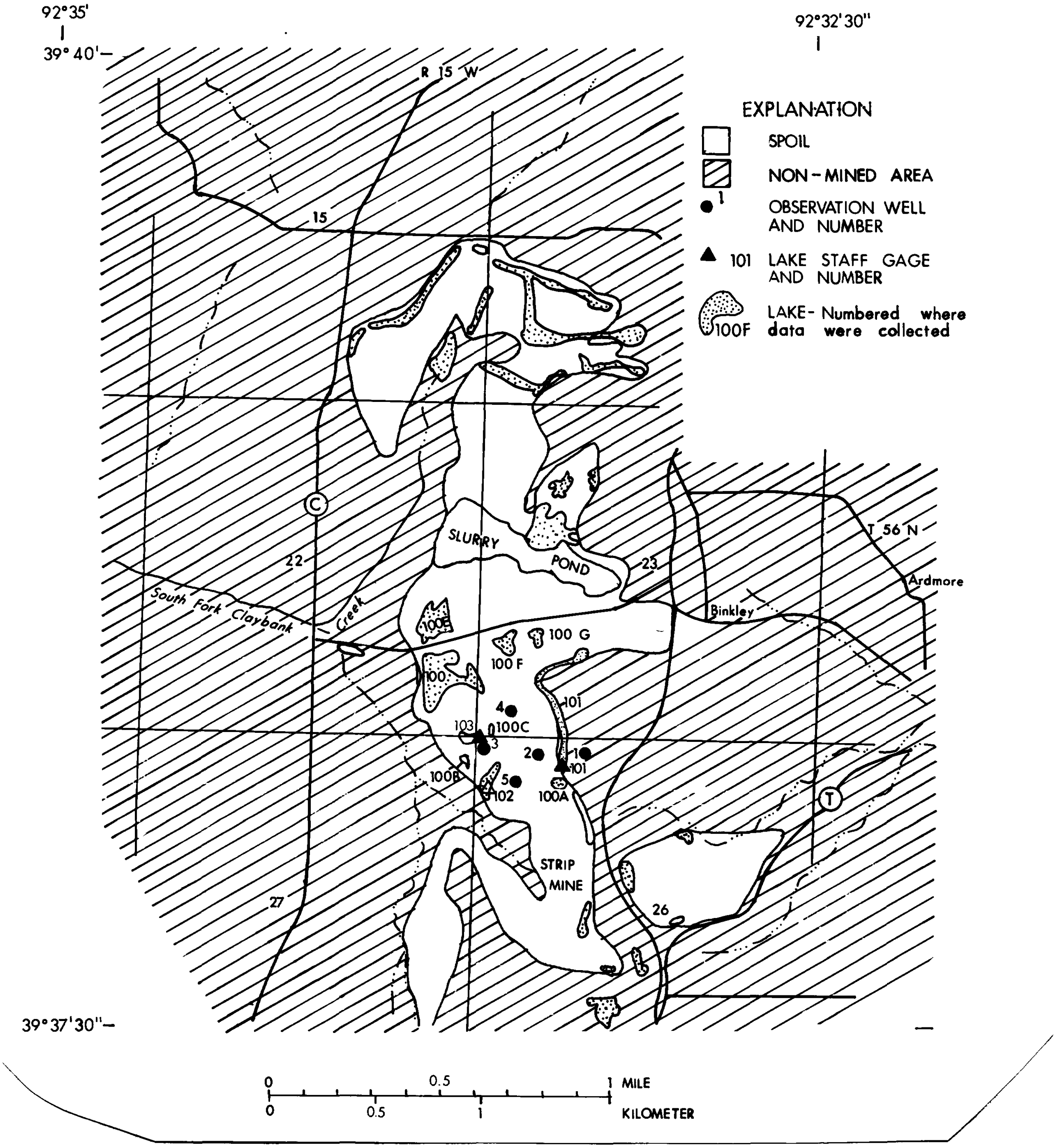

Figure 2.--Location of observation wells, lake staff gages, and miscellaneous lakes in 1940 spoil.

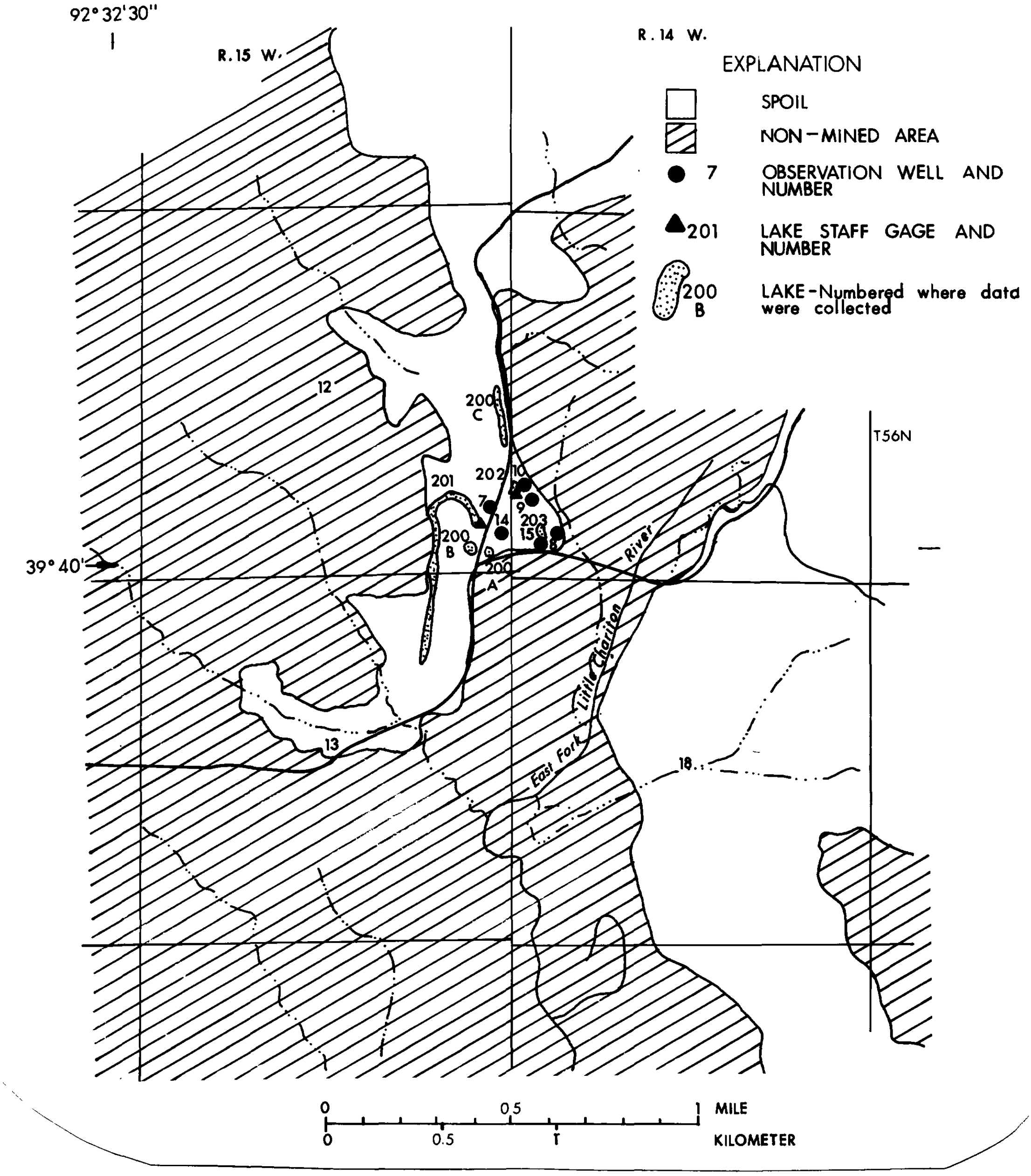

Figure 3.--Location of observation wells, lake staff gages, and miscellaneous lakes in 1952 spoil.

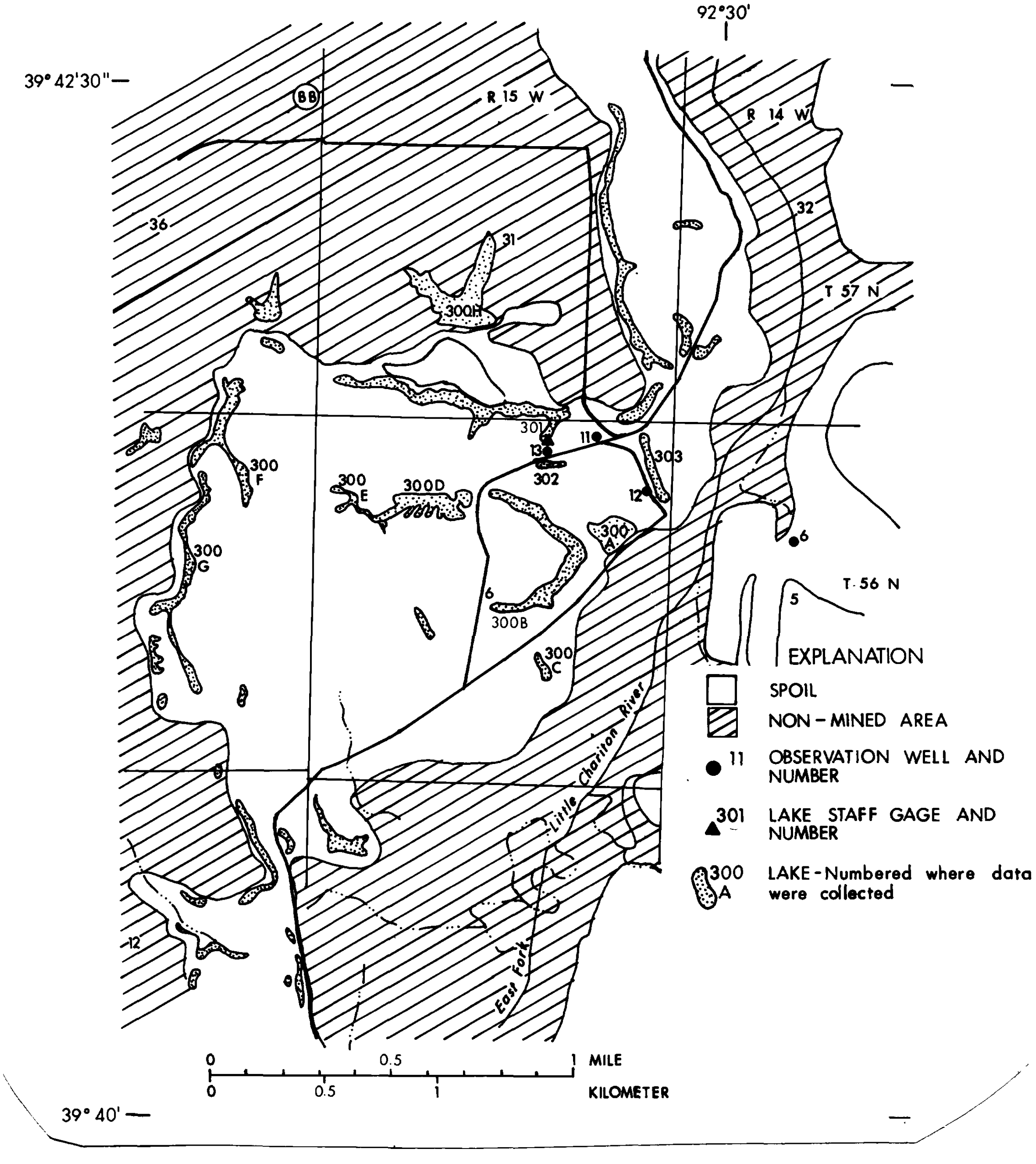

Figure 4.--Location of observation wells, lake staff gages, and miscellaneous lakes in 1968 spoil.

Previous Investigations

Studies of the coal resources of Missouri have been made by Gentile (1967), Robertson (1971 and 1973), Robertson and Smith (1981), and Searight (1967). Studies of ground-water resources in and near the study area have been made by Haliburton Associates (1981), Horner and Shifrin, Inc. (1981), and Vaill and Barks (1980). Studies made by Draney (1982); Lewis (1982); Older (1982); and Seifert (1982) relate directly to certain geologic and hydrologic aspects of the study area.

Physiography and Drainage

North-central Missouri has been glaciated and is in the Dissected Till Plains physiographic area (Fenneman, 1938). The topography consists of rolling hills with about 100 feet of relief. The major streams, East and Middle Forks Little Chariton River, drain southward to the Missouri River. Two major reservoirs, Thomas Hill and Long Branch, are located in the study area (see fig. 1).

Climate

North-central Missouri has a humid climate. Mean annual precipitation for 1941-70 at Macon (fig. 1) was 38.7 inches (National Weather Service, 1981-83). The mean annual temperature was 52.1 °F (National Weather Service, 1981-83). Mean annual potential evapotranspiration is 28 inches (Lewis, 1982, p. 23) and mean annual runoff is 8 to 9 inches (Skelton, 1971, plate 1).

Precipitation at Macon (fig. 5) was 52.4 inches during 1981; 47.4 inches during 1982; and 41.7 inches during 1983 (National Weather Service, 1981-83; and U.S. Army, Corps of Engineers, Long Branch Reservoir, oral commun., 1983). The 1981 and 1982 values were considerably greater than the mean annual precipitation.

Coal Mining in Missouri

Missouri has an estimated 47 billion tons of coal reserves, of which 18 billion tons are identified, 12 billion tons are hypothetical, and 17 billion tons are speculative (Robertson and Smith, 1981, p. 12-13). Of the 18 billion tons of identified reserves, 5 billion tons are considered recoverable. Of these recoverable reserves, 2 billion tons are considered recoverable by strip mining. The coal in Missouri is bituminous and has a relatively large sulfur content. In a study by Wedge and others (1976), the sulfur content of Missouri coal ranged from 2.7 to 6.9 percent, averaging 4.3 percent.

Macon County produced 43 million tons of coal from 1889 to 1964 (Gentile, 1967), which was more than any other county in Missouri. During the same period, Randolph County produced 24 million tons of coal. Both underground and strip mines have been significant in the production of coal. About 37 percent of the total coal produced has been strip mined and almost all coal produced since the mid-1960's has been strip mined. In the 108 square-mile drainage of East Fork Little Chariton River between Macon and Huntsville (see fig. 1), 14 percent of the area has been disrupted by strip mining.

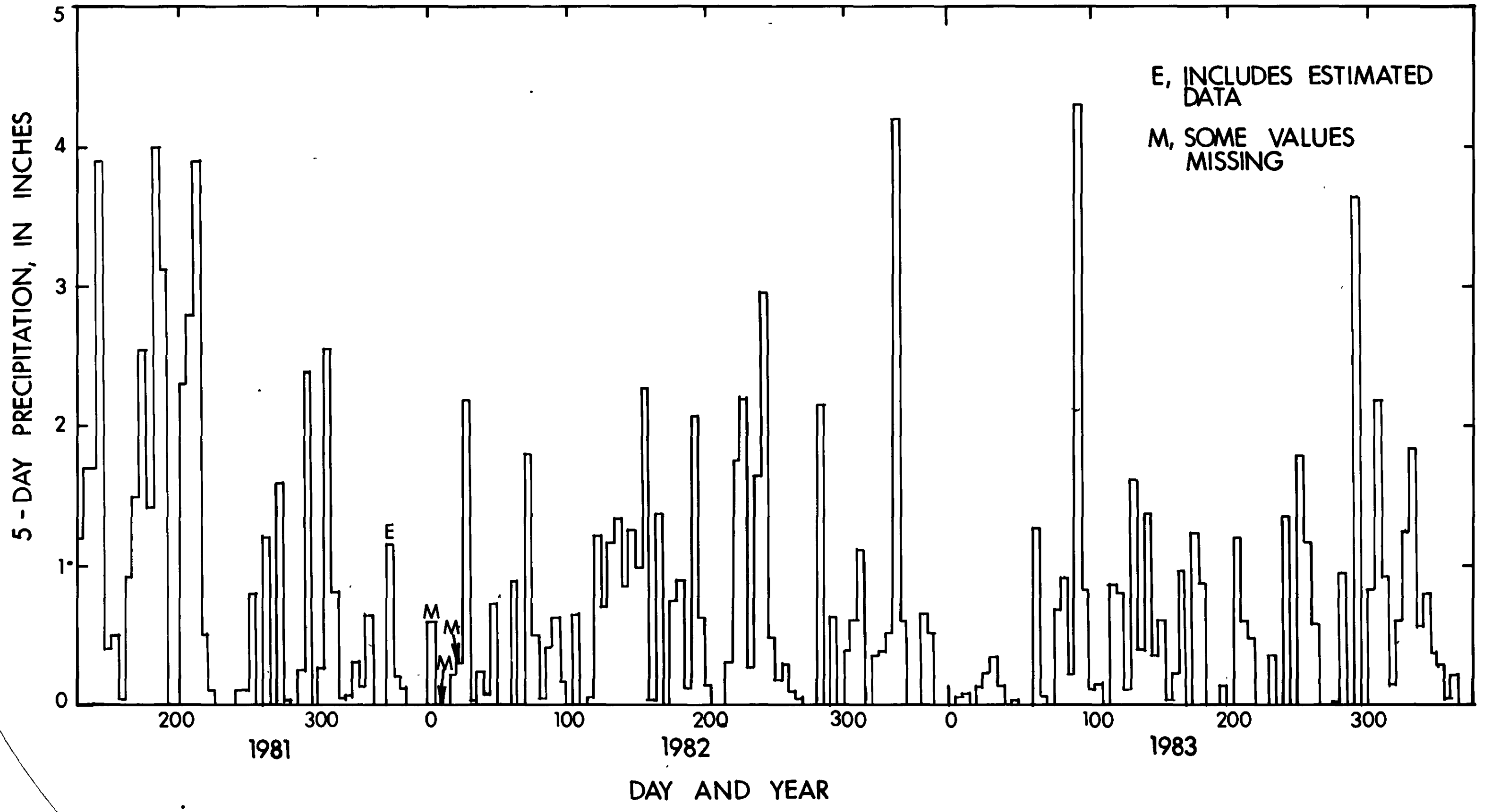

Figure 5.--Precipitation at Macon, May 1981 through December 1983. (Data from National Weather Service 1981-1983, except days 305-334, 1982, from U.S. Army, Corps of Engineers, Long Branch Reservoir, oral commun., 1982.)

The hilly topography has made contour strip mining the method of choice in Macon and Randolph Counties (Vaill and Barks, 1980). By this method, the overburden is removed successively in strips following the contour of the land (fig. 6). Mining generally continues until the thickness of the overburden makes mining uneconomical or until the thickness of the overburden exceeds the removal capacity of the equipment. The maximum thickness of overburden removed in Missouri generally is not more than 150 feet.

Before 1972, reclamation was not required and ordinarily was not practiced in Missouri mining operations. After the coal was removed, strip mines were abandoned and left to natural processes. The mine areas were not recontoured, topsoil was not replaced, and the fertility of the surface material varied widely. As a result, vegetation varies from sparse to dense in unreclaimed areas.

Public Law 95-87 (U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 1979) requires that land stripped for mining be reclaimed. With reclamation the spoil is recontoured, the topsoil is replaced, and the area is reseeded and revegetated. However, high-wall lakes are still a characteristic feature.

Acknowledgments

We are grateful for the cooperation of the Associated Electric Cooperative, Inc., which owns much of the property where this study was made; and to the many employees who offered assistance, particularly Kimery C. Vories and Daniel L. Henry. Also, many thanks to Scott and Carol Phillips, owners of Phillips Farms, who permitted the installation of wells and staff gages on their property.

GEOLOGY

Stratigraphy

The near-surface geology of northern Missouri consists of Quaternary alluvium, loess, and glacial drift overlying Pennsylvanian bedrock (fig. 7). Alluvium primarily is present in the larger stream valleys and consists of sand, silt, and clay. Maximum thickness of the alluvium is about 50 feet. The loess is a post-glacial deposit composed of fine-grained, wind-blown material and primarily occurs on the higher ridges. The loess generally is 5 to 10 feet thick (Gentile, 1967). The glacial drift, consisting of till and outwash deposits, is composed of poorly sorted sand, silt, and clay with some well-sorted sand lenses. Glacial drift is present throughout most of the study area, except where locally eroded, and is as much as 150 feet thick, generally thinning to the south. In some areas, fractures occur in the glacial drift (Horner and Shifrin, Inc., 1981).

Pennsylvanian bedrock underlies the entire area (fig. 8) and consists of shale, limestone, sandstone, and coal with shale predominating (Gentile, 1967). Total thickness of Pennsylvanian bedrock in southwest Macon County is about 280 feet. Coal seams of interest are the Mulky and Bevier-Wheeler seams that generally are within 100 feet of the land surface.

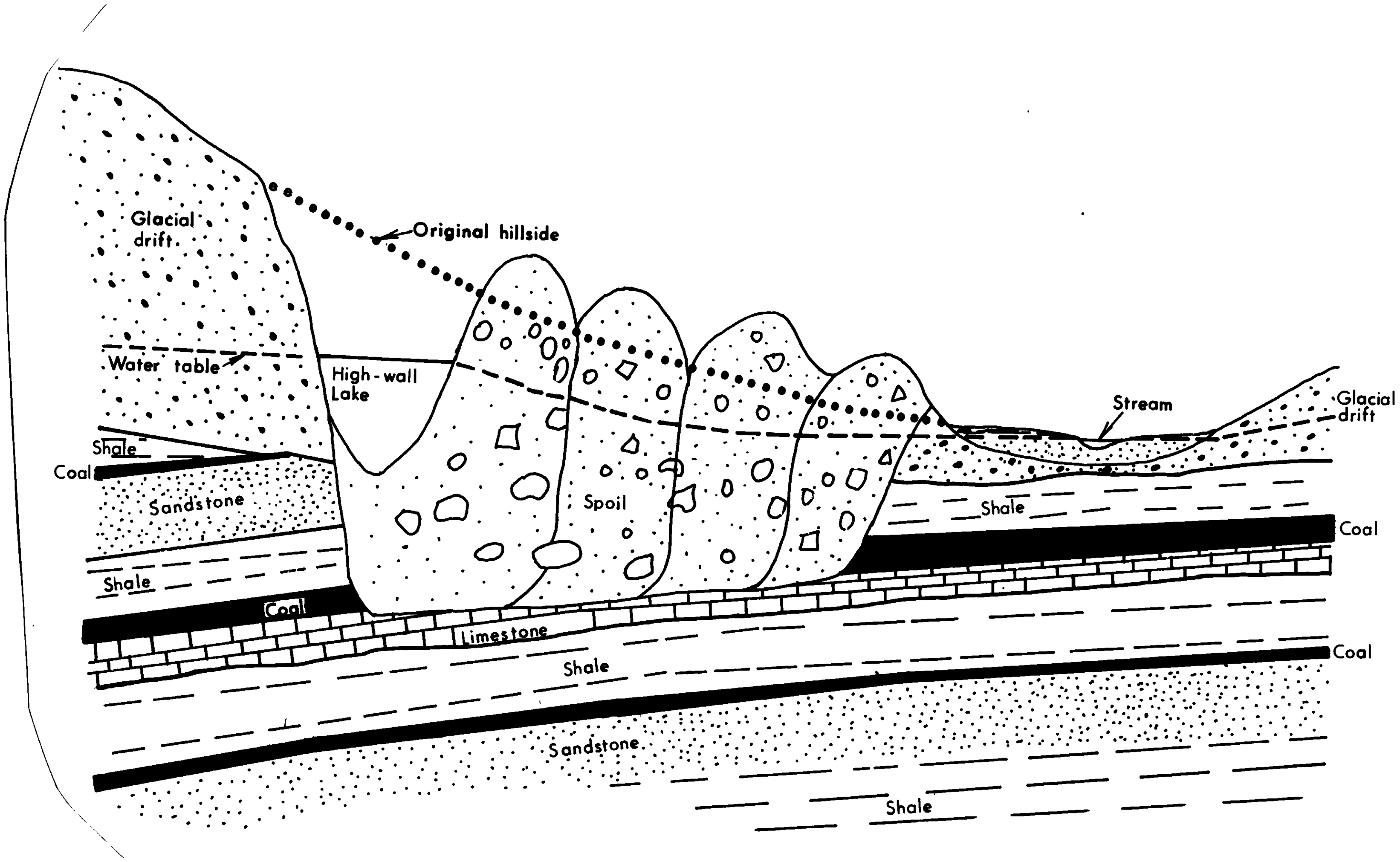

Figure 6.--Generalized lithologic section through an abandoned strip mine.

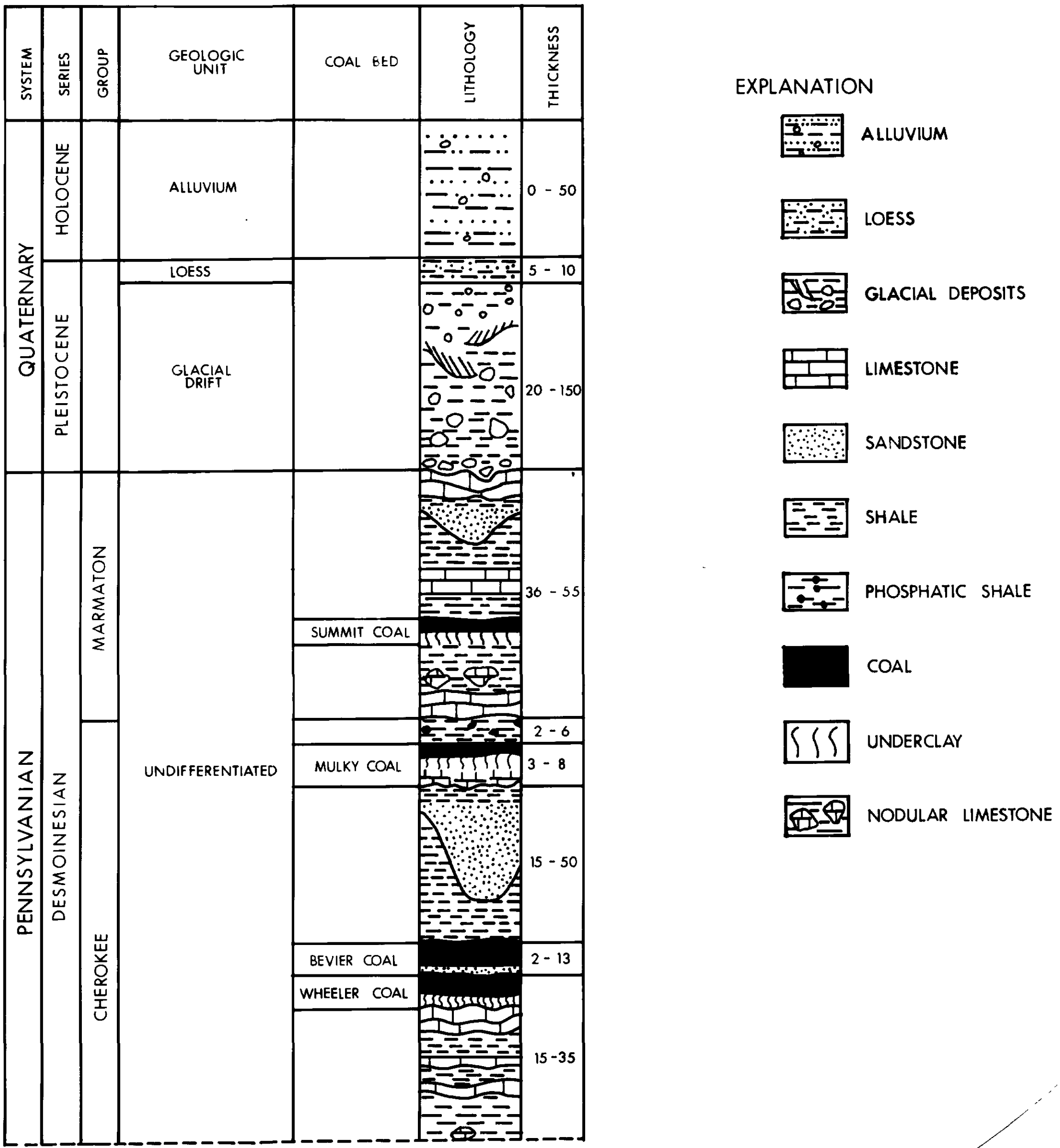

Figure 7.--Generalized stratigraphy of study area. (Modified from Older, 1982; and Gentile, 1967.)

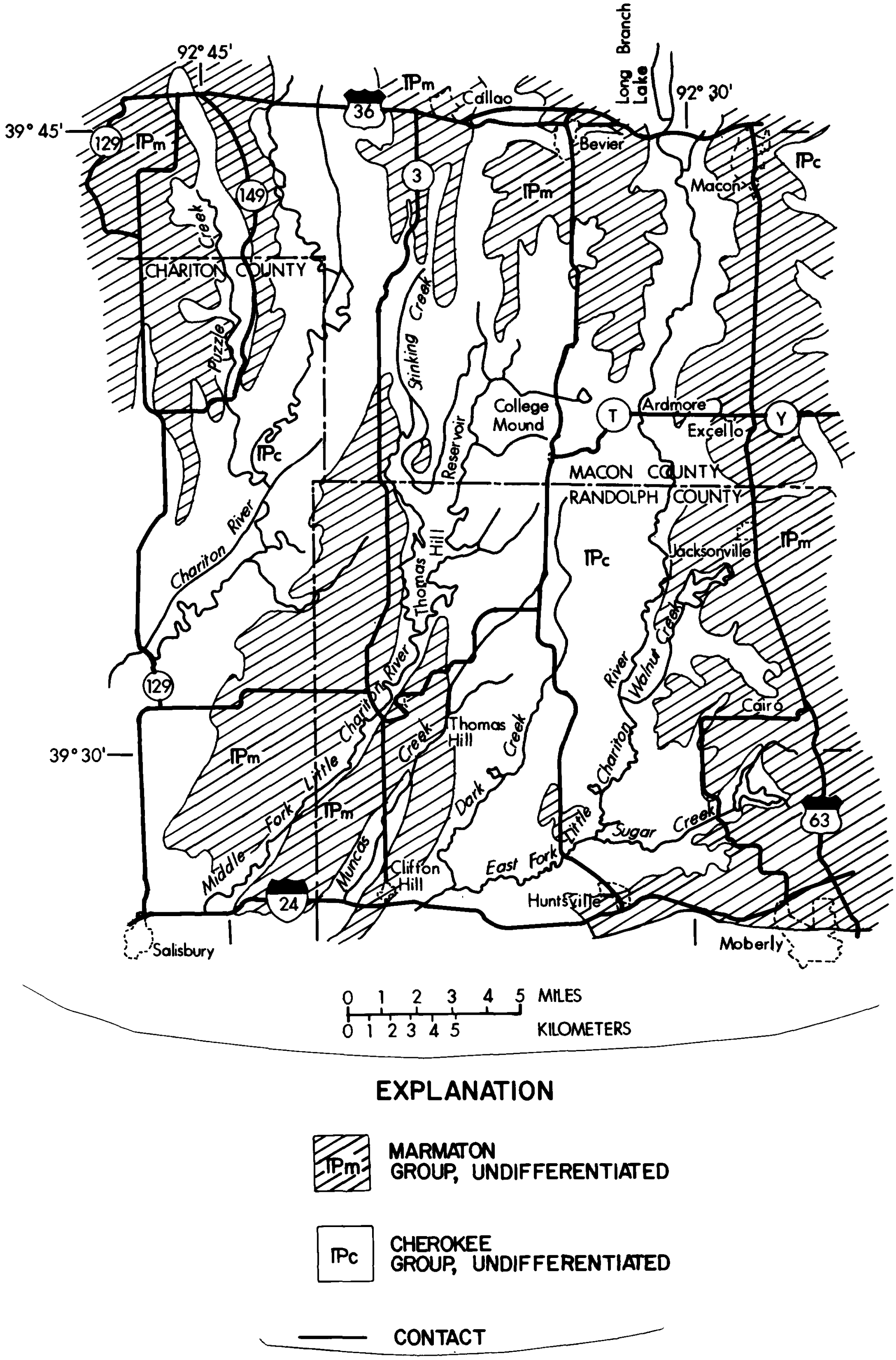

Figure 8.--Pennsylvanian bedrock in the study area. (Geology by Anderson, 1979.)

Soils in the study area vary depending on the parent material (Vaill and Barks, 1980). Soils formed from alluvium or loess are rich and fertile, and soils formed from glacial drift are less fertile.

Spoil is present where surface mining has occurred. The spoil consists of a heterogeneous mixture of glacial drift and broken bedrock. The composition of spoil varies from place to place depending on the relative quantities of disturbed glacial drift and bedrock. Thicknesses are about 30 to 55 feet in the 1940 spoil, 30 to 40 feet in the 1952 spoil, and 25 to 110 feet in the 1968 spoil.

Mineralogy

The major minerals present in the spoil are quartz, calcite, dolomite, and various clays. Pyrite, gypsum, goethite, amorphous iron hydroxide, and jarosite also are present (Older, 1982). Quartz, is the dominant mineral in the sand-silt fraction of glacial drift and spoil (table 1).

Calcite and dolomite are present in approximately equal quantities ranging from about 2 to 10 percent and averaging about 4 to 5 percent (table 2). Calcite generally was observed in the clay fraction (grains less than 2 micrometers in diameter).

The clay-mineral groups are calcium montmorillonite, vermiculite, kaolin, illite, mixed-layer illite-vermiculite, and degraded chlorite (Older, 1982). Calcium montmorillonite, vermiculite, kaolin, and illite probably are derived from the glacial drift; kaolin, illite, and also small quantities of vermiculite probably are derived from the bedrock. The average quantity of clay in the spoil was 39 percent. Calcium montmorillonite has the largest cation-exchange capacity of the clay present, although iron-hydroxide coatings on the clay probably inhibit exchange. The major minerals or mineral groups observed or expected to be in the spoil and selected for geochemical modeling are listed in table 3 (Seifert, 1982).

GROUND-WATER MOVEMENT

Alluvium, glacial drift, bedrock, and spoil are aquifers in the study area. The alluvial aquifer generally is confined, although unconfined conditions may exist locally. The glacial drift and bedrock aquifers generally are confined. The spoil aquifer is unconfined.

Transmissivity

Data on hydraulic properties of the aquifers are few. A summary of available data is given in table 4. Although the ranges of known values vary considerably, transmissivities generally are greatest for the spoil and decrease in the following order: alluvium, glacial drift, bedrock above the coal, and bedrock below the coal. Transmissivities determined for the spoil with permeameters in the laboratory were considerably less than those determined in wells. However, the investigators (Shell Engineering Associates, 1981) stated that the samples in the permeameters were packed too tightly.

Table 1.--Sand-silt-clay grain-size distribution in glacial drift

[Data from Draney, 1982]

Well number and identifying letter (figs. 1-4)	Percent[1] Sand	Silt	Clay
		Glacial drift	
1	33	28	39
W	30	32	38
Average	32	30	38
		1940 spoil	
2	32	30	38
3	26	34	41
4	34	26	40
5	27	30	43
Average	30	30	40
		1952 spoil	
7	5	40	55
8	16	50	34
9	19	41	40
10	28	34	38
14	24	43	33
15	32	40	27
Average	21	41	38
		1968 spoil	
6	22	42	37
11	12	45	43
12	10	54	36
13	18	38	43
Average	16	45	40
Average spoil	22	39	39

[1] Due to rounding of numbers, percentages may not always total 100.

Table 2.--Percentage of calcite and dolomite by weight in glacial drift and spoil

[Data from Draney, 1982]

Well number and identifying letter (figs. 1-4)	Percentage, by weight	
	Calcite	Dolomite
	Glacial drift	
1	5.8	4.7
W	5.9	5.5
Average	5.8	5.1
	1940 spoil	
2	6.4	5.4
3	4.0	3.4
4	7.1	5.4
5	3.4	3.6
Average	5.2	4.4
	1952 spoil	
7	1.9	4.8
8	2.5	2.4
9	3.9	3.2
10	9.9	8.2
14	3.1	2.8
15	4.6	2.8
Average	4.3	4.0
	1968 spoil	
6	6.0	4.7
11	7.3	4.9
12	6.4	5.5
13	4.7	4.7
Average	6.1	5.0
Average spoil	5.1	4.4

Table 3.--Minerals selected for geochemical modeling

[Modified from Seifert, 1982]

Adularia ($KAlSi_3O_8$)

Albite ($NaAlSi_3O_8$)

Alunite [$KAl_3(SO_4)_2(OH)_8$]

Amorphous aluminum hydroxide [$Al(OH)_3A$]

Amorphous iron hydroxide [$Fe(OH)_3A$]

Calcite ($CaCO_3$)

Calcium montmorillonite [$Ca_{0.17}Al_{2.33}Si_{3.67}O_{10}(OH)_2$]

Dolomite [$CaMg(CO_3)_2$]

Goethite [$FeO(OH)$]

Gypsum ($CaSO_4 \cdot 2H_2O$)

Illite [$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2$]

Jarosite [$KFe(SO_4)_2(OH)_6$]

Kaolinite [$Al_2Si_2O_5(OH)_4$]

Pyrite (FeS_2)

Quartz (SiO_2)

Siderite ($FeCO_3$)

Table 4.--Reported transmissivities of alluvium, glacial drift, spoil, and bedrock in the Macon, Randolph, and Chariton Counties area

[>, greater than]

Source	Aquifer	Location	Number of sites or well number (figs. 2-4)	Transmissivity (T), in feet squared per day
Haliburton Associates (1981)	Alluvium	Near Excello	1 site	4.1
Do.	Glacial drift	do.	7 sites	0.02 - 3.3
Do.	Bedrock	do.	2 sites	.089 - 1.0
Horner and Shifrin, Inc. (1981)	Alluvium	Near Thomas Hill	2 sites	9.9 ->11
Do.	Glacial drift	do.	5 sites	.0021 - 29
Do.	Bedrock above Bevier coal	do.	5 sites	.007 - 1.0
Do.	Bedrock, Bevier coal and below	do.	4 sites	.003 - .016
J. H. Williams, (Missouri Department of Natural Resources, written commun., 1982)	Glacial drift	Near Excello	3 sites	1 - 51

Table 4.--Reported transmissivities of alluvium, glacial drift, spoil, and bedrock in the Macon, Randolph, and Chariton Counties area--Continued

Source	Aquifer	Location	Number of sites or well number (figs. 2-4)	Transmissivity (T), in feet squared per day	
Seifert (1982, p. 37-40)	Glacial drift	Study area	Well 1	(a)	11
Do.	Spoil	do.	Well 3	(b)	23
Do.	do.	do.	Well 7	(c)	8.7
Do.	do.	do.	Well 8	(d)	2.9
Do.	do.	do.	Well 9	(e)	57
Do.	do.	do.	Well 12	(f)	35
Shell Engineering Associates (1981, p. 21 and 51-54)	Spoil	Near Thomas Hill	Laboratory permeameters	(g) 0.08	- 10

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[a] Saturated thickness, 13.0 feet.

[b] Saturated thickness, 26.6 feet.

[c] Saturated thickness, 9.2 feet.

[d] Saturated thickness, 20.8 feet.

[e] Saturated thickness, 59.4 feet.

[f] Saturated thickness, 40.3 feet.

[g] Assumes a hypothetical saturated thickness of 25 feet.

During well drilling in spoil and in glacial drift close to the spoil, layers were encountered in which penetration was rapid and large quantities of drilling fluid containing Revert[1] were lost. This was true for wells 1, 6, 7, 11 and 12 (figs. 2, 3, and 4). These wells all had yields of more than 5 gallons per minute. Attempted slug tests failed in wells 1, 7, 11, and 12 because recovery was too rapid to measure manually.

Recharge and Discharge

Recharge to the alluvium occurs by infiltration of precipitation and by lateral and probably vertical flow from adjacent aquifers. Recharge probably occurs during periods of high stream stage. The rate of recharge by infiltration of precipitation is unknown, but probably is small.

Recharge to glacial drift occurs by infiltration of precipitation and lateral flow from adjacent aquifers. The potential rate of infiltration in glacial drift is about 0.06 inch per hour (Dennis K. Potter, U.S. Soil Conservation Service, oral commun., April 1984). Due to extensive layers of clay in the glacial drift, infiltration of precipitation probably occurs mainly in localized areas where sand lenses or fractures are present. The actual rate of recharge to the glacial drift probably is small. Based on tritium dating, Haliburton Associates (1981, p. 173-174) report that no significant vertical recharge to the deeper parts of glacial drift has occurred since 1952 in an area east of Excello. By means of a ground-water flow model, Horner and Shifrin, Inc. (1981, p. 32) estimate an annual recharge rate of 4×10^{-5} inch to the glacial drift throughout a 100-square-mile area in Randolph and Chariton Counties near Thomas Hill. However, Lewis (1982, p. 38-40), also using a ground-water flow model for part of the Excello basin east of the study area, determined a possible range of annual recharge to the glacial drift of 0.2 to 5.2 inches.

Recharge to bedrock probably occurs by infiltration of precipitation and vertical flow from overlying alluvium and glacial drift. The rate of recharge is unknown, but probably is small.

Recharge to spoil is from precipitation, lateral flow from glacial drift, and lateral and vertical flow from bedrock. Precipitation probably is the major source of recharge, both directly by infiltration and indirectly as leakage from lakes. The potential rate of infiltration into spoil ranges from 0.2 to 0.6 inch per hour (Dennis K. Potter, U.S. Soil Conservation Service, oral commun., April 1984). The annual recharge to the spoil is unknown.

Reclamation of spoil areas, as is currently (1984) practiced in newer surface mines, may have a significant effect on recharge. Smoothing of the reclaimed surface eliminates many small ponds and puddles conducive to infiltration, although high-wall lakes and sediment ponds are retained. In

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[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

addition, topsoil is replaced and planted with grasses and legumes. Topsoil would most likely be less permeable than the unreclaimed spoil surface, and thick vegetative cover would result in an increased evapotranspiration loss. Recharge in reclaimed spoil, although less than in unreclaimed spoil, would still be greater than in nonmined parts of the study area.

Ground-water discharge from glacial drift, bedrock, and spoil is to the alluvium. The alluvium generally discharges to streams.

Potentiometric Surface

The potentiometric surface in the shallow aquifers (alluvium, glacial drift, and spoil) in parts of Macon, Randolph, and Chariton Counties generally conformed to the topography (fig. 9). The larger streams and some of the smaller streams gain from ground-water inflow during wet weather. However, during extended periods of dry weather, ground-water contribution decreases and may be entirely consumed by evapotranspiration.

In and near the 1940 spoil, the potentiometric surface sloped away from high-wall lake 101 on the east, west, and south sides (fig. 10). Ground-water flow on the east side was to tributaries of the East Fork Little Chariton River; ground-water flow on the west side was toward the South Fork Claybank Creek; and ground-water flow to the south probably contributes to both surface-water systems. Ground-water flow immediately north of lake 101 was toward the lake. The hydraulic gradient in the spoil area ranged from about 110 to 210 feet per mile outside the spoil and from 40 to 120 feet per mile inside the spoil.

In and near 1952 spoil, the potentiometric surface generally sloped from west to east toward the East Fork Little Chariton River (fig. 11). The hydraulic gradient outside the spoil was not determined, but inside the spoil the hydraulic gradient ranged from 120 to 400 feet per mile.

In and near 1968 spoil, the potentiometric surface sloped from north and west to the east toward the East Fork Little Chariton River (see fig. 11). The hydraulic gradient was about 240 feet per mile outside the spoil on the north and west and ranged from 20 to 80 feet per mile inside the spoil.

Because precipitation in the study areas was considerably greater than normal during 1981-82, the altitudes of the potentiometric surfaces during 1981-83 also may have been greater than normal. The response time between precipitation and changes in the potentiometric surfaces is not known, although it probably is days or months because altitudes of water in observation wells in or near spoil have considerable seasonal variability. Changes of as much as 13.5 feet were measured during 1981-83 (figs. 12-14).

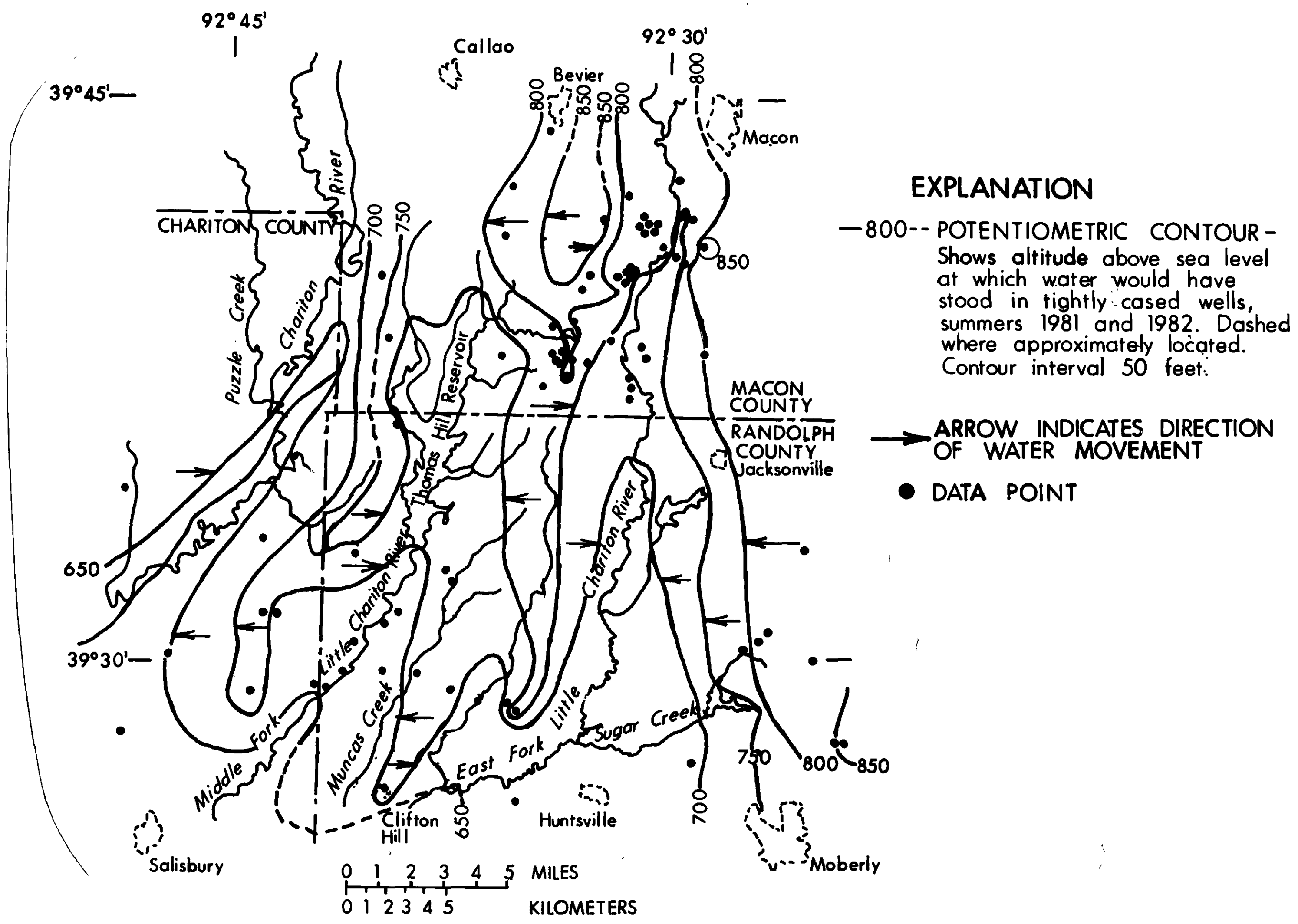

Figure 9.--Potentiometric surface in shallow aquifers in parts of Macon, Randolph, and Chariton Counties, summers 1981 and 1982.

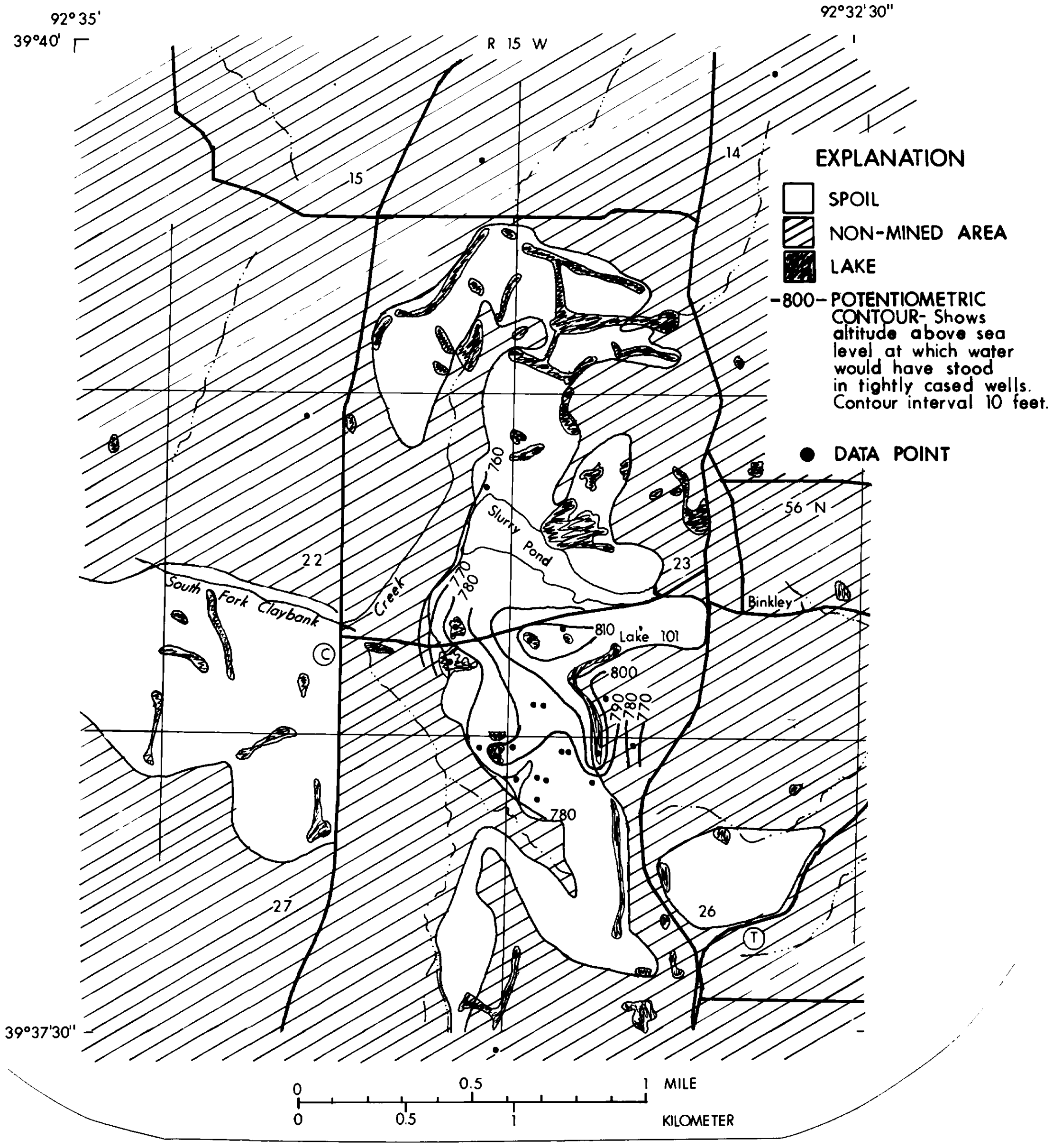

Figure 10.--Potentiometric surface of shallow aquifers in 1940 spoil, summer 1983.

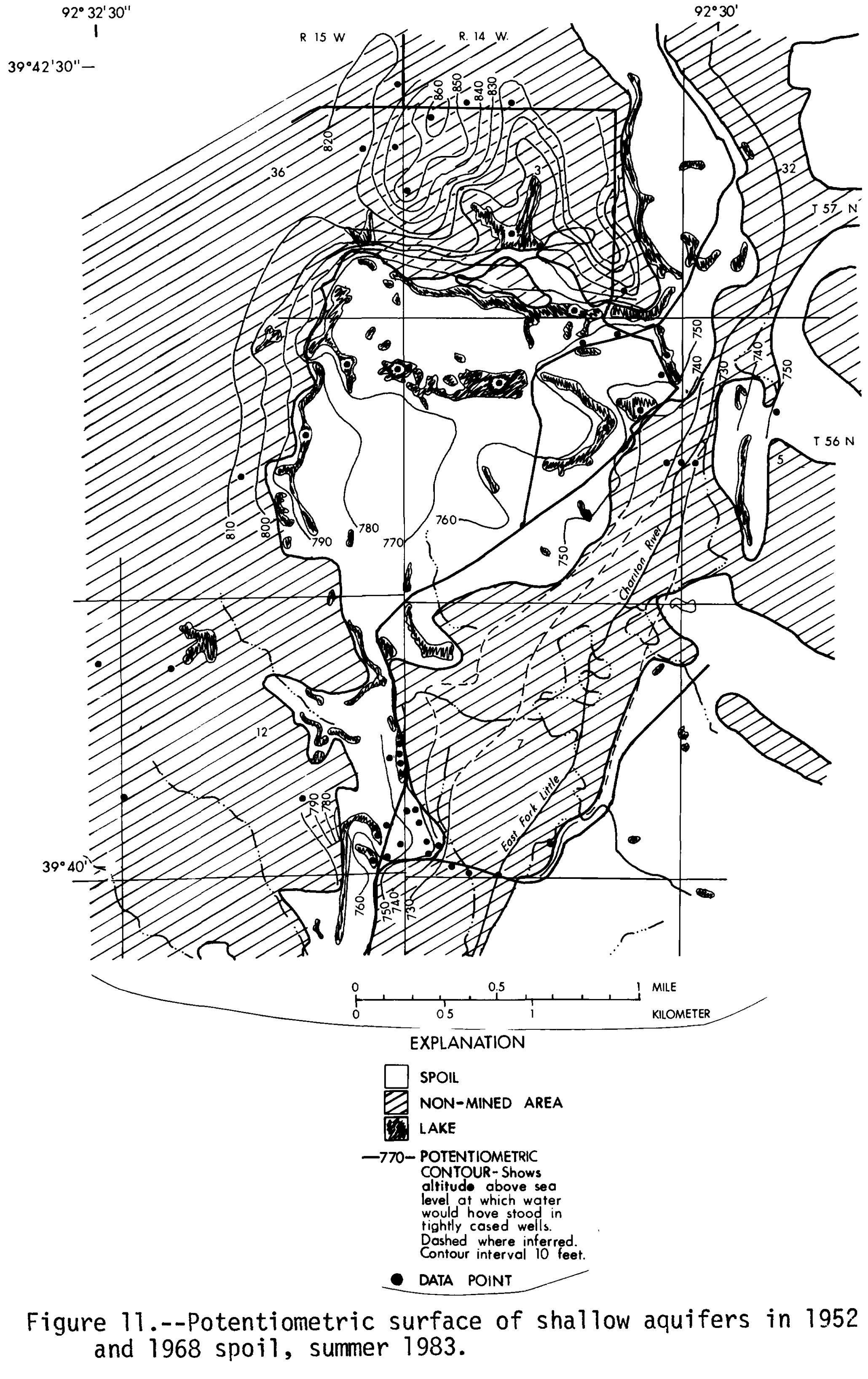

Figure 11.--Potentiometric surface of shallow aquifers in 1952 and 1968 spoil, summer 1983.

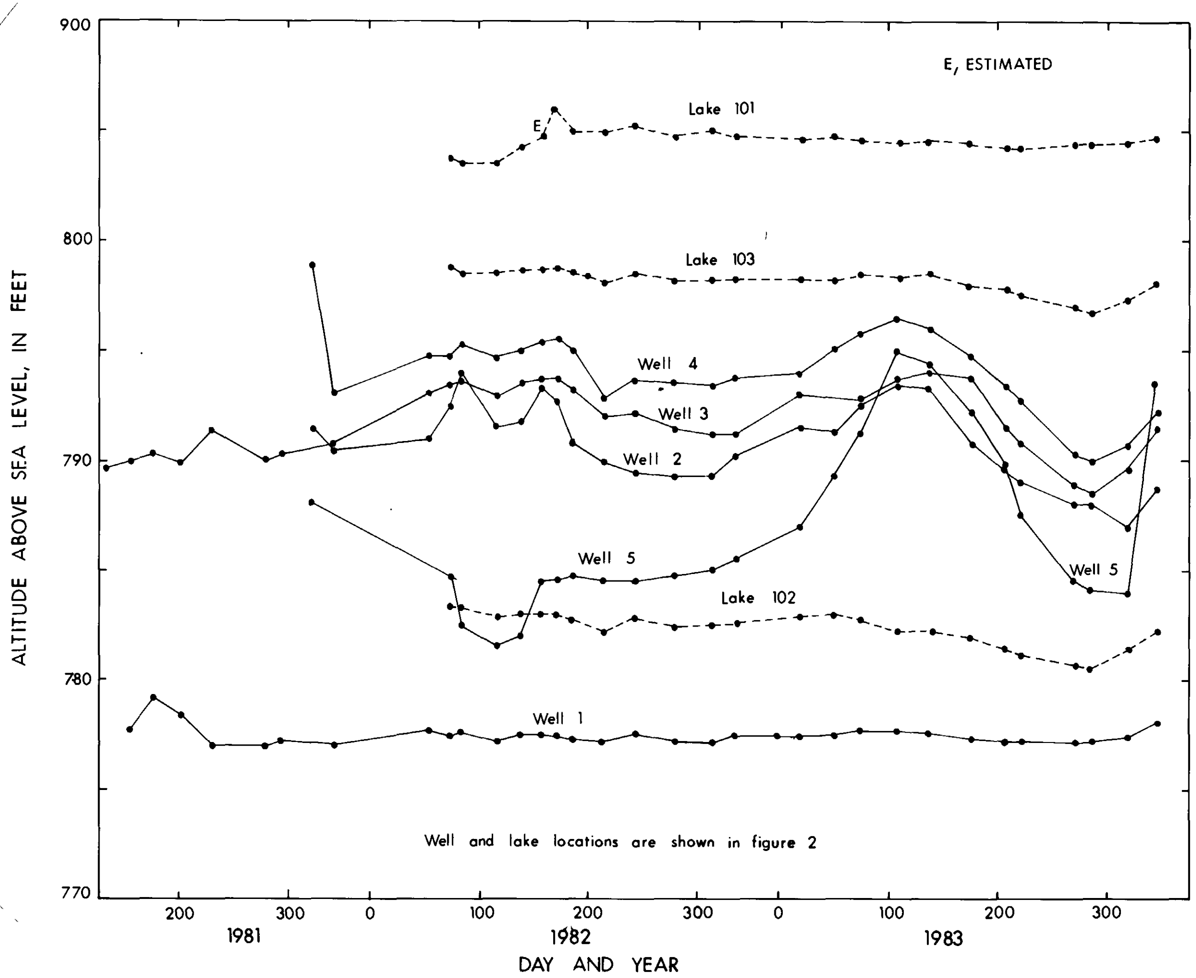

Figure 12.--Altitude of water surface in wells and lakes in 1940 spoil, May 1981 through December 1983.

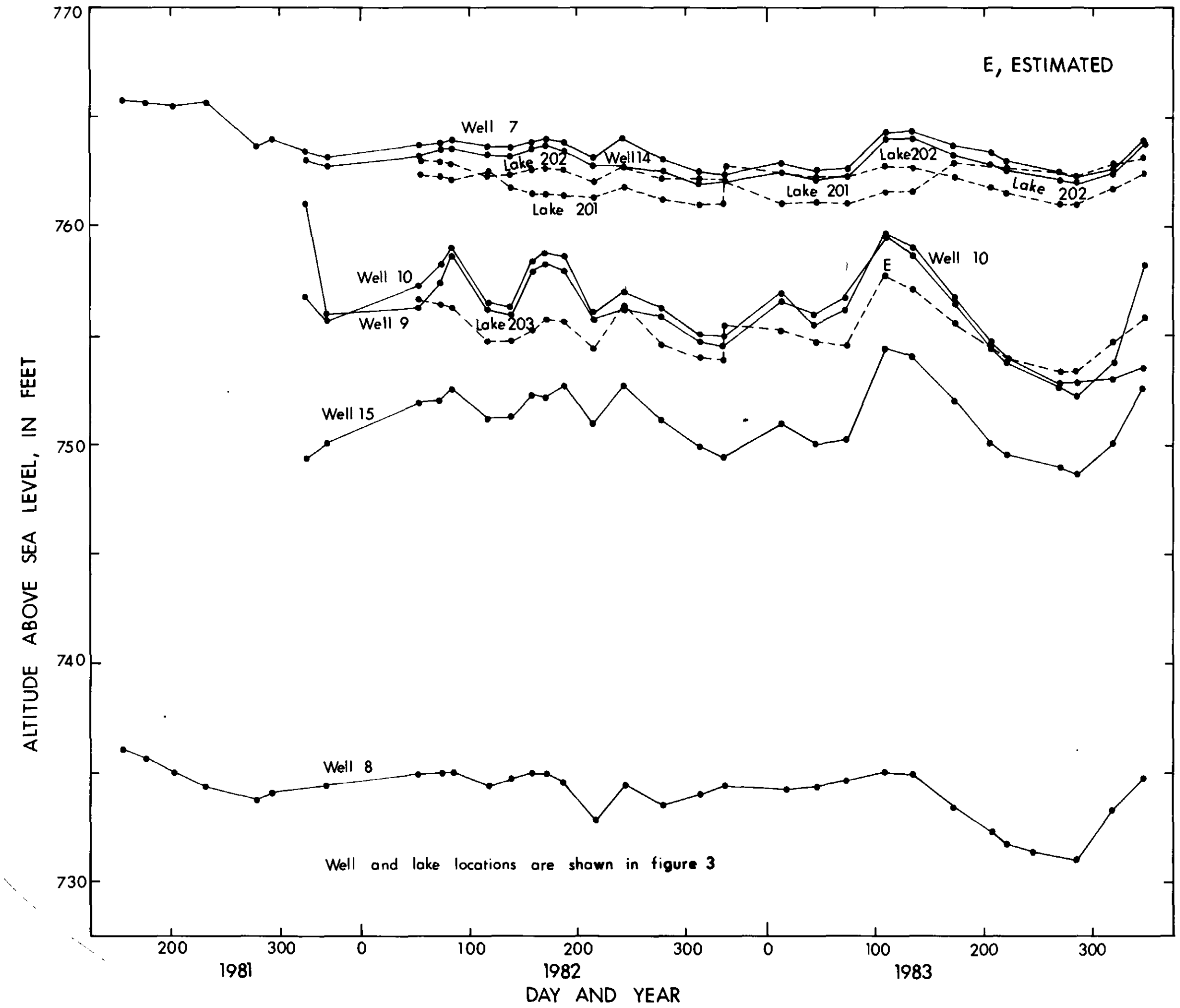

Figure 13.--Altitude of water surfaces in wells and lakes in 1952 spoil, May 1981 through December 1983.

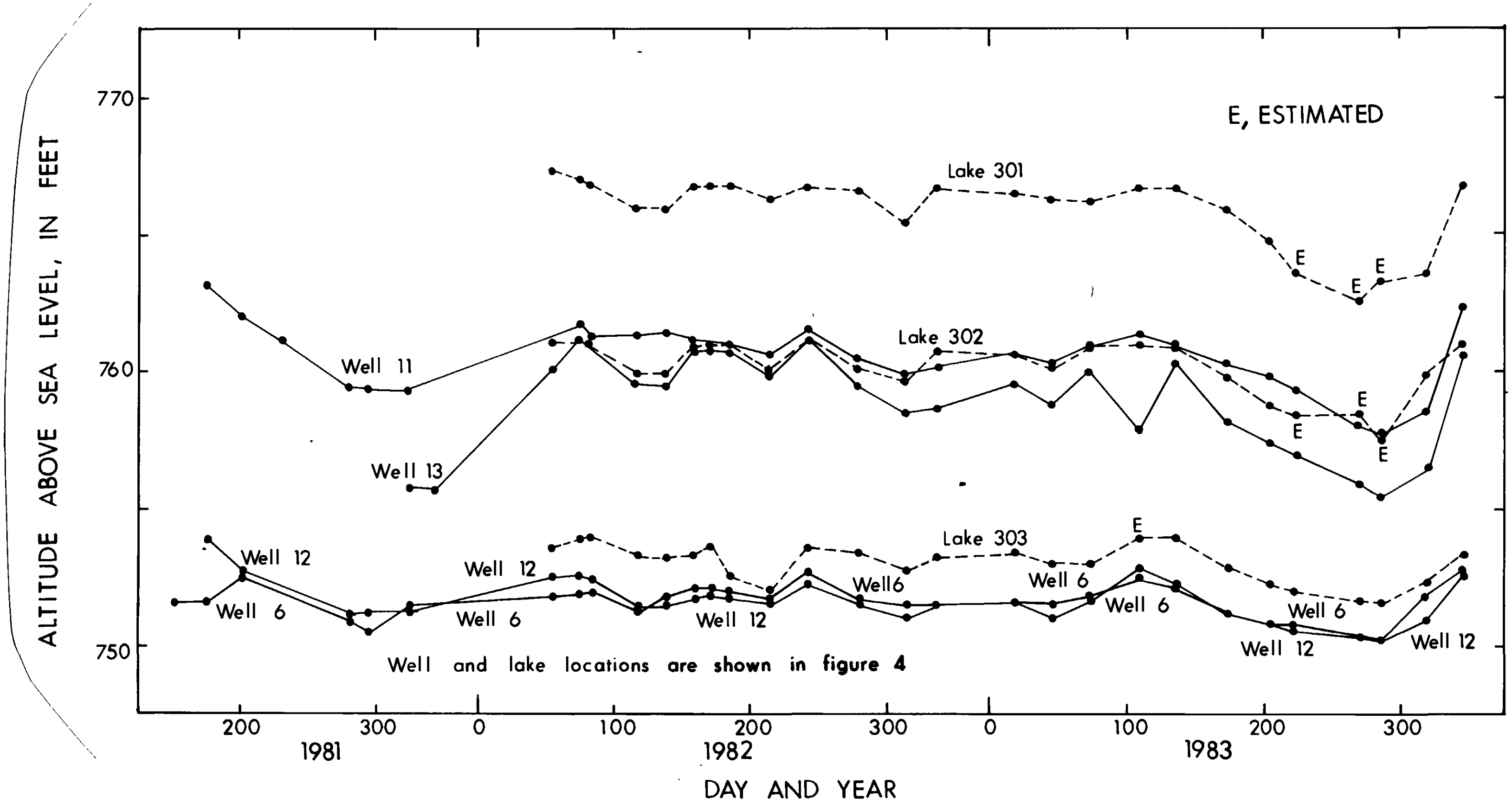

Figure 14.--Altitude of water surfaces in wells and lakes in 1968 spoil, May 1981 through December 1983.

GENERAL GEOCHEMICAL PROCESSES AFFECTING GROUND-WATER QUALITY

The general geochemical processes that affect the ground-water quality in the study area usually begin with the dissolution of carbonate minerals or the oxidation of pyrite, or both. In a near-surface environment, carbon dioxide gas (CO_2) from organic decay or the atmosphere reacts with water (H_2O):

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \tag{1}$$

the resulting carbonic acid (H_2CO_3) dissociates

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \quad \text{and} \tag{2}$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-} . \tag{3}$$

The effect of reactions 1, 2, and 3 is to produce a slightly acidic environment conducive to the dissolution of calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$]:

$$CaCO_3 + H^+ \rightleftharpoons Ca^{2+} + HCO_3^- \quad \text{and} \tag{4}$$

$$CaMg(CO_3)_2 + 2H^+ \rightleftharpoons Ca^{2+} + Mg^{2+} + 2HCO_3^- . \tag{5}$$

Reactions 4 and 5 result in an increase in the concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}), and an increase in bicarbonate (HCO_3^-) concentration.

If pyrite (FeS_2) is present in an oxidizing environment, the acidity (H^+ concentration) of the water can be increased:

$$4FeS_2 + 15O_2 + 14H_2O \rightleftharpoons 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+ . \tag{6}$$

The iron compounds formed by reaction 6 can be iron hydroxide [$Fe(OH)_3$] as shown or iron oxyhydroxide [$FeO(OH)$] (goethite). The sulfate (SO_4^{2-}) produced either remains in solution or precipitates, probably as calcium sulfate ($CaSO_4$). The H^+ produced increases the acidity and promotes the dissolution of carbonate minerals, if present, as in reactions 4 and 5. The carbonate dissolution results in a decrease in H^+ concentration.

The adsorption of Ca^{2+} and Mg^{2+} and the release of sodium (Na^+) by exchange reactions with clay minerals and organic materials results in decreased Ca^{2+} and Mg^{2+} concentrations and an increased Na^+ concentration. This process also results in additional carbonate-mineral dissolution, resulting in a decrease in H^+ concentration and an increase in HCO_3^- concentration.

The geochemical processes that predominate in an area are dependent on the hydrologic and mineralogic conditions. Therefore, depending on local conditions, the ground water can be of a calcium magnesium bicarbonate, calcium magnesium sulfate, sodium bicarbonate, or sodium sulfate type. Although the initial reactions result in an increase in acidity, much of the acidity is buffered by dissolution of carbonate materials.

EFFECTS OF STRIP MINING ON WATER QUALITY OF HIGH-WALL LAKES AND AQUIFERS

Water from high-wall lakes and aquifers in the study area had dissolved-solids concentrations several orders of magnitude greater than precipitation. Precipitation at Ashland (45 miles south of the study area) had a dissolved-solids concentration of about 7 milligrams per liter. Concentrations of specific constituents in precipitation also were determined (table 5).

Dissolved-solids concentrations in water from three high-wall lakes ranged from 1,090 to 2,410 milligrams per liter, and had a median value of 2,059 milligrams per liter (table 6). The water generally was a calcium magnesium sulfate type (fig. 15).

Concentrations of dissolved-solids in water from the glacial drift ranged from 239 to 1,280 milligrams per liter, and had a median value of 559 milligrams per liter (table 7). The water generally was either a calcium magnesium bicarbonate or calcium magnesium sulfate type (fig. 16).

Dissolved-solids concentrations in water from bedrock ranged from 580 to 883 milligrams per liter and had a median value of 775.5 milligrams per liter (table 8). The water generally was either a sodium bicarbonate or calcium bicarbonate type (see fig. 16).

Concentrations of dissolved-solids in water from wells in or near spoil ranged from 1,890 to 4,660 milligrams per liter, and had a median value of 2,860 milligrams per liter (table 9). The water generally was a calcium magnesium sulfate type (see fig. 15), which was similar to water from high-wall lakes and similar to some of the water in the glacial drift. Water from wells completed in or near spoil was more uniform in composition than water from wells completed in glacial drift or bedrock, as shown by the closer grouping of ion-percentage values of water from spoil (see figs. 15 and 16).

Water from wells completed in or near spoil had greater median concentrations of many ions than water from other wells completed in the glacial drift or bedrock (table 10.) In water from wells completed in or near spoil, the median concentration of calcium was 5 times greater, magnesium 6 times greater, sulfate 24 times greater, iron 19 times greater, and manganese 15 times greater than in water from wells completed in glacial drift. The median concentrations of potassium and chloride were smaller in water from wells completed in or near spoil than in water from wells completed in glacial drift.

Water from wells completed in or near spoil also had greater median concentrations of many ions than water from wells completed in the bedrock. In water from wells completed in or near spoil, the median concentration of calcium was 45 times greater, magnesium 22 times greater, sulfate 16 times greater, iron 242 times greater, and manganese 47 times greater than in water from wells completed in bedrock. In contrast, the median concentrations of sodium, potassium, and chloride were smaller in water from wells completed in or near spoil than in water from wells completed in bedrock.

Table 5.--Average chemical composition of precipitation at Ashland, December 1981 to April 1982

Property or constituent[1]	Quantity or concentration
pH, in units	4.5
Calcium	0.30
Magnesium	0.06
Sodium	0.11
Potassium	0.05
Bicarbonate[2]	2.0
Sulfate	2.44
Chloride	0.22
Ammonia	0.27
Nitrate	1.30
Phosphate	Less than 0.003

[1] In milligrams per liter, unless otherwise noted. Averages are weighted by volume for 20 weeks, except pH which is for 7 months, beginning during November 1981. From G. S. Henderson (Columbia, University of Missouri, written commun., 1983).

[2] Estimated from data compiled by Freeze and Cherry (1979, p. 239).

Table 6.--Summary of selected properties and concentrations of chemical constituents in water from three high-wall lakes

[Concentrations in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter at 25° Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, in µS/cm	3	2,460	2,460	1,420	3,300	1,040
pH, in units	3	--	7.4	2.3	8.2	--
Water temperature, in °C	3	25.2	27.5	18	30	6.3
Hardness, as $CaCO_3$	3	1,191	1,265	690	1,620	468
Noncarbonate hardness, as $CaCO_3$	3	1,076	1,265	570	1,390	443
Dissolved calcium	3	297	350	140	400	137
Dissolved magnesium	3	109	95	83	150	36
Dissolved sodium	3	47	40	33	68	19
Dissolved potassium	3	8	8.3	6.4	10	1.8
Bicarbonate	3	82	96	0	150	76
Alkalinity, as $CaCO_3$	3	116	125	0	224	112

Table 6.--Summary of selected properties and concentrations of chemical constituents in water from three high-wall lakes--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Dissolved sulfate	3	1,337	1,400	710	1,900	596
Dissolved chloride	3	3.9	4.0	3.6	4.1	0.3
Dissolved fluoride	2	0.35	0.35	0.3	0.4	0.07
Dissolved silica, as SiO_2	2	9.3	9.3	3.6	15	8.1
Dissolved solids, calculated sum	3	1,854	2,059	1,090	2,410	685
Dissolved aluminum, in µg/L	3	5,300	10	0	16,000	9,230
Dissolved iron, in µg/L	3	30,000	40	19	90,000	51,900
Dissolved manganese, in µg/L	3	1,700	340	8	4,700	2,620

Table 7.--Summary of selected properties and concentrations of chemical constituents in water from nonstrip-mine affected glacial drift

[Concentrations in milligrams per liter unless otherwise indicated; µS/cm, micrsiemens per centimeter at 25° Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, in µS/cm	4	778	679	405	1,340	405
pH, in units	18	--	7.4	6.8	8.3	--
Water temperature, in °C	6	15.3	14.85	11	21	3.3
Hardness, as $CaCO_3$	1	670	670	670	670	--
Noncarbonate hardness, as $CaCO_3$	1	240	240	240	240	--
Dissolved calcium	18	102	85.5	42	210	47
Dissolved magnesium	18	31	28.5	4.6	84	19
Dissolved sodium	17	46	48	1.0	120	38
Dissolved potassium	15	20	10	0.22	69	24
Bicarbonate	18	354	363	124	618	154

Table 7.--Summary of selected properties and concentrations of chemical constituents in water from nonstrip-mine affected glacial drift--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Alkalinity, as $CaCO_3$	4	306	326.5	136	435	126
Dissolved sulfate	18	158	77	10	756	184
Dissolved chloride	18	17.9	10.5	4	62	17
Dissolved fluoride	16	0.35	0.305	0.00	0.73	0.19
Dissolved silica, as SiO_2	7	17	16	7.4	33	8.4
Dissolved solids, calculated sum	18	602	559	239	1,280	289
Dissolved aluminum, in µg/L	5	4.0	0	0	10	5
Dissolved iron, in µg/L	17	944	260	0	3,500	1,207
Dissolved manganese, in µg/L	15	919	300	0	5,000	1,350

Table 8.--Summary of selected properties and concentrations of chemical constituents in water from bedrock

[Concentrations in milligrams per liter, unless otherwise indicated; µS/cm at 25°C, microsiemens per centimeter at 25° Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, in µS/cm	2	1,410	1,410	1,370	1,450	57
pH, in units	4	--	8.95	7.8	10.3	--
Water temperature, in °C	4	14.4	14.1	14.0	15.3	0.6
Hardness, as $CaCO_3$	2	38	37.5	13	62	35
Noncarbonate hardness, as $CaCO_3$	2	0	0	0	0	0
Dissolved calcium	4	25	10.9	3.7	76	34
Dissolved magnesium	4	8.4	8.35	0.8	16	6.3
Dissolved sodium	4	187	190	49	320	143
Dissolved potassium	4	38	15	1.8	120	55
Bicarbonate	4	414	418	269	550	133

Table 8.--Summary of selected properties and concentrations of chemical constituents in water from bedrock--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Alkalinity, as $CaCO_3$	2	710	710.5	461	960	353
Dissolved sulfate	4	124	113.5	0	270	111
Dissolved chloride	4	10	7.35	6.6	19	6.0
Dissolved fluoride	4	0.8	0.3	0	2	1.0
Dissolved silica, as SiO_2	4	18	17.5	9.4	28	8.8
Dissolved solids, calculated sum	4	754	775.5	580	883	134
Dissolved aluminum, in µg/L	4	10	5	0	30	14
Dissolved iron, in µg/L	4	28	21	20	50	15
Dissolved manganese, in µg/L	4	2,550	100	7	10,000	4,970

Table 9.--Summary of selected properties and concentrations of chemical constituents in water from in or near spoil

[Concentrations in milligrams per liter, unless otherwise indicated; µS/cm at 25°C, microsiemens per centimeter at 25° Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, in µS/cm	55	3,180	3,060	2,210	4,680	534
pH, in units	55	--	6.6	4.2	7.4	--
Water temperature, in °C	55	14.5	15.5	9.5	18.5	2.4
Hardness, as $CaCO_3$	55	2,010	2,000	910	3,400	513
Noncarbonate hardness, as $CaCO_3$	55	1,590	1,600	590	2,900	506
Dissolved calcium	55	484	500	220	650	99
Dissolved magnesium	55	194	190	86	420	75
Dissolved sodium	55	104	75	9.8	410	101
Dissolved potassium	55	7.7	6.1	2.2	19	4.3
Bicarbonate	55	504	510	0	910	241

Table 9.--Summary of selected properties and concentrations of chemical constituents in water from in or near spoil--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Alkalinity, as $CaCO_3$	55	413	418	0	746	198
Dissolved sulfate	55	1,860	1,900	1,100	3,000	445
Dissolved chloride	55	4.7	3.6	1.1	18	3.7
Dissolved fluoride	55	0.7	0.4	0.2	2.8	0.57
Dissolved silica, as SiO_2	55	14	15	1.3	21	4.2
Dissolved solids, calculated sum	55	2,900	2,860	1,890	4,660	610
Dissolved nitrate, as N	18	0.03	0.00	0.00	0.16	0.04
Dissolved aluminum, in µg/L	55	1,510	40	0	25,000	5,110
Dissolved iron, in µg/L	55	14,900	5,100	250	96,000	19,000
Dissolved manganese, in µg/L	55	5,880	4,700	1,000	18,000	3,860

Table 10.--Comparison of medians of properties and selected chemical constituents in precipitation, high-wall lake water, and well water from glacial drift, bedrock, and in or near spoil

[Results reported in milligrams per liter unless otherwise indicated; µg/L, micrograms per liter --, no data]

Property or constituent	Precipitation[1]	High-wall lakes	Wells		
			Glacial drift	Bedrock	In or near spoil
pH, in units	4.5	7.4	7.4	8.95	6.6
Dissolved calcium	0.30	350	85.5	10.9	500
Dissolved magnesium	0.06	95	28.5	8.35	190
Dissolved sodium	0.11	40	48	190	75
Dissolved potassium	0.05	8.3	10	15	6.1
Bicarbonate	2.0	95	363	418	510
Dissolved sulfate	2.44	1,400	77	113.5	1,900
Dissolved chloride	0.22	4.0	10.5	7.35	3.6
Dissolved silica, as SiO_2	--	9.3	16	17.5	15
Dissolved solids	7	2,059	559	775.5	2,860
Dissolved iron, in µg/L	--	40	260	21	5,100
Dissolved manganese, in µg/L	--	340	300	100	4,700

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[1] Values for precipitation are volume-weighted means (see table 5).

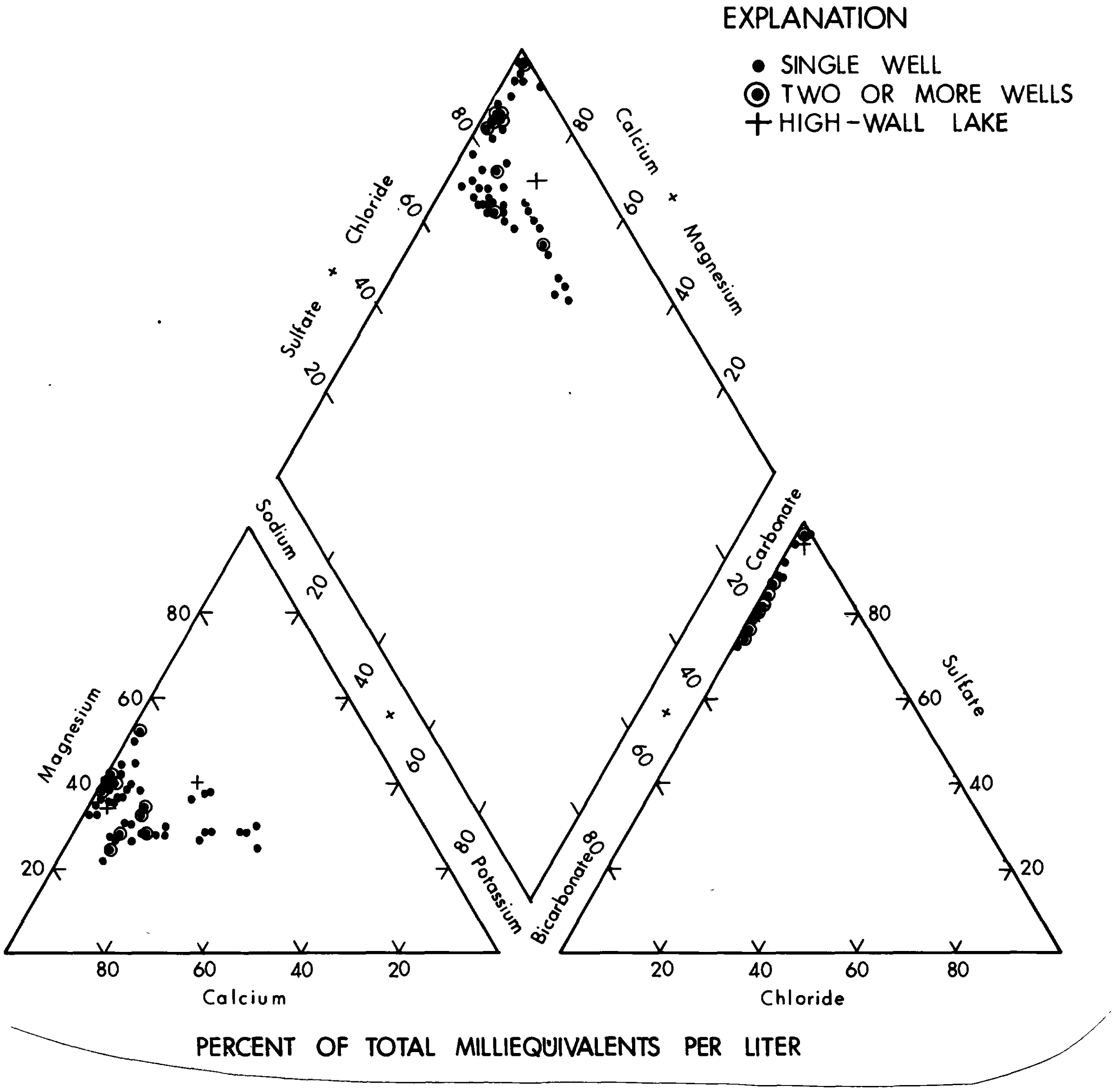

Figure 15.--Major ions in water from 14 wells (55 analyses) completed in or near spoil and 3 high-wall lakes in or near spoil.

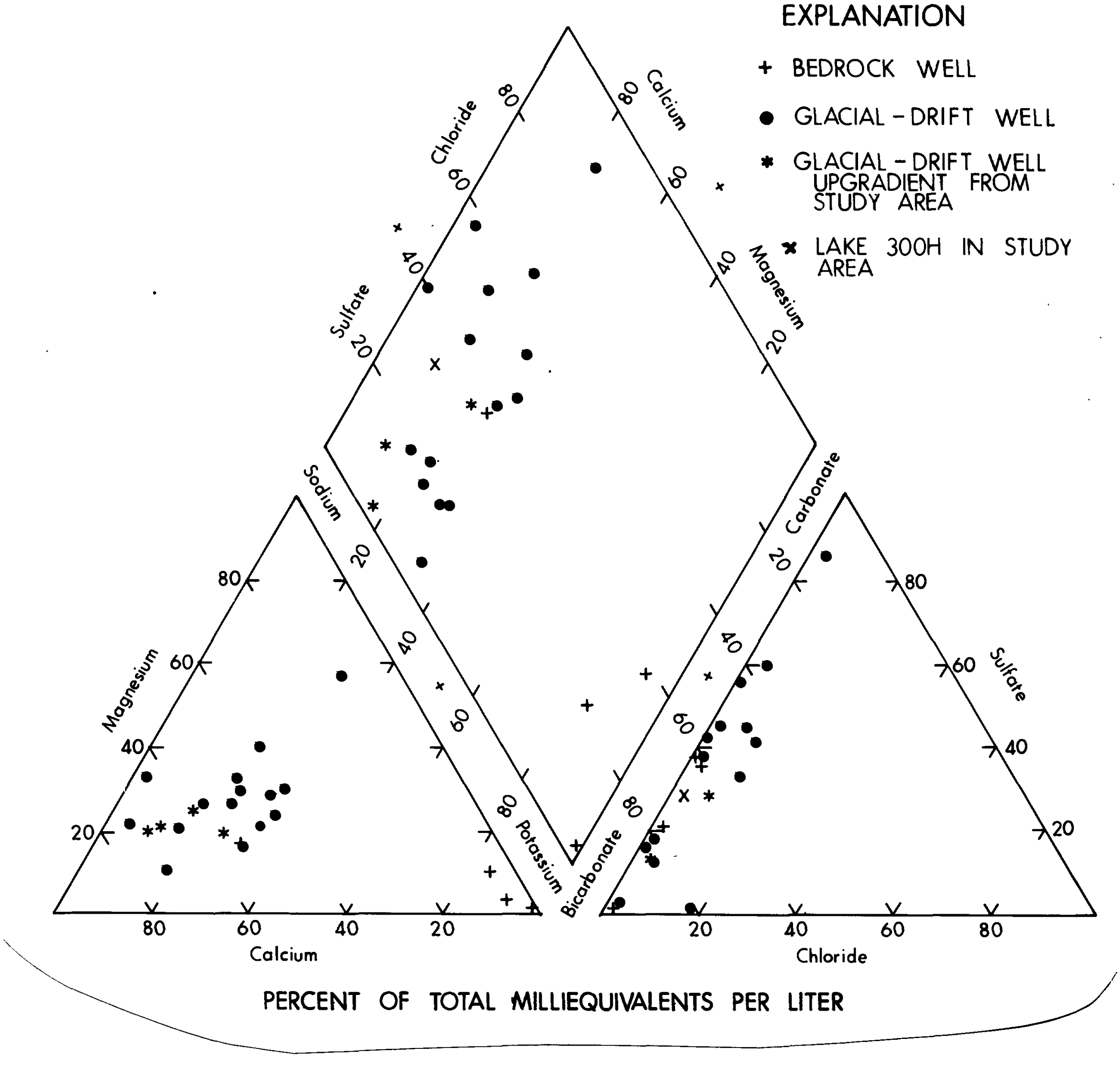

Figure 16.--Major ions in water from 4 wells completed in bedrock, 18 wells completed in glacial drift, and 1 lake in glacial drift, not affected by strip mining.

The median pH of water from in or near spoil was 6.6, which was smaller than the median pH of water from glacial drift (7.4) and the median pH of water from bedrock (8.95). The smaller pH in water from in or near spoil probably was caused by sulfuric acid produced from pyrite oxidation, although carbonate reactions probably neutralize most of the acidity that is produced. The pH of water from the bedrock was somewhat alkaline and probably results from carbonate reactions in a hydrologic system closed to the atmosphere (G. G. Seifert, University of Missouri, written commun., 1981; Freeze and Cherry, 1979, p. 108-112 and 256-257).

Changes in pH and selected chemical constituents along flow paths were examined in each spoil area. In 1940 spoil, wells 2 and 3 are downgradient from well 4 (see fig. 10) and water from wells 2 and 3 generally had larger concentrations of magnesium, sulfate, and dissolved solids (fig. 17). In 1952 spoil, the concentration of manganese increased downgradient, but pH and concentrations of calcium, magnesium, and dissolved solids decreased downgradient (see figs. 11 and 18). Concentrations in water from well 8 generally did not conform to these trends, possibly due to different solute sources or mixing with water from the underlying bedrock. In 1968 spoil, well 12 was downgradient from wells 11 and 13 (see fig. 11), and water from well 12 generally had larger concentrations of calcium, magnesium, iron, manganese, sulfate, and dissolved solids and had a smaller pH value (fig. 19).

The downgradient trends in water quality were similar for the 1940 and 1968 spoil areas, but different for the 1952 spoil. The lack of a similar trend in water-quality changes for all three spoil areas indicates different solute sources or different sources of recharge to the spoils. Because mineralogical changes were not discerned, the source of recharge probably was the main contributing factor.

Statistical comparisons were used to determine if the general water quality differed between the 1940-, 1952- and 1968-spoil areas. Because the data generally were not normally distributed, the nonparametric Duncan multiple-range test on the means of the ranks of the data was used. Statistical summaries of data by spoil area are given in the "Supplemental Data" section at the back of the report.

Comparisons of mean rank values of pH, and concentrations of calcium, magnesium, iron, manganese, sulfate, chloride, and dissolved solids are shown in table 11. For each property or constituent shown in the table, spoil-area mean designated by the same arbitrary letter are not different at the 95-percent level of confidence. For example, the mean-rank pH values of the 1940 and 1952 spoil were not significantly different, as indicated by the letter designation of B. However, they were significantly different from the mean-rank pH of 1968 spoil, indicated by A. If the letter designation for a mean includes both A and B, as for manganese from the 1940 spoil, then that mean was not significantly different from the means of either the A or B classification.

The 1940 and 1952 spoil mean-rank values were not significantly different for pH, calcium, iron, manganese, and dissolved solids and were significantly different for magnesium, sulfate, and chloride. The 1952 and 1968 spoil values were not significantly different for iron, but were significantly different for pH, calcium, magnesium, manganese, sulfate, chloride, and dissolved solids. However, the 1940- and 1968-spoil values were not significantly different for the listed constituents, except calcium and pH. Therefore, although differences in general water quality existed among the spoil areas, these differences cannot be attributed to age of the spoil. For the spoil areas studied, the major changes in water quality occurred within 12 years or less and have persisted for more than 40 years.

Chemical-equilibrium relationships were determined using the computer program WATEQF (Plummer and others, 1976). WATEQF calculates the degree of saturation of the water from a water-quality analysis with respect to given minerals. The degree of saturation is expressed by the saturation index, which is the logarithm of the ratio of the ion-activity product to the temperature-corrected equilibrium constant (see "Supplemental Data" section at the back of report). Positive values of the saturation index indicate supersaturation, negative values indicate undersaturation, and values of about zero indicate saturation or equilibrium.

To evaluate the saturation index for minerals involved in oxidation or reduction reactions, the oxidation potential (Eh) needs to be determined. For water from wells N, P, Q, and R (see fig. 1), which were completed in either glacial drift or bedrock, the Eh was determined by calomel electrode. These measured values range from 0.075 to 0.222 volt, which represent oxidizing conditions (table 12). The Eh of water from most other wells completed in either glacial drift or bedrock was assumed to be 0.222 volt, based on the measured value from well N.

For water from wells completed in or near spoil (wells 1-15), the Eh was determined in WATEQF from the ratio of the concentrations of sulfate to sulfide. The odor of hydrogen sulfide gas was detected in water from all wells in or near spoil and, because the odor is detectable in water containing small concentrations, the sulfide concentration was estimated to be 0.1 milligram per liter. The calculated Eh values ranged from -0.197 to 0.014 volt (see table 12), which generally indicates reducing conditions.

For water from wells T, U, and V, which were completed in glacial drift, and water from high-wall lakes, Eh was not determined or estimated. The value of 0.000 volt was used for these calculations in WATEQF.

Because most Eh values used for equilibrium calculations were estimated, the results of calculations for all minerals involved in oxidation or reduction reactions need to be considered with caution. However, the results can be useful to discern general equilibrium conditions and trends. The minerals of interest that are involved in oxidation or reduction reactions are amorphous ferric hydroxide, goethite, pyrite, and siderite.

The saturation indices for water from precipitation, high-wall lakes, and wells in the study area are included in the "Supplemental Data" section at the back of this report. A summary of the saturation indices is given in table 13. Water from all sources, except precipitation, generally was near equilibrium with respect to calcite, dolomite, and quartz; water from all sources, except wells completed in or near spoil, was undersaturated with respect to gypsum.

Table 11.--Comparison of means of property or constituent concentration in water from spoil of different ages

Property or constituent	Mean-rank comparison letter[1] 1940 spoil (18 samples)	1952 spoil (25 samples)	1968 spoil (12 samples)
pH	B	B	A
Dissolved solids	A,B	A	B
Dissolved calcium	A	A	B
Dissolved magnesium	B	A	B
Dissolved iron	A	A	A
Dissolved manganese	A,B	A	B
Dissolved sulfate	B	A	B
Dissolved chloride	A	B	A

[1] Mean-rank values with the same letter symbol underneath are not significantly different at the 95 percent level of confidence as determined by the Duncan multiple-range test on ranks.

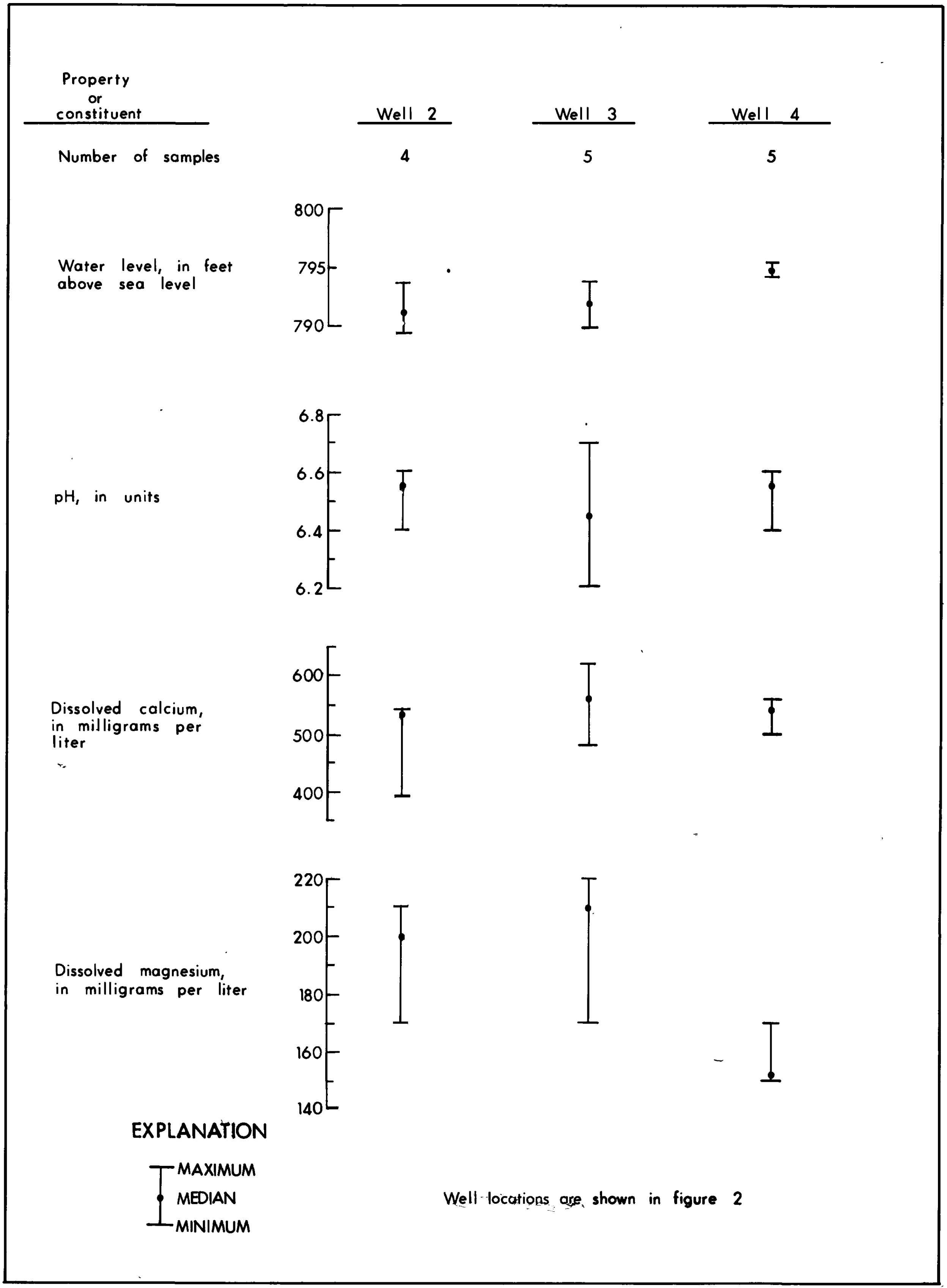

Figure 17.--Ranges and medians of water levels, pH, and selected chemical constituents in water from three wells completed in 1940 spoil.

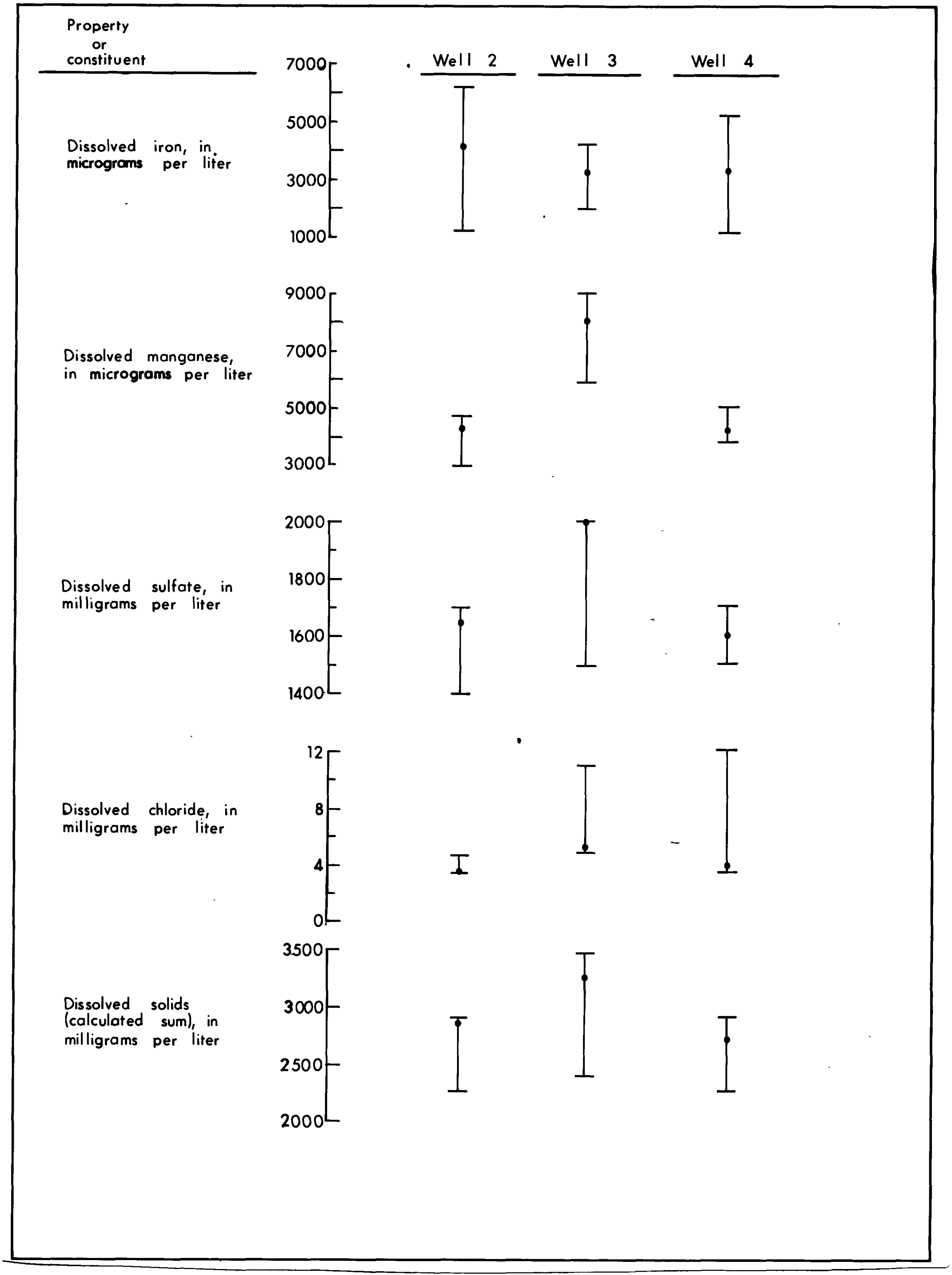

Figure 17.--Ranges and medians of water levels, pH, and selected chemical constituents in water from three wells completed in 1940 spoil--Continued.

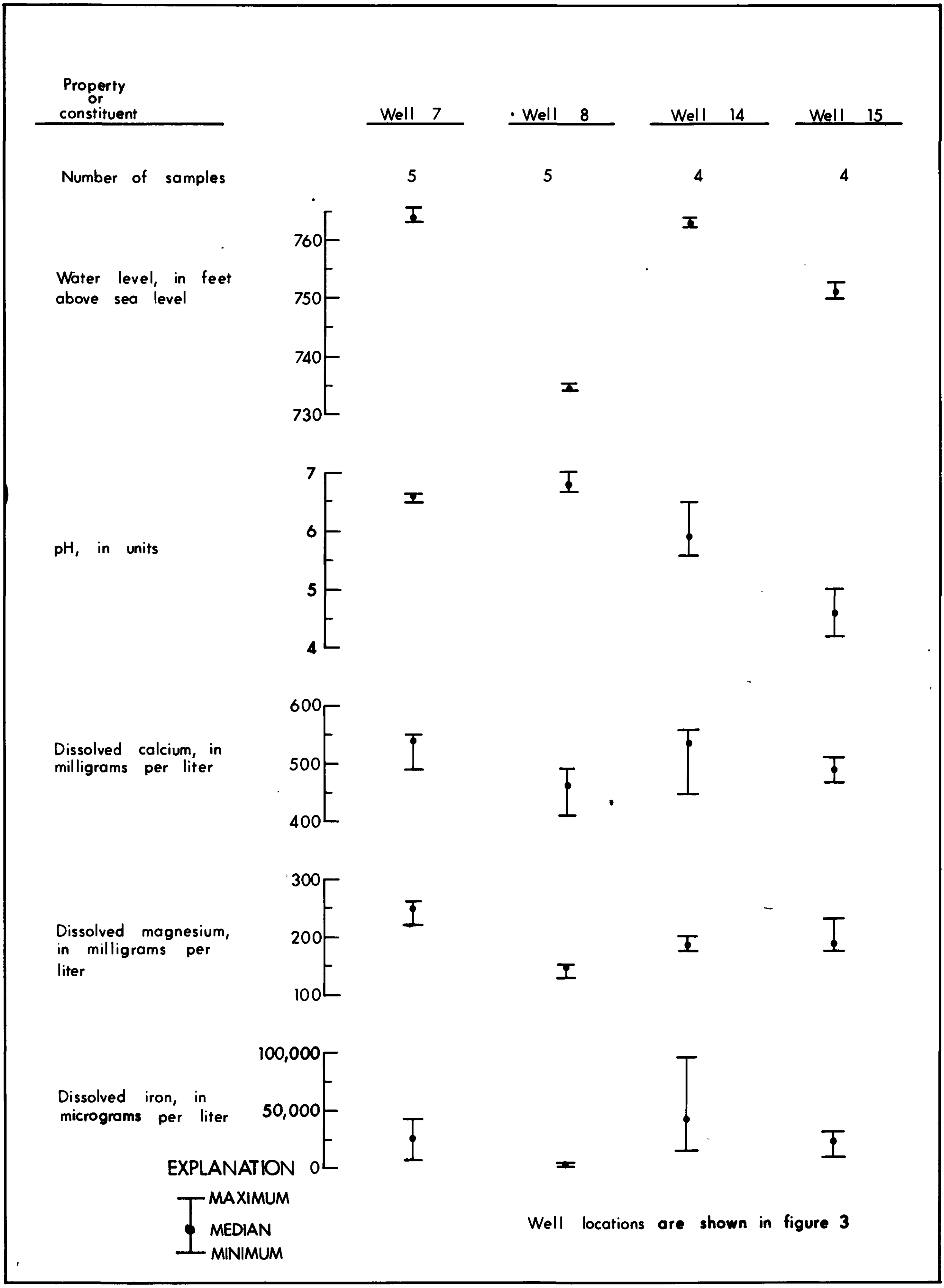

Figure 18.--Ranges and medians of water levels, pH, and selected chemical constituents in water from four wells completed in 1952 spoil.

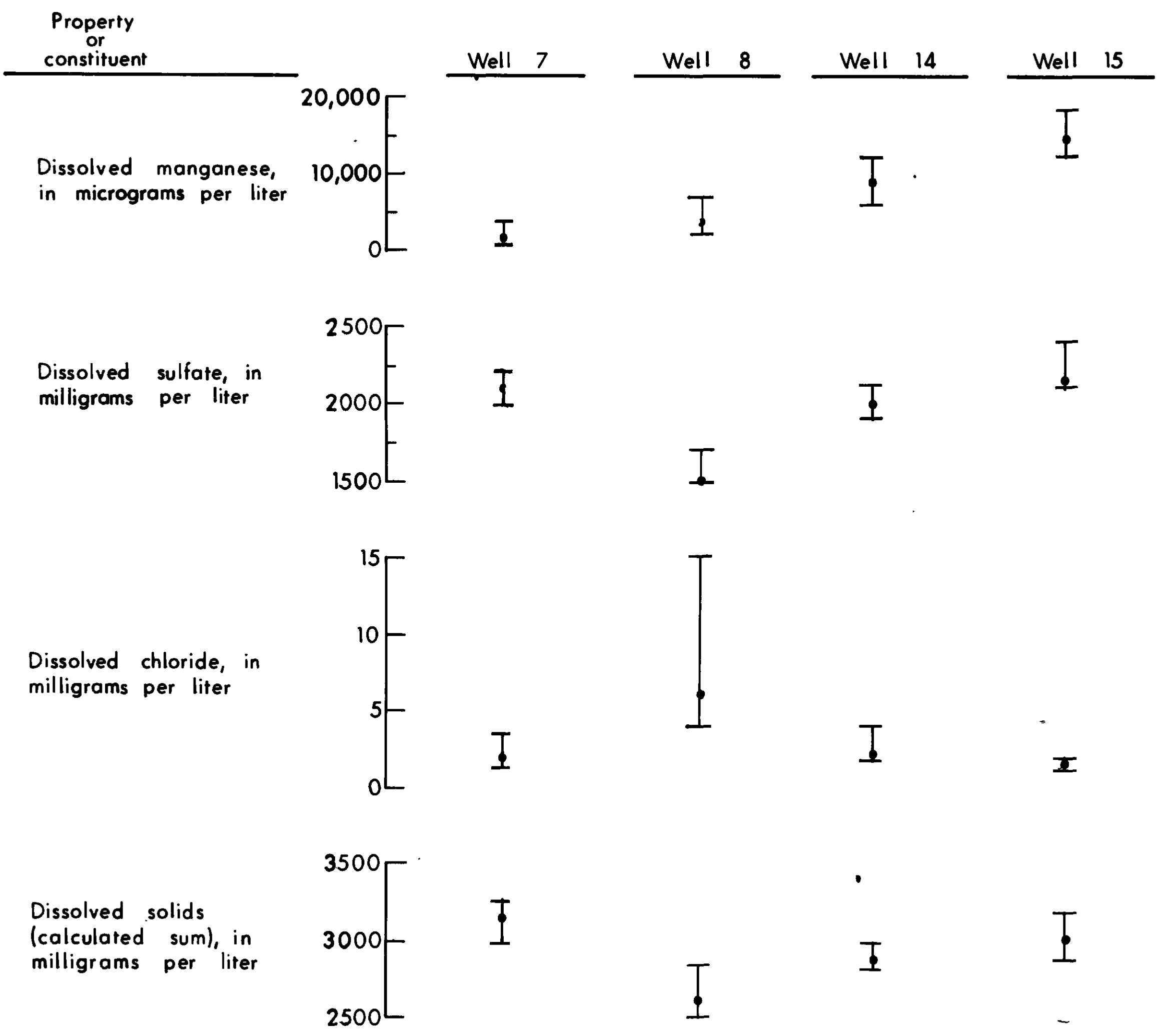

Figure 18.--Ranges and medians of water levels, pH, and selected chemical constituents in water from four wells completed in 1952 spoil--Continued.

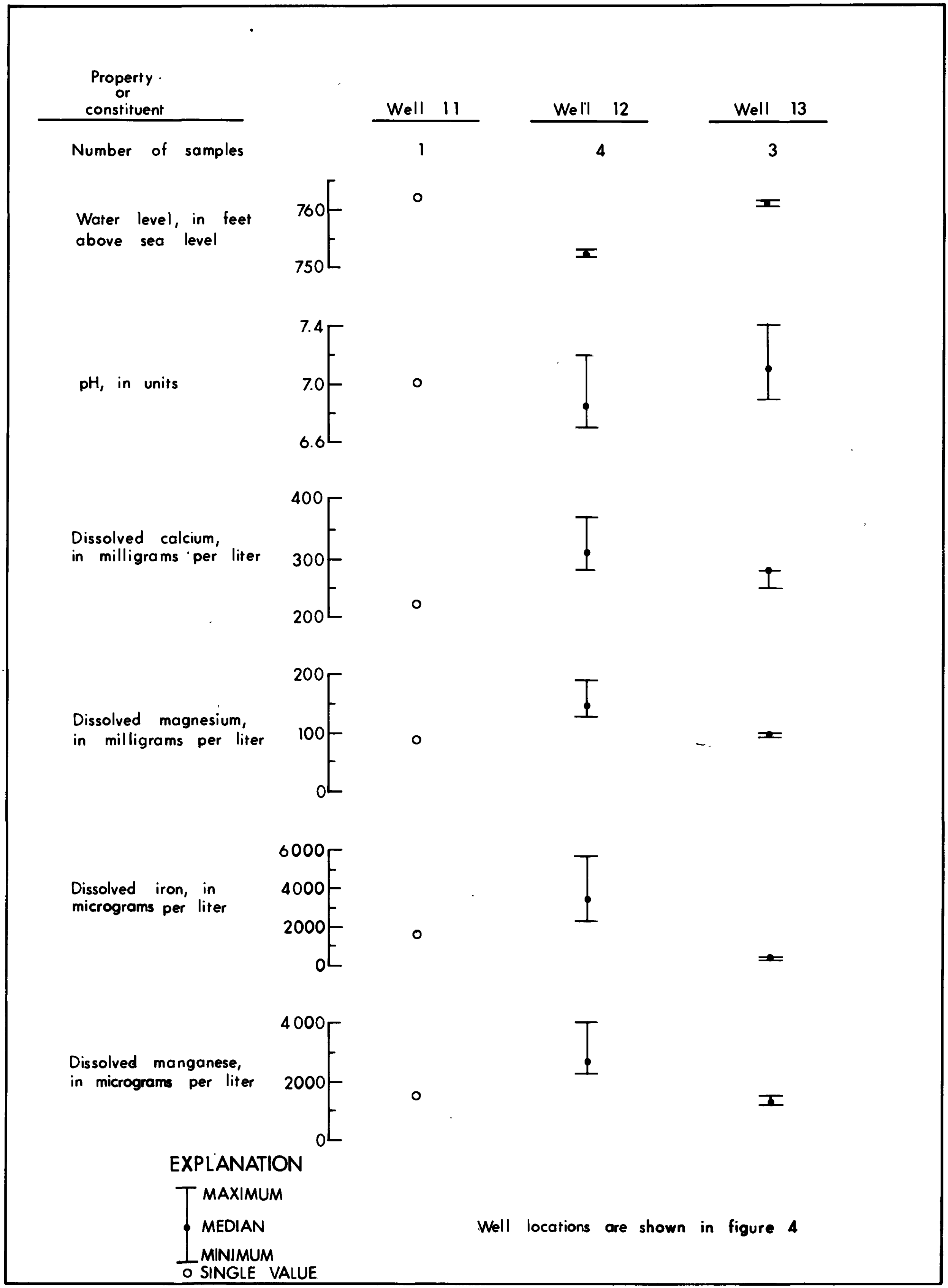

Figure 19.--Ranges and medians of water levels, pH, and selected chemical constituents in water from three wells completed in 1968 spoil.

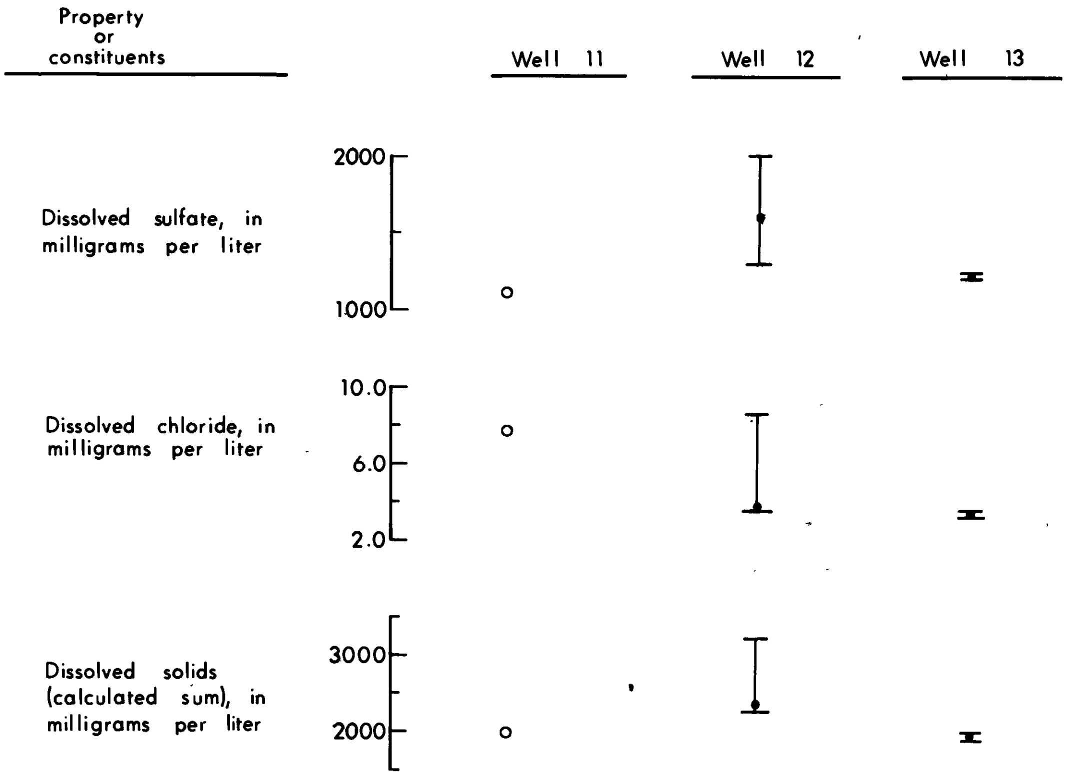

Figure 19.--Ranges and medians of water levels, pH, and selected chemical constituents in water from three wells completed in 1968 spoil--Continued.

Table 12.--Oxidation-potential (Eh) values used in chemical-equilibrium calculations

[--, not applicable]

Sample source	Eh value, in volts	Method of determining Eh
	WELLS (figs. 1-4)	
1	-0.155 to -0.133	Sulfate-to-sulfide-ion ratio[1]
2	-.146 to -.131	Do.
3	-.153 to -.118	Do.
4	-.145 to -.132	Do.
6	-.168 to -.158	Do.
7	-.149 to -.122	Do.
8	-.173 to -.144	Do.
9	-.177 to -.123	Do.
10	-.167 to -.136	Do.
11	-.174	Do.
12	-.197 to -.154	Do.
13	-.191 to -.168	Do.
14	-.138 to -.068	Do.
15	-.348 to .025	Do.
A	.222	Assigned[2]
B	.222	Do.
C	.222	Do.
D	.222	Do.
E	.222	Do.
F	.222	Do.
G	.222	Do.
H	.222	Do.
I	.222	Do.
H	.222	Do.
I	.222	Do.
J	.222	Do.
K	.222	Do.
L	.222	Do.
M	.222	Do.
N	.222	Measured by calomel electrode[3]
O	.222	Assigned[2]
P	.142	Measured by calomel electrode[3]
Q	.075	Do.
R	.109	Do.

Table 12.--Oxidation-potential (Eh) values used in chemical-equilibrium calculations--Continued

Sample source	Eh value, in volts	Method of determining Eh
	WELLS (figs. 1-4)--continued	
S	0.222	Assigned[2]
T	--	Oxidation or reduction ignored
U	--	Do.
V	--	Do.
	LAKES (figs. 2-4)	
101	--	Oxidation or reduction ignored
201	--	Do.
301	--	Do.
300H	--	Do.
	PRECIPITATION (table 5)	
Ashland	--	Oxidation or reduction ignored

[1] Sulfide-ion concentration assumed to be 0.1 milligram per liter.

[2] Assigned the same value as measured for well N.

[3] From Seifert, 1982.

Table 13.--Summary of saturation states in water from precipitation, high-wall lakes, and wells completed in glacial drift, bedrock, and in or near spoil

[U, undersaturated; E, equilibrium; S, supersaturation; --, not calculated]

Mineral	General saturation state for water from indicated source[1]				
			Wells		
	Precipitation	High-wall lakes	Glacial drift	Bedrock	In or near spoil
Calcite ($CaCO_3$)	U	E to S	E	E to S	E (except wells 14 and 15)
Dolomite [$CaMg(CO_3)_2$]	U	E to S	Near E	E to S	E (except wells 14 and 15)
Gypsum ($CaSO_4 \cdot 2H_2O$)	U	U to E	U	U	E
Amorphous ferric hydroxide [$Fe(OH)_3$]	--	U to S	S	E to S	U
Goethite [$FeO(OH)$]	--	S	S	S	E to S (except well 15)
Siderite ($FeCO_3$)	--	U	U	U	U to S
Pyrite (FeS_2)	--	--	--	--	S
Quartz (SiO_2)	--	E	E	E	E

[1] Saturation indices for individual water samples are in "Supplemental Data" section at back of report.

Precipitation infiltrating through glacial drift, bedrock, or spoil would dissolve quartz and carbonate minerals, such as calcite and dolomite, until chemical equilibrium is attained. Precipitation infiltrating spoil also would dissolve gypsum or oxidize pyrite until equilibrium is attained or limiting reactants, such as oxygen, are consumed.

Water flowing from high-wall lakes, glacial drift, or bedrock through spoil would dissolve gypsum or oxidize pyrite until equilibrium is attained. Carbonate minerals also probably would be dissolved because they are more soluble at the lesser pH values in water from spoil.

Water from glacial drift and bedrock generally was undersaturated with respect to gypsum, whereas water in or near spoil generally was saturated with respect to gypsum. The difference in spoil could be attributed either to dissolution of freshly exposed gypsum or to oxidation of freshly exposed pyrite, or both. The exposure of the minerals probably resulted from disturbance of the glacial drift and bedrock overburden during mining because, during a long period, any exposed gypsum would have been dissolved in the chemically undersaturated environment and any exposed pyrite would have been oxidized in the generally oxidizing environment.

Mass-balance calculations using the computer program BALANCE (Parkhurst and others, 1982) determined the quantities of the principal minerals or other reactants that hypothetically would have dissolved or precipitated in the spoil (tables 14 and 15). The calculations are based on the change in concentration of the principal constituents in water moving into spoil from an outside source: namely, precipitation, high-wall lakes, glacial drift, or bedrock. The computer program BALANCE requires that the number of constituents equals the number of minerals or other reactants and that each constituent be present in at least one mineral or reactant.

For this study, the principal constituents are calcium, magnesium, carbon (present in water as carbonate, bicarbonate, carbon dioxide gas, and carbonic acid), sulfur (present in water mainly as sulfate), iron, and sodium. Two different sets of minerals and other reactants were used for all calculations, the difference being the mineral assumed to be the source of sulfate in water in spoil.

For the calculations in table 14, the source of sulfate was assumed to be pyrite. Considering all initial-water and spoil-water sources shown, the determined changes in water quality generally resulted from dissolution of calcite and dolomite, consumption of oxygen gas, release of carbon dioxide gas, dissolution of pyrite, and precipitation of goethite (or iron hydroxide). Ion exchange, which is the adsorption of calcium ions and subsequent release of sodium ions, occurred in all examples except for bedrock water flowing into spoil at wells 3 and 8. At wells 3 and 8, ion exchange probably was not occurring; more likely, the smaller sodium concentrations are caused by adsorption of sodium ions by organic materials in the spoil.

For the calculations in table 15, the source of sulfate was assumed to be gypsum. Considering all initial-water and spoil-water sources shown, the determined changes in water quality generally resulted from precipitation of calcite, dissolution of dolomite and gypsum, consumption of carbon dioxide gas, and the same ion-exchange reactions as described for the data in table 14.

Table 14.--Results of mass-balance calculations for chemical changes resulting from selected initial sources to spoil using pyrite as the parent-material source of sulfate

Initial water source and date (fig. 1)	Spoil-water source and date (figs. 2, 3, and 4)	Millimoles per liter of indicated reactant added to solution (positive) or released from solution (negative)[1]						
		Calcite	Dolomite	Oxygen(gas)	Carbon dioxide (gas)	Pyrite	Goethite	Ion exchange
Precipitation (see table 5, footnotes 1 and 2)	Well 3 (12-9-81)	7.29	8.23	39.00	-6.04	10.39	-10.31	2.83
	Well 8 (12-9-81)	8.73	6.19	33.37	-9.59	8.89	-8.87	3.92
	Well 12 (3-25-82)	9.61	7.84	39.07	-16.38	10.44	-10.34	8.95
Lake 101 (9-22-83)	Well 3 (7-26-83)	8.62	14.30	4.11	-17.42	1.00	-2.55	2.76
Lake 201 (7-26-83)	Well 8 (7-26-83)	3.96	-.41	12.92	9.40	.50	-.39	2.32
Lake 301 (7-25-83)	Well 12 (7-25-83)	5.34	1.93	20.81	-2.58	3.06	-3.04	3.52
Glacial-drift well V (8-25-83)	Well 3 (7-26-83)	7.34	8.27	69.99	-10.26	10.34	-10.29	2.83
	Well 8 (7-26-83)	7.33	4.98	29.21	-12.87	7.74	-7.64	2.83

Table 14.--Results of mass-balance calculations for chemical changes resulting from selected initial sources to spoil using pyrite as the parent-material source of sulfate--Continued

Initial water source and date (fig. 1)	Spoil-water source and date (figs. 2, 3, and 4)	Millimoles per liter of indicated reactant added to solution (positive) or released from solution (negative)[1]						
		Calcite	Dolomite	Oxygen(gas)	Carbon dioxide (gas)	Pyrite	Goethite	Ion exchange
Glacial-drift well T (8-24-83)	Well 12 (7-25-83)	6.12	4.89	43.99	-9.98	6.48	-6.47	4.82
Glacial-drift well Q (9-15-81)	Well 3 (12-9-81)	3.72	6.05	33.00	-6.22	8.78	-8.73	1.56
	Well 8 (12-9-81)	5.15	4.01	27.37	-9.77	7.28	-7.29	2.66
	Well 12 (3-25-82)	6.04	5.66	33.07	-16.59	8.84	-8.75	7.68
Bedrock well R (9-15-84)	Well 3 (12-9-81)	.71	7.94	33.77	-5.68	9.00	-8.92	-3.72
	Well 8 (12-9-81)	2.15	5.90	28.14	-9.23	7.50	-7.48	-2.62
	Well 12 (3-25-82)	3.03	7.55	33.84	-16.02	9.04	-8.94	2.40

Table 14.--Results of mass-balance calculations for chemical changes resulting from selected initial sources to spoil using pyrite as the parent-material source of sulfate--Continued

Initial water source and date (fig. 1)	Spoil-water source and date (figs. 2, 3, and 4)	Millimoles per liter of indicated reactant added to solution (positive) or released from solution (negative)[1]						
		Calcite	Dolomite	Oxygen(gas)	Carbon dioxide (gas)	Pyrite	Goethite	Ion exchange
Bedrock well S (9-15-81)	Well 3 (12-9-81)	0.29	8.20	38.94	-1.72	10.37	-10.30	-4.12
	Well 8 (12-9-81)	1.73	6.16	33.31	-5.28	8.87	-8.86	3.02
	Well 12 (3-25-82)	2.61	7.81	39.01	-12.06	10.42	-10.32	2.00

[1] Results from computer program BALANCE (Parkhurst and others, 1982). A positive millimole-per-liter value for ion exchange indicates binding of that quantity of calcium ion and release of twice that quantity of sodium ion. Conversely, a negative value indicates binding of twice the millimole-per-liter quantity of sodium ion and release of that quantity of calcium ion.

Table 15.--Results of mass-balance calculations for chemical changes resulting from selected initial sources to spoil using gypsum as the parent-material source of sulfate

Initial water source and date (fig. 1)	Spoil-water source and date (figs. 2, 3, and 4)	Millimoles per liter of indicated reactant added to solution (positive) or released from solution (negative)[1]				
		Calcite	Dolomite	Gypsum	Carbon dioxide (gas)	Ion exchange
Precipitation (see table 5, footnotes 1 and 2)	Well 3 (12-9-81)	-13.48	8.23	20.77	14.74	2.83
	Well 8 (12-9-81)	-9.05	6.19	17.77	8.18	3.92
	Well 12 (3-25-82)	-11.26	7.84	20.87	4.50	8.95
Lake 101 (9-22-83)	Well 3 (7-26-83)	6.62	14.30	2.00	-15.42	2.76
Lake 201 (7-26-83)	Well 8 (7-26-83)	2.96	-.41	1.00	10.40	2.32
Lake 301 (7-25-83)	Well 12 (7-25-83)	-.77	1.93	6.11	3.53	3.52
Glacial-drift well V (8-25-83)	Well 3 (7-26-83)	-13.34	8.27	20.68	10.42	2.83
	Well 8 (7-26-83)	-8.15	4.98	15.48	2.62	2.83

Table 15.--Results of mass-balance calculations for chemical changes resulting from selected initial sources to spoil using gypsum as the parent-material source of sulfate--Continued

Initial water source and date (fig. 1)	Spoil-water source and date (figs. 2, 3, and 4)	Millimoles per liter of indicated reactant added to solution (positive) or released from solution (negative)[1]				
		Calcite	Dolomite	Gypsum	Carbon dioxide (gas)	Ion exchange
Glacial-drift well T (8-24-83)	Well 12 (7-25-83)	-6.85	4.89	12.97	2.99	4.82
Glacial-drift well Q (9-15-81)	Well 3 (12-9-81)	-13.86	6.05	17.57	11.36	1.56
	Well 8 (12-9-81)	-9.42	4.01	14.57	4.80	2.66
	Well 12 (3-25-82)	-11.64	5.66	17.67	1.12	7.68
Bedrock well R (9-15-84)	Well 3 (12-9-81)	-17.28	7.94	17.99	12.31	-3.72
	Well 8 (12-9-81)	-12.84	5.90	14.99	5.76	-2.62
	Well 12 (3-25-82)	-15.06	7.55	18.09	2.07	2.40

Table 15.--Results of mass-balance calculations for chemical changes resulting from selected initial sources to spoil using gypsum as the parent-material source of sulfate--Continued

Initial water source and date (fig. 1)	Spoil-water source and date (figs. 2, 3, and 4)	Millimoles per liter of indicated reactant added to solution (positive) or released from solution (negative)[1]				
		Calcite	Dolomite	Gypsum	Carbon dioxide (gas)	Ion exchange
Bedrock well S (9-15-81)	Well 3 (12-9-81)	-20.46	8.20	20.75	19.02	-4.12
	Well 8 (12-9-81)	-16.02	6.16	17.75	12.49	-3.02
	Well 12 (3-25-82)	-18.24	7.81	20.85	8.78	2.00

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[1] Results from computer program BALANCE (Parkhurst and others, 1982). A positive millimole-per-liter value for ion exchange indicates binding of that quantity of calcium ion and release of twice that quantity of sodium ion. Conversely, a negative value indicates binding of twice the millimole-per-liter quantity of sodium ion and release of that quantity of calcium ion.

The chemical processes that occur as water moves into spoil probably are a combination of the two sets of processes shown in tables 14 and 15. Generally, these processes are dissolution and precipitation of calcite, dissolution of dolomite, dissolution of pyrite and gypsum, precipitation of goethite (or iron hydroxide), and release of sodium ions by ion exchange.

SUMMARY

The near-surface geology of northern Missouri consists of Quaternary loess, alluvium, and glacial drift overlying Pennsylvanian bedrock. The loess is composed of fine-grained, wind-blown material and occurs on the higher ridges. The alluvium and glacial drift are composed of sand, silt, and clay. The bedrock is composed of shale, limestone, sandstone, and coal. Coal deposits of interest are the Mulky and Bevier-Wheeler seams that generally are within 100 feet of land surface. Spoil, which consists of a heterogeneous mixture of glacial drift and broken bedrock, is present where the coal seams have been strip mined. Most older mines were abandoned without reclamation.

Alluvium, glacial drift, bedrock, and spoil are aquifers in the study area. Transmissivities generally are greatest for spoil and decrease in the following order: alluvium, glacial drift, and bedrock.

Recharge to alluvium is by infiltration of precipitation and by lateral and probably vertical flow from adjacent aquifers. Recharge to glacial drift is by infiltration of precipitation and lateral flow from adjacent aquifers. Recharge to bedrock is by infiltration of precipitation and vertical flow from glacial drift. Recharge to spoil is from precipitation, lateral flow from glacial drift, and lateral and vertical flow from bedrock. Precipitation probably is the major source of recharge, both directly by infiltration and indirectly as leakage from high-wall lakes. The rate of recharge to the aquifers is unknown, but probably is small. Ground-water discharge from glacial drift, bedrock, and spoil is to alluvium, which generally discharges to streams.

The potentiometric surface in the shallow aquifers generally conformed to the topography. The direction of flow generally was from high-wall lakes in the spoil toward the East Fork Little Chariton River or South Fork Claybank Creek.

Water from high-wall lakes had a median dissolved-solids concentration of 2,059 milligrams per liter and was a calcium magnesium sulfate type. Water from glacial drift had a median dissolved-solids concentration of 559 milligrams per liter and was either a calcium magnesium bicarbonate or calcium magnesium sulfate type. Water from bedrock had a median dissolved-solids concentration of 775.5 milligrams per liter and was either a sodium bicarbonate or calcium bicarbonate type. Water from spoil had a median dissolved-solids concentration of 2,860 milligrams per liter and was a calcium magnesium sulfate type. Water from spoil had a median pH value of 6.6, which was less than the median pH value of water from drift (7.4) and the median pH value of water from bedrock (9.0).

Dissolved-solids concentration increased downgradient in two of three spoil areas. Although differences in water quality existed between the three spoil areas, the differences cannot be attributed to the age of the spoil. The changes occurred in fewer than 12 years and have persisted for more than 40 years.

Water from high-wall lakes, glacial drift, bedrock, and spoil was saturated with respect to calcite, dolomite, and quartz, but only water from spoil was saturated with respect to gypsum. The difference can be attributed either to dissolution of freshly exposed gypsum or to oxidation of freshly exposed pyrite, or both, in spoil. The exposure of the minerals probably results from disturbance of the glacial drift and bedrock overburden during mining.

The general chemical processes that occur as water moves into spoil are dissolution and precipitation of calcite, dissolution of dolomite, consumption of oxygen gas, consumption and release of carbon dioxide gas, dissolution of pyrite and gypsum, precipitation of goethite (or iron hydroxide), and release of sodium ions by ion exchange.

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SUPPLEMENTAL DATA

Table 16.--Selected data pertaining to wells for which quality-of-water data were obtained

Depth of perforated interval: O, open hole.

Type of seal: B, bentonite; C, concrete.

Method of development: A, compressed air surging; D, flushed with water from nearby lake.

Drilling fluid: E, Revert (Johnson Screens); F, Petro SH-1200 L and Stafoam 202 (Petro-Chem, Inc.).

Producing aquifer: H, glacial drift; I, consolidated rock above coal; J, coal and 15 to 20 feet beneath coal; K, spoil; L, glacial drift adjacent to spoil.

Additional comments: M, drilling losses substantial during drilling; N, obstruction after construction--water samples cannot be obtained with available equipment; P, obstruction--water samples can no longer be obtained with present equipment; Q, observation well of the U.S. Geological Survey; R, observation well of Associated Electric Cooperative, Inc.; S, dug well, rock or brick lined U, information not available.

Wells 1-15 are located in spoil areas. Wells A-V are outside of spoil areas.

--, No data or comments.

Well number and identifying letter (figs. 1-4)	Altitude of land suface (feet above sea level)	Depth of well (feet)	Depth of perforated interval (feet)	Depth of seal (feet)	Type of seal	Drilling fluid	Date completed	Method of develop-ment	Producing aquifer	Addi-tional comments
1	850.38	86.2	77.0-83.0	10.0	B	E	5-19-81	A	L	M
2	818.99	51.2	41.2-49.2	1.0	B	F	10-8-81	A, D	K	--
3	798.70	35.0	26.0-34.0	6.5	B	E	5-13-81	A, D	K	--
4	817.79	50.6	40.6-48.6	3.2	B	F	10-29-81	D	K	N
5	806.25	37.2	27.2-35.2	8.0	B	F	10-28-81	A, D	K	--
6	791.41	56.1	46.1-54.1	9.0	B	E	5-21-81	A	K	M
7	782.43	27.2	17.2-25.2	9.0	B	E	6-3-81	A	L	M
8	752.75	39.5	29.5-37.5	17.0	B	E	6-2-81	A	L	--
9	779.91	31.2	21.2-29.2	4.0	B	F	10-29-81	A, D	K	--
10	765.96	13.8	3.8-11.8	3.5	B	F	10-30-81	A, D	K	--

Table 16.--Selected data pertaining to wells for which quality-of-water data were obtained--Continued

Well number and identifying letter (figs. 1-4)	Altitude of land suface (feet above sea level)	Depth of well (feet)	Depth of perforated interval (feet)	Depth of seal (feet)	Type of seal	Drilling fluid	Date completed	Method of develop- ment	Producing aquifer	Addi- tional comments
11	801.39	101.5	91.5-99.5	16.0	B	E	6-9-81	A	K	M, P
12	770.63	59.7	49.7-57.5	20.0	B	E	6-11-81	A	K	M
13	783.64	47.0	37.0-45.0	4.0	B	F	11-2-81	A, D	K	--
14	770.42	25.2	15.2-23.2	4.5	B	F	10-30-81	A, D	L	M
15	764.99	22.2	12.2-20.2	3.0	B	F	11-2-81	A, D	L	--
A	849	22	--	--	--	--	U	U	L	O
B	844	22	--	--	--	--	U	U	L	S
C	838	30	--	--	--	--	U	U	L	O
D	848	24	--	--	--	--	U	U	L	O
E	823	31	--	--	--	--	U	U	L	S
F	822	27	--	--	--	--	U	U	L	S
G	810	23	--	--	--	--	U	U	L	S
H	828	77	U	U	U	U	U	U	L	--
I	780	32	--	--	--	--	U	U	L	S
J	834	35	U	U	U	U	U	U	L	--
K	845	45	U	U	U	U	U	U	L	--
L	768	60	U	U	U	U	U	U	L	--
M	863	98	U	U	U	U	U	U	L	--
N	771	105.0	84.25-89.25	4.0	C	U	5-5-80	U	H	--
O	771	137.5	109.0-137.5, 0	109.5	C	U	4-31-80	U	I	--

Table 16.--Selected data pertaining to wells for which quality-of-water data were obtained--Continued

Well number and identifying letter (figs. 1-4)	Altitude of land suface (feet above sea level)	Depth of well (feet)	Depth of perforated interval (feet)	Depth of seal (feet)	Type of seal	Drilling fluid	Date completed	Method of develop- ment	Producing aquifer	Addi- tional comments
P	771	160.5	140.0-160.5, 0	140.0	C	U	4-15-80	U	J	--
Q	775.06	64.5	59.5-64.5	4.0	C	U	5-7-80	U	H	--
R	775.83	125.0	71.0-125.0, 0	71.0	C	U	5-12-80	U	I	--
S	775.08	151.0	125.0-151.0, 0	125.0	C	U	5-6-80	U	J	--
T	832	14.6	--	--	--	--	U	U	L	S
U	824	13.5	--	--	--	--	U	U	L	S
V	860	14.5	--	--	--	--	U	U	L	S

Table 17.--Water-quality analysis data for wells and lakes

[UMHOS, micromhos per centimeter at 25 ^{o}Celsius--now reported as microsiemens per centimeter at 25 ^{o}Celsius; DEG C, degrees Celsius; MG/L, milligrams per liter; UG/L, micrograms per liter; numbers in parentheses in column headings are WATSTORE codes; --, no data; <, less than]

WELL OR LAKE IDENTIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (UMHOS) (00095)	PH (STANDARD UNITS) (00400)	TEMPERATURE (DEG C) (00010)	COLOR (PLATINUM-COBALT UNITS) (00080)	OXYGEN, DISSOLVED (MG/L) (00300)	OXYGEN, DISSOLVED (PERCENT SATURATION) (00301)	HARDNESS (MG/L AS CACO3) (00900)	HARDNESS, NONCARBONATE (MG/L CACO3) (00902)	ACIDITY (MG/L AS CACO3) (00435)
1	81-07-21	2670	6.7	16.5	--	0.0	0	1637	0	79
	81-12-08	2650	6.6	12.5	10	.0	0	1479	0	--
	82-03-24	2530	6.7	15.0	--	.0	0	1603	0	114
	82-06-07	2670	6.4	16.0	--	.0	0	1653	0	94
	82-09-01	2730	6.6	16.0	--	.0	0	1678	0	--
2	81-12-08	2590	6.5	12.0	5	.8	8	1676	0	--
	82-03-24	3350	6.6	12.0	--	.0	0	2165	0	79
	82-06-07	3330	6.4	15.0	--	.0	0	2174	0	293
	82-09-01	3130	6.6	15.5	--	.0	0	2174	0	--
3	81-07-20	3090	6.5	16.5	5	.0	0	1901	0	149
	81-12-09	3870	6.5	11.0	5	.0	0	2100	0	--
	82-03-26	3630	6.7	9.5	--	.0	0	2266	0	209
	82-06-07	3700	6.2	16.0	--	.8	8	2457	0	596
	82-08-31	3660	6.3	16.0	--	.0	0	2432	0	--
	83-07-26	3680	6.3	16.0	--	.4	--	2357	0	--
	83-09-28	3580	6.6	16.0	--	.0	--	--	0	--
4	81-12-09	3150	6.6	10.5	0	.4	4	1868	0	--
	82-03-24	3320	6.5	11.5	--	.0	0	2076	0	25
	82-06-07	3025	6.4	15.5	--	.0	0	2018	0	129
	82-09-01	3020	6.6	15.0	--	.0	0	1943	0	--
6	81-07-21	3540	6.8	18.5	10	.0	0	2095	0	149
	82-03-25	4550	7.0	13.0	--	.0	0	2691	0	174
	82-06-08	4680	6.8	16.0	--	.0	0	2755	0	253
	82-09-02	4320	6.9	16.5	--	.0	0	2600	0	--
7	81-07-21	3650	6.6	17.5	10	.0	0	2305	0	154
	81-12-09	3460	6.5	10.0	5	.0	0	2296	0	.0
	82-03-25	3150	6.6	11.5	--	.0	0	2364	0	65
	82-06-08	3340	6.6	16.0	--	.2	2	2405	0	74
	82-09-02	3130	6.6	15.0	--	.0	0	2256	0	50

Table 17.--Water-quality analysis data for wells and lakes--Continued

LAKE OR WELL IDENTIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	CALCIUM DIS-SOLVED (MG/L AS CA) (00915)	MAGNESIUM, DIS-SOLVED (MG/L AS MG) (00925)	SODIUM, DIS-SOLVED (MG/L AS NA) (00930)	POTASSIUM, DIS-SOLVED (MG/L AS K) (00935)	BICARBONATE (MG/L AS HCO3) (00440)	CARBONATE (MG/L AS CO3) (00445)	ALKALINITY FIELD (MG/L AS CACO3) (00410)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2) (00405)	SULFATE DIS-SOLVED (MG/L AS SO4) (00945)	CHLORIDE, DIS-SOLVED (MG/L AS CL) (00940)	FLUORIDE, DIS-SOLVED (MG/L AS F) (00950)	SILICA, DIS-SOLVED (MG/L AS SIO2) (00955)
1	81-07-21	490	100	75	6.8	550	0	451	167	1400	18	0.6	16
	81-12-08	410	110	90	8.0	440	0	361	176	1400	15	.7	14
	82-03-24	460	110	84	7.9	370	0	303	132	1500	8.5	.6	16
	82-06-07	480	110	75	7.6	450	0	369	285	1500	8.2	.7	16
	82-09-01	490	110	77	7.6	440	0	361	176	1500	8.2	.6	16
2	81-12-08	390	170	76	5.1	560	0	459	281	1400	4.6	.5	19
	82-03-24	520	210	64	2.9	720	0	591	287	1700	3.6	.4	20
	82-06-07	540	200	56	2.9	740	0	607	468	1700	3.4	.4	21
	82-09-01	540	200	69	2.7	740	0	607	295	1600	3.4	.4	21
3	81-07-20	480	170	11	6.2	560	0	459	316	1500	11	.3	12
	81-12-09	510	200	130	8.0	860	0	705	432	2000	5.8	.4	17
	82-03-26	560	210	140	6.1	860	0	705	273	2000	5.1	.4	15
	82-06-07	620	220	150	6.2	860	0	705	862	2000	4.9	.4	18
	82-08-31	610	220	150	5.7	820	0	673	653	2000	5.2	.3	16
	83-07-26	580	220	140	6.1	870	0	--	693	2000	4.0	.4	17
	83-09-28	--	--	--	--	900	0	--	359	1900	--	--	--
4	81-12-09	500	150	95	5.2	750	0	615	299	1700	12	.4	17
	82-03-24	550	170	110	4.0	740	0	607	372	1700	3.7	.4	17
	82-06-07	560	150	98	4.7	720	0	591	455	1500	4.0	.4	19
	82-09-01	530	150	90	3.8	720	0	591	287	1500	3.4	.4	18
6	81-07-21	490	210	18	14	910	0	746	246	1700	4.5	.3	16
	82-03-25	580	300	300	17	860	0	705	137	2900	6.2	.4	14
	82-06-08	570	320	340	19	830	0	681	209	3000	6.4	.3	12
	82-09-02	530	310	360	15	780	0	640	156	2700	6.1	.3	12
7	81-07-21	510	250	11	10	510	0	418	194	2100	3.4	.6	14
	81-12-09	490	260	49	13	430	0	353	216	2200	2.9	.7	11
	82-03-25	550	240	41	11	380	0	312	152	2100	1.8	.7	11
	82-06-08	550	250	33	12	390	0	320	156	2200	1.3	.8	10
	82-09-02	540	220	26	9.5	340	0	279	136	2000	1.4	.7	10

Table 17.--Water-quality analysis data for well and lakes--Continued

WELL OR LAKE IDEN- TIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	SOLIDS, RESIDUE AT 180 DEG. C DIS- SOLVED (MG/L) (70300)	SOLIDS, SUM OF CONSTI- TUENTS, DIS- SOLVED (MG/L) (70301)	NITRO- GEN, NITRATE DIS- SOLVED (MG/L AS N) (00618)	NITRO- GEN, NITRITE DIS- SOLVED (MG/L AS N) (00613)	NITRO- GEN, AMMONIA DIS- SOLVED (MG/L AS N) (00608)	PHOS- PHORUS, ORTHO, DIS- SOLVED (MG/L AS P) (00671)	ALUM- INUM, DIS- SOLVED (UG/L AS AL) (01106)	ARSENIC DIS- SOLVED (UG/L AS AS) (01000)	CADMIUM DIS- SOLVED (UG/L AS CD) (01025)	CHRO- MIUM, DIS- SOLVED (UG/L AS CR) (01030)	CHRO- MIUM, HEXA- VALENT, DIS. (UG/L AS CR) (01032)	COPPER, DIS- SOLVED (UG/L AS CU) (01040)
1	81-07-21	2340	2398	0.05	0.000	0.720	0.000	0	2	0	10	--	0
	81-12-08	2460	2288	--	<.020	.880	<.010	<10	<1	<1	10	--	2
	82-03-24	2630	2394	--	--	--	--	10	--	--	--	--	--
	82-06-07	2520	2442	--	--	--	--	90	--	--	--	--	--
	82-09-01	2510	2449	--	--	--	--	<10	--	--	--	--	--
2	81-12-08	2680	2353	--	<.020	3.70	<.010	30	1	1	<10	--	<1
	82-03-24	3260	2885	--	--	--	--	20	--	--	--	--	--
	82-06-07	3090	2898	--	--	--	--	10	--	--	--	--	--
	82-09-01	2390	2813	--	--	--	--	<10	--	--	--	--	--
3	81-07-20	2720	2480	.28	.000	.440	.010	1000	3	1	10	--	1
	81-12-09	3560	3309	--	<.020	.670	<.010	10	4	1	10	--	2
	82-03-26	3620	3372	--	--	--	--	70	--	--	--	--	--
	82-06-07	3620	3456	--	--	--	--	<10	--	--	--	--	--
	82-08-31	3580	3424	--	--	--	--	10	--	--	--	--	--
	83-07-26	3540	3409	--	--	--	--	10	--	--	--	--	--
	83-09-28	--	--	--	--	--	--	--	--	--	--	--	--
4	81-12-09	3050	2857	--	<.020	.810	<.010	160	2	<1	<10	--	2
	82-03-24	3200	2931	--	--	--	--	80	--	--	--	--	--
	82-06-07	2960	2700	--	--	--	--	80	--	--	--	--	--
	82-09-01	2340	2659	--	--	--	--	10	--	--	--	--	--
6	81-07-21	3520	2969	.04	.010	1.60	.000	0	2	0	10	--	0
	82-03-25	4710	4616	--	--	--	--	20	--	--	--	--	--
	82-06-08	4680	4735	--	--	--	--	20	--	--	--	--	--
	82-09-02	4360	4354	--	--	--	--	10	--	--	--	--	--
7	81-07-21	3400	3193	.07	.000	.530	.000	1000	2	0	10	--	0
	81-12-09	3530	3286	--	<.020	.900	<.010	90	2	<1	10	--	<1
	82-03-25	3110	3174	--	--	--	--	40	--	--	--	--	--
	82-06-08	3380	3282	--	--	--	--	40	--	--	--	--	--
	82-09-02	3200	2986	--	--	--	--	10	--	--	--	--	--

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL AND LAKE IDENTIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	IRON, DIS-SOLVED (UG/L AS FE) (01046)	LEAD, DIS-SOLVED (UG/L AS PB) (01049)	MANGANESE, DIS-SOLVED (UG/L AS MN) (01056)	MERCURY DIS-SOLVED (UG/L AS HG) (71890)	NICKEL, DIS-SOLVED (UG/L AS NI) (01065)	SELENIUM, DIS-SOLVED (UG/L AS SE) (01145)	STRONTIUM, DIS-SOLVED (UG/L AS SR) (01080)	ZINC, DIS-SOLVED (UG/L AS ZN) (01090)
1	81-07-21	15000	0	3500	0.1	0	0	1500	20
	81-12-08	17000	<1	4000	<.1	2	<1	1500	60
	82-03-24	19000	--	4300	--	2	--	1500	80
	82-06-07	18000	--	3900	--	<1	--	1400	30
	82-09-01	18000	--	3900	--	<1	--	1500	30
2	81-12-08	1200	<1	4400	<.1	14	<1	1600	590
	82-03-24	4100	--	3900	--	16	--	1800	20
	82-06-07	4500	--	4200	--	15	--	1600	20
	82-09-01	6200	--	4700	--	7	--	1800	20
3	81-07-20	3300	0	5900	.0	33	0	1700	110
	81-12-09	4200	<1	7900	<.1	24	<1	2100	140
	82-03-26	2000	--	8500	--	30	--	2100	50
	82-06-07	3100	--	8100	--	27	--	2200	20
	82-08-31	3600	--	8200	--	37	--	2100	70
	83-07-26	3300	--	7900	--	39	--	2300	20
	83-09-28	3000	--	--	--	--	--	--	--
4	81-12-09	1100	2	4500	<.1	12	<1	1800	100
	82-03-24	5100	--	5000	--	12	--	1900	30
	82-06-07	3600	--	3800	--	11	--	1900	100
	82-09-01	3300	--	3900	--	8	--	1800	40
6	81-07-21	49000	0	12000	.1	5	0	5600	20
	82-03-25	61000	--	7600	--	21	--	5600	50
	82-06-08	42000	--	5200	--	7	--	12000	50
	82-09-02	32000	--	4800	--	9	--	400	50
7	81-07-21	35000	0	3500	.1	470	0	2000	470
	81-12-09	42000	<1	2500	<.1	250	<1	1700	480
	82-03-25	28000	--	1600	--	300	--	1600	530
	82-06-08	24000	--	1300	--	260	--	2200	490
	82-09-02	7700	--	1000	--	380	--	1800	590

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDENTIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (UMHOS) (00095)	PH (STANDARD UNITS) (00400)	TEMPERATURE (DEG C) (00010)	COLOR (PLATINUM-COBALT UNITS) (00080)	OXYGEN, DISSOLVED (MG/L) (00300)	OXYGEN, DISSOLVED (PERCENT SATURATION) (00301)	HARDNESS (MG/L AS CACO3) (00900)	HARDNESS, NONCARBONATE (MG/L CACO3) (00902)	ACIDITY (MG/L AS CACO3) (00435)
8	81-07-21	2880	6.7	16.5	0	.2	2	1562	0	74
	81-12-09	3100	6.8	10.0	0	.2	2	1719	0	.0
	82-03-25	2650	7.0	15.0	--	.2	2	1728	0	129
	82-06-08	3000	6.7	18.0	--	2.1	22	1844	0	149
	82-09-02	2950	6.8	14.5	--	2.2	21	1844	0	--
	83-07-26	2750	6.6	16.5	--	.4	--	1703	0	--
	83-09-29	2940	6.9	16.5	--	--	--	--	0	--
9	81-12-09	2860	7.2	12.0	80	.4	4	1857	0	--
	82-03-25	3920	7.1	14.5	--	--	--	3354	0	--
	82-06-08	4030	6.3	15.5	--	.0	0	3058	0	442
	82-09-01	4040	6.4	16.5	--	.0	0	3146	0	104
10	82-03-25	3100	7.0	12.0	5	1.6	15	2454	0	--
	82-06-08	3040	6.5	15.0	--	.1	1	2322	0	89
	82-09-01	3030	6.4	18.0	--	.2	2	2289	0	65
11	81-07-21	2440	7.0	15.5	0	.0	0	907	0	--
12	81-07-21	3630	6.8	17.0	30	.0	0	1589	0	55
	82-03-25	3630	7.2	11.5	--	.0	0	1637	0	--
	82-06-08	3030	6.9	15.5	--	.0	0	1239	0	154
	82-09-01	2920	6.7	16.5	--	.0	0	1239	0	--
	83-07-25	271	6.9	17.0	--	.0	--	1264	9	--
	83-09-28	2660	7.0	16.0	--	.0	--	--	0	--
13	82-03-25	2210	7.4	10.0	0	.0	0	1115	0	--
	82-06-08	2370	7.1	15.5	--	.0	0	1107	0	--
	82-09-01	2260	6.9	16.0	--	.0	0	1016	0	--
	83-09-28	2150	7.6	16.5	--	.0	--	--	0	--
14	81-12-09	2830	6.5	15.0	25	.0	0	1907	0	.0
	82-03-25	2930	5.6	11.0	--	--	--	2141	0	55
	82-06-08	3025	5.8	15.5	--	.0	0	2173	0	74
	82-09-02	3010	6.0	16.0	--	.0	0	2067	0	25
15	81-12-09	3060	5.0	13.5	5	.0	0	1957	0	--
	82-03-25	2910	4.4	13.0	--	.0	0	2221	0	377
	82-06-08	2920	4.2	15.5	--	.2	2	1940	0	223
	82-09-02	2900	4.8	17.5	--	.0	0	2032	0	114

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDEN-TIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	CALCIUM DIS-SOLVED (MG/L AS CA) (00915)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG) (00925)	SODIUM, DIS-SOLVED (MG/L AS NA) (00930)	POTAS-SIUM, DIS-SOLVED (MG/L AS K) (00935)	BICAR-BONATE (MG/L AS HCO3) (00440)	CAR-BONATE (MG/L AS CO3) (00445)	ALKA-LINITY FIELD (MG/L AS CACO3) (00410)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2) (00405)	SULFATE DIS-SOLVED (MG/L AS SO4) (00945)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL) (00940)	FLUO-RIDE, DIS-SOLVED (MG/L AS F) (00950)	SILICA, DIS-SOLVED (MG/L AS SIO2) (00955)
8	81-07-21	410	130	160	8.6	430	0	353	140	1500	15	.2	14
	81-12-09	440	150	180	5.7	630	0	517	159	1700	4.0	.4	18
	82-03-25	460	140	140	5.0	610	0	500	97	1500	4.1	.4	16
	82-06-08	490	150	130	4.8	590	0	484	187	1600	4.1	.4	18
	82-09-02	490	150	140	5.3	580	0	476	146	1500	4.1	.4	17
	83-07-26	450	140	140	5.3	580	0	--	232	1500	4.0	.5	17
	83-09-29	--	--	--	--	600	0	--	120	1400	--	--	--
9	81-12-09	430	190	31	4.3	480	0	394	48	1900	2.3	1.0	12
	82-03-25	650	420	31	5.1	560	0	459	71	2800	2.6	.8	9.4
	82-06-08	580	390	26	4.9	560	0	459	446	2600	2.0	.9	9.7
	82-09-01	600	400	27	4.8	610	0	500	386	2600	2.6	.8	10
10	82-03-25	570	250	18	4.6	360	0	295	57	2100	1.4	1.2	1.3
	82-06-08	550	230	13	2.2	330	0	271	166	2000	1.2	1.5	11
	82-09-01	570	210	14	2.4	340	0	279	215	1900	1.7	1.3	12
11	81-07-21	220	86	260	11	390	0	320	59	1100	7.7	.3	8.3
12	81-07-21	370	160	38	15	580	0	476	146	1700	8.5	.2	11
	82-03-25	340	190	410	14	610	0	500	61	2000	3.8	.3	11
	82-06-08	280	130	300	12	510	0	418	102	1300	3.5	.4	8.8
	82-09-01	280	130	280	12	470	0	385	149	1500	3.6	.3	8.8
	83-07-25	290	130	230	13	440	9	--	88	1300	5.1	.3	8.7
	83-09-28	--	--	--	--	430	0	--	68	1100	--	--	--
13	82-03-25	280	100	180	15	340	0	279	22	1200	3.5	.4	8.3
	82-06-08	280	98	180	14	360	0	295	45	1200	3.2	.4	8.3
	82-09-01	250	94	180	14	340	0	279	68	1200	3.3	.3	7.7
	83-09-28	--	--	--	--	320	0	--	13	1000	--	--	--
14	81-12-09	450	190	27	10	290	0	238	146	1900	3.9	.7	15
	82-03-25	560	180	18	3.8	48	0	39	192	2000	1.8	1.7	21
	82-06-08	540	200	20	5.3	120	0	98	302	2100	1.8	1.2	18
	82-09-02	530	180	22	6.1	200	0	164	318	2000	2.4	1.0	18
15	81-12-09	470	190	11	3.5	16	0	13	254	2400	1.8	2.8	19
	82-03-25	510	230	12	3.0	0	0	.0	.0	2200	1.6	2.4	20
	82-06-08	480	180	9.8	3.0	0	0	.0	.0	2100	1.1	2.4	17
	82-09-02	500	190	12	3.7	12	0	10	302	2100	1.5	1.6	16

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDENTIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L) (70300)	SOLIDS, SUM OF CONSTITUENTS, DIS-SOLVED (MG/L) (70301)	NITROGEN, NITRATE DIS-SOLVED (MG/L AS N) (00618)	NITROGEN, NITRITE DIS-SOLVED (MG/L AS N) (00613)	NITROGEN, AMMONIA DIS-SOLVED (MG/L AS N) (00608)	PHOSPHORUS, ORTHO, DIS-SOLVED (MG/L AS P) (00671)	ALUMINUM, DIS-SOLVED (UG/L AS AL) (01106)	ARSENIC DIS-SOLVED (UG/L AS AS) (01000)	CADMIUM DIS-SOLVED (UG/L AS CD) (01025)	CHROMIUM, DIS-SOLVED (UG/L AS CR) (01030)	CHROMIUM, HEXA-VALENT, DIS. (UG/L AS CR) (01032)	COPPER, DIS-SOLVED (UG/L AS CU) (01040)
8	81-07-21	2700	2459	.00	.020	.280	.030	10	1	<1	10	--	0
	81-12-09	2970	2816	--	<.020	.300	.010	60	1	<1	10	0	<1
	82-03-25	2830	2573	--	--	--	--	20	--	--	--	--	--
	82-06-08	2390	2700	--	--	--	--	40	--	--	--	--	--
	82-09-02	2810	2600	--	--	--	--	10	--	--	--	--	--
	83-07-26	2620	2554	--	--	--	--	10	--	--	--	--	--
	83-09-29	--	--	--	--	--	--	--	--	--	--	--	--
9	81-12-09	3230	2852	--	<.020	2.90	<.010	<10	4	<1	<10	0	<1
	82-03-25	4270	4207	--	--	--	--	40	--	--	--	--	--
	82-06-08	4170	3907	--	--	--	--	30	--	--	--	--	--
	82-09-01	4220	3964	--	--	--	--	10	--	--	--	--	--
10	82-03-25	3310	3132	0.22	.020	.250	.020	40	<1	7	10	--	1
	82-06-08	3220	2980	--	--	--	--	120	--	--	--	--	--
	82-09-01	3170	2887	--	--	--	--	10	--	--	--	--	--
11	81-07-21	2030	1897	.51	.000	1.20	.000	1500	4	<1	10	--	0
12	81-07-21	2970	2604	.00	.000	1.30	.000	1000	3	0	10	--	0
	82-03-25	3590	3284	--	--	--	--	30	--	--	--	--	--
	82-06-08	2410	2294	--	--	--	--	40	--	--	--	--	--
	82-09-01	2560	2454	--	--	--	--	<10	--	--	--	--	--
	83-07-25	2310	2219	--	--	--	--	10	--	--	--	--	--
	83-09-28	--	--	--	--	--	--	--	--	--	--	--	--
13	82-03-25	1990	1962	.08	.020	1.40	.010	60	1	<1	<10	--	2
	82-06-08	2000	1966	--	--	--	--	70	--	--	--	--	--
	82-09-01	1940	1922	--	--	--	--	10	--	--	--	--	--
	83-09-28	--	--	--	--	--	--	--	--	--	--	--	--
14	81-12-09	3140	2851	--	<.020	1.70	<.010	50	3	<1	10	0	7
	82-03-25	3080	2835	--	--	--	--	620	--	--	--	--	--
	82-06-08	3140	2989	--	--	--	--	460	--	--	--	--	--
	82-09-02	3060	2921	--	--	--	--	90	--	--	--	--	--
15	81-12-09	3380	3167	--	<.020	.710	<.010	12000	3	5	10	--	3
	82-03-25	3280	3051	--	--	--	--	20000	--	--	--	--	--
	82-06-08	3360	2851	--	--	--	--	25000	--	--	--	--	--
	82-09-02	3130	2880	--	--	--	--	19000	--	--	--	--	--

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDEN-FYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	IRON, DIS-SOLVED (UG/L AS FE) (01046)	LEAD, DIS-SOLVED (UG/L AS PB) (01049)	MANGA-NESE, DIS-SOLVED (UG/L AS MN) (01056)	MERCURY DIS-SOLVED (UG/L AS HG) (71890)	NICKEL, DIS-SOLVED (UG/L AS NI) (01065)	SELE-NIUM, DIS-SOLVED (UG/L AS SE) (01145)	STRON-TIUM, DIS-SOLVED (UG/L AS SR) (01080)	ZINC, DIS-SOLVED (UG/L AS ZN) (01090)
8	81-07-21	280	1	6800	.0	33	1	2500	80
	81-12-09	960	<1	3800	<.1	20	<1	2300	90
	82-03-25	1800	--	3000	--	30	--	2200	100
	82-06-08	4700	--	6100	--	58	--	2000	30
	82-09-02	3600	--	2400	--	40	--	2200	60
	83-07-26	6000	--	3300	--	46	--	2400	200
	83-09-29	2300	--	--	--	--	--	--	--
9	81-12-09	27000	<1	13000	<.1	26	<1	1100	50
	82-03-25	1100	--	10000	--	79	--	1500	150
	82-06-08	6100	--	8600	--	62	--	3000	170
	82-09-01	8800	--	9200	--	75	--	840	150
10	82-03-25	250	<1	4900	<0.1	120	2	950	430
	82-06-08	600	--	6300	--	190	--	830	680
	82-09-01	1100	--	5300	--	190	--	890	520
11	81-07-21	1600	0	1500	.0	15	0	3100	10
12	81-07-21	3900	0	3400	.0	14	0	5000	10
	82-03-25	5600	--	4000	--	14	--	5000	30
	82-06-08	2700	--	2300	--	9	--	3900	40
	82-09-01	2300	--	2300	--	11	--	4000	40
	83-07-25	1000	--	1700	--	13	--	4200	30
	83-09-28	530	--	--	--	--	--	--	--
13	82-03-25	440	1	1500	.1	16	<1	3600	20
	82-06-08	310	--	1200	--	18	--	3900	40
	82-09-01	430	--	1300	--	19	--	3300	40
	83-09-28	200	--	--	--	--	--	--	--
14	81-12-09	96000	<1	12000	<.1	130	<1	810	300
	82-03-25	16000	--	6000	--	460	--	850	1000
	82-06-08	33000	--	8500	--	290	--	930	450
	82-09-02	52000	--	9000	--	220	--	1600	320
15	81-12-09	29000	<1	16000	<.1	610	<1	560	1500
	82-03-25	31000	--	13000	--	800	--	530	1400
	82-06-08	18000	--	13000	--	580	--	500	850
	82-09-02	16000	--	12000	--	550	--	580	750

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDEN- TIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	SPE- CIFIC CON- DUCT- ANCE (UMHOS) (00095)	PH (STAND- ARD UNITS) (00400)	TEMPER- ATURE (DEG C) (00010)	COLOR (PLAT- INUM- COBALT UNITS) (00080)	OXYGEN, DIS- SOLVED (MG/L) (00300)	OXYGEN, DIS- SOLVED (PER- CENT SATUR- ATION) (00301)	HARD- NESS (MG/L AS CACO3) (00900)	HARD- NESS, NONCAR- BONATE (MG/L CACO3) (00902)	ACIDITY (MG/L AS CACO3) (00435)
Q	81-09-15	1340	7.1	14.0	5	.1	0	669	0	--
R	81-09-15	1370	8.1	14.0	0	.5	5	62	6	--
S	81-09-15	1450	10.3	14.0	5	.0	0	13	330	--
T	83-08-24	405	7.3	16.0	--	--	--	150	0	--
U	83-08-24	770	7.1	15.0	--	--	--	416	0	--
V	83-08-25	588	7.6	21.0	--	--	--	251	0	--
101	83-09-22	3500	2.3	18.0	--	--	--	1265	--	695
201	83-07-26	2460	7.4	27.5	--	--	--	1618	0	15
301	83-07-25	1420	8.2	30.0	--	--	--	693	0	--
300H	83-08-12	180	8.2	27.5	--	--	--	86	0	--

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDEN-TIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	CALCIUM DIS-SOLVED (MG/L AS CA) (00915)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG) (00925)	SODIUM, DIS-SOLVED (MG/L AS, NA) (00930)	POTAS-SIUM, DIS-SOLVED (MG/L AS K) (00935)	BICAR-BONATE (MG/L AS HCO3) (00440)	CAR-BONATE (MG/L AS CO3) (00445)	ALKA-LINITY FIELD (MG/L AS CACO3) (00410)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2) (00405)	SULFATE DIS-SOLVED (MG/L AS SO4) (00945)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL) (00940)	FLUO-RIDE, DIS-SOLVED (MG/L AS F) (00950)	SILICA, DIS-SOLVED (MG/L AS SIO2) (00955)
Q	81-09-15	180	53	58	4.1	530	0	435	70	310	5.2	.5	22
R	81-09-15	13	7.0	300	10	550	6	461	6.9	270	6.6	.6	12
S	81-09-15	3.7	.8	320	20	500	330	960	.0	<5.0	19	2.1	9.4
T	83-08-24	42	11	8.5	26	170	0	--	14	51	10	.3	7.4
U	83-08-24	130	22	15	1.7	430	0	--	54	58	11	.3	17
V	83-08-25	69	19	9.8	20	360	0	--	14	11	6.8	.3	16
101	83-09-22	350	95	40	10	--	--	.0	.0	1900	4.1	--	--
201	83-07-26	400	150	33	8.3	96	0	--	6.1	1400	3.6	.4	15
301	83-07-25	140	83	68	6.4	150	0	--	1.5	710	4.0	.3	3.6
300H	83-08-12	25	5.6	4.9	2.3	78	0	--	.3	25	2.2	.2	2.7

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDENTIFYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L) (70300)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L) (70301)	NITROGEN, NITRATE DISSOLVED (MG/L AS N) (00618)	NITROGEN, NITRITE DISSOLVED (MG/L AS N) (00613)	NITROGEN, AMMONIA DISSOLVED (MG/L AS N) (00608)	PHOSPHORUS, ORTHO, DISSOLVED (MG/L AS P) (00671)	ALUMINUM, DISSOLVED (UG/L AS AL) (01106)	ARSENIC DISSOLVED (UG/L AS AS) (01000)	CADMIUM DISSOLVED (UG/L AS CD) (01025)	CHROMIUM, DISSOLVED (UG/L AS CR) (01030)	CHROMIUM, HEXAVALENT, DIS. (UG/L AS CR) (01032)	COPPER, DISSOLVED (UG/L AS CU) (01040)
Q	81-09-15	909	897	.03	.000	.310	.010	10	4	<1	0	--	1
R	81-09-15	883	904	.14	.010	1.10	.000	10	1	<1	0	--	16
S	81-09-15	831	956	.39	.020	3.10	.010	30	2	<1	0	--	16
T	83-08-24	248	240	--	--	--	--	10	--	--	--	--	--
U	83-08-24	459	469	--	--	--	--	<10	--	--	--	--	--
V	83-08-25	318	331	--	--	--	--	<10	--	--	--	--	--
101	83-09-22	2670	--	--	--	--	--	16000	--	--	--	--	37
201	83-07-26	2430	2059	--	--	--	--	10	--	--	--	--	--
301	83-07-25	1130	1090	--	--	--	--	<10	--	--	--	--	--
300H	83-08-12	114	106	--	--	--	--	10	--	--	--	--	--

Table 17.--Water-quality analysis data for wells and lakes--Continued

WELL OR LAKE IDEN-FYING NUMBER OR LETTER (FIGS. 1-4)	DATE OF SAMPLE	IRON, DIS-SOLVED (UG/L AS FE) (01046)	LEAD, DIS-SOLVED (UG/L AS PB) (01049)	MANGA-NESE, DIS-SOLVED (UG/L AS MN) (01056)	MERCURY DIS-SOLVED (UG/L AS HG) (71390)	NICKEL, DIS-SOLVED (UG/L AS NI) (01065)	SELE-NIUM, DIS-SOLVED (UG/L AS SE) (01145)	STRON-TIUM, DIS-SOLVED (UG/L AS SR) (01080)	ZINC, DIS-SOLVED (UG/L AS ZN) (01090)
Q	81-09-15	1100	2	870	.0	22	0	920	33
R	81-09-15	20	2	100	.1	7	0	400	29
S	81-09-15	22	4	7	.1	13	0	61	24
T	83-08-24	21	--	32	--	3	--	140	130
U	83-08-24	260	--	1300	--	5	--	360	22
V	83-08-25	180	--	1300	--	5	--	270	7
101	83-09-22	90000	<1	4700	--	--	--	--	1400
201	83-07-26	40	--	340	--	8	--	330	20
301	83-07-25	19	--	8	--	7	--	1200	24
300H	83-08-12	50	--	21	--	2	--	95	5

Table 18.--Reported chemical compositions of water from wells not affected by strip mining

[PBAC, bedrock above Bevier coal seam; PBBC, bedrock including Bevier coal and below; °C, degrees Celsius; mg/L, milligrams per liter; --, no data; < , less than]

Well-identifying letter (fig. 1)	Aquifer	Date of sample	pH (units)	Temperature (°C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate (mg/L)
A[1]	Glacial drift	10-11-80	7.4	--	66.8	28.3	54	2.6	408.7
B[1]	--do--	10-9-80	7.3	--	60.2	16.9	44.7	3.4	317.2
C[1]	--do--	10-20-80	7.4	--	86.1	29.3	77.1	.8	305.0
D[1]	--do--	10-2-80	7.3	--	69.4	13.4	40.4	6.9	173.2
E[1]	--do--	10-20-80	7.4	--	74.4	14.1	1.7	6.9	257.4
F[1]	--do--	9-2-80	7.2	--	93.7	39.7	47.9	4.4	475.1
G[1]	--do--	9-23-80	6.8	--	159	31.5	28.8	26.9	366
H[1]	--do--	10-22-80	7.0	--	135.8	42.6	1.0	10.3	433.1
I[1]	--do--	9-14-80	8.0	--	46.8	4.6	6.1	12.2	147.6
J[2]	--do--	2-26-80	8.0	--	213	83.5	115.5	--	124.2
K[2]	--do--	2-26-80	8.3	11.0	78.9	23.4	52.6	--	189.6
L[3]	--do--	3-16-66	7.4	--	108	35	[4]58	--	496
M[3]	--do--	3-15-66	7.6	--	85	40	81	0.22	581
N[5]	--do--	4-9-81	7.4	14.7	130	49	120	5.4	618
O[5]	PBAC	4-9-81	7.8	14.2	76	16	49	1.8	269
P[5]	PBBC	4-9-81	9.8	15.3	8.8	9.7	80	120	336

Table 18.--Reported chemical compositions of water from wells not affected by strip mining--Continued

Well-identifying letter (fig. 1)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved as silica dioxide (mg/L)	Solids, dissolved residue (mg/L)	Nitrogen, nitrate dissolved (mg/L)	Aluminum, dissolved (mg/L)	Arsenic, dissolved (mg/L)	Borium, dissolved (mg/L)	Cadmium, dissolved (mg/L)
A	65	5.5	0.65	--	427	0.40	--	<0.005	--	<0.0025
B	<10	43.9	.31	--	388	4.1	--	<.005	--	<.0025
C	206	8	.73	--	641	40	--	<.005	--	<.0025
D	129	17	.38	--	461	36	--	<.005	--	<.0025
E	60	6	.37	--	378	.40	--	<.005	--	<.0025
F	25	62	.39	--	659	.22	--	<.005	--	<.0025
G	246	51	.21	--	803	1.1	--	<.005	--	<.0025
H	226	4	.54	--	776	3.8	--	<.005	--	<.0025
I	18	6	.15	--	239	9.2	--	<.005	--	<.0025
J	756.3	32.5	--	--	1,142	106	--	--	--	--
K	251.2	17.7	--	--	570	60.4	--	--	--	--
L	89	7.5	0.3	15	594	18	--	--	--	--
M	16	12	.1	10	548	12	--	--	--	--
N	310	14	<.1	33	1,276	.49	0.01	<0.1	0.036	<0.01
O	125	6.8	<.1	28	580	1.60	.01	<.1	.065	<.01
P	102	7.9	<.1	23	720	7.23	.03	<.1	.021	<.01

Table 18.--Reported chemical compositions of water from wells not affected by strip mining--Continued

Well-identifying letter (fig. 1)	Chromium, dissolved (mg/L)	Copper, dissolved (mg/L)	Iron, dissolved (mg/L)	Lead, dissolved (mg/L)	Manganese, dissolved (mg/L)	Mecury, dissolved (mg/L)	Selenium, dissolved (mg/L)	Strontium, dissolved (mg/L)	Zinc, dissolved (mg/L)
A	<0.0025	0.2	3.4	0.033	0.3	<0.0005	0.0055	--	--
B	<.0025	.09	3.4	.024	.94	.0005	<.0025	--	--
C	<.0025	.08	.11	<.01	.02	<.005	<.0025	--	--
D	<.0025	.14	.10	<.01	<.02	<.0005	<.0025	--	--
E	<.0025	.24	3.3	<.01	.73	<.0005	<.0025	--	--
F	<.0025	.01	.62	<.01	5.0	<.0005	<.0025	--	--
G	<.0025	.13	2.7	<.01	2.4	<.0005	<.0025	--	--
H	<.0025	.08	.39	<.01	<.02	<.0005	.0093	--	--
I	<.0025	.03	.10	<.01	.12	<.0005	<.0025	--	--
J	--	--	.0	--	--	--	--	--	--
K	--	--	6.2	--	--	--	--	--	--
L	--	--	1.8	--	.00	--	--	--	--

Table 18.--Reported chemical compositions of water from wells not affected by strip mining--Continued

Well-identifying letter (fig. 1)	Chromium, dissolved (mg/L)	Copper, dissolved (mg/L)	Iron, dissolved (mg/L)	Lead, dissolved (mg/L)	Manganese, dissolved (mg/L)	Mecury, dissolved (mg/L)	Selenium, dissolved (mg/L)	Strontium, dissolved (mg/L)	Zinc, dissolved (mg/L)
M	--	--	1.7	--	0.22	--	--	--	--
N	<0.01	0.02	<0.02	<0.05	.99	--	<0.1	0.77	<0.01
O	.02	.02	.02	<.05	.10	--	<.1	.28	.02
P	<.01	.01	.05	<.05	.01	--	<.1	.21	<.01

[1] R. W. Maley, (Missouri Division of Health, written commun., 1983).

[2] Haliburton Associates (1981).

[3] Gann and others (1971).

[4] Sodium plus potassium.

[5] Seifert (1982).

[6] Total iron.

Table 19.--Surface altitudes of and selected quality-of-water data for lakes in spoil areas

[ft, feet; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; --, no data; (E), estimated]

Lake number (figs. 2-4)	Date of sample	Altitude of surface above sea level (ft)	Temperature (°C)	Specific conductance (µS/cm)	pH (units)	Bicarbonate (mg/L)	Dissolved oxygen (mg/L)
101	3-24-82	803.38	10.0	1,800	3.2	0	--
	6-7-82	804.78(E)	27.0	2,280	2.7	0	--
	9-1-82	805.28	24.5	2,700	3.0	0	--
	6-16-83	--	24.0	2,100	2.8	--	4.6
	6-16-83	--	23.0	3,300	2.9	--	4.7
	6-16-83	--	19.0	2,160	2.8	--	.9
102	3-24-82	783.07	10.5	750	7.8	140	--
	6-7-82	782.92	26.0	878	7.9	130	--
	9-1-82	782.79	25.0	715	7.8	72	--
103	3-26-82	788.46	9.0	860	7.9	120	--
	6-7-82	788.61	28.0	950	8.0	140	--
	9-1-82	788.45	27.0	895	8.4	74	--
	1-16-83	--	24.5	1,070	6.4	--	5.9
	6-16-83	--	20.0	1,600	6.4	--	3.2
201	3-25-82	762.18	10.5	1,170	7.0	82	--
	6-8-82	761.59	15.0	2,040	7.4	80	--
	9-2-82	761.83	23.0	1,150	7.3	40	--
	7-26-83	762.78	27.5	2,460	7.4	79	--
202	3-25-82	762.82	9.5	1,120	8.2	120	--
	6-8-82	762.63	23.0	1,300	8.1	120	--
	9-1-82	762.69	27.5	1,080	8.6	53	--
203	3-25-82	756.42	11.0	1,075	7.6	18	--
	6-8-82	755.26	25.0	1,770	3.8	0	--
	9-2-82	756.40	24.0	1,070	4.2	0	--
301	3-25-82	766.79	8.5	905	8.1	110	--
	6-8-82	766.77	23.0	1,320	8.2	130	--
	9-1-82	767.20	24.5	1,180	8.1	110	--
	7-25-83	764.78	30.0	1,420	8.2	120	--
302	3-25-82	761.02	8.5	1,060	7.8	110	--
	6-8-82	760.93	23.0	1,320	7.6	130	--
	9-1-82	761.25	24.0	1,360	7.7	130	--

Table 19.--Surface altitudes of and selected quality-of-water data for lakes in spoil areas--Continued

[ft, feet; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; --, no data; (E), estimated]

Lake number (figs. 2-4)	Date of sample	Altitude of surface above sea level (ft)	Temperature (°C)	Specific conductance (µS/cm)	pH (units)	Bicarbonate (mg/L)	Dissolved oxygen (mg/L)
303	3-25-82	753.98	9.0	1,210	8.2	95	--
	6-8-82	753.36	22.0	1,320	8.5	67	--
	9-1-82	753.59	24.5	1,280	8.2	77	--
100 A	8-10-83	786.19	26.0	2,560	7.1	--	--
B	--do--	791.12	31.0	540	8.3	--	--
C	--do--	797.21	32.0	775	7.8	--	--
D	--do--	778.69	32.0	2,450	8.1	--	--
E	--do--	789.72	31.5	2,150	3.2	--	--
F	--do--	810.64	32.0	920	3.4	--	--
G	--do--	810.68	32.5	320	8.5	--	--
200 A	8-9-83	760.08	35.0	3,100	7.6	--	--
B	--do--	751.22	36.0	5,300	2.8	--	--
C	--do--	749.85	30.0	1,545	7.6	--	--
300 A	8-11-83	742.96	25.5	3,780	7.9	--	--
B	--do--	759.92	30.0	3,280	8.1	--	--
C	--do--	749.89	29.0	4,350	7.8	--	--
D	--do--	769.81	30.0	2,980	8.3	--	--
E	--do--	769.84	30.5	3,480	8.0	--	--
F	--do--	787.40	31.0	580	8.6	--	--
G	--do--	787.84	29.5	1,400	8.0	--	--
H	8-12-83	791.88	27.5	180	8.2	64	--

Table 20.--Summary of selected properties and concentrations of chemical constituents in water from 1940 spoil

[Concentrations in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter at 25° Celsius; µg/L, micrograms per liter; °C, degrees Celsius; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, µS/cm	18	3,120	3,110	2,680	3,870	418
pH, in units	18	--	6.55	6.2	6.7	--
Water temperature, in °C	18	14.0	15.0	9.5	16.5	2.4
Hardness, as $CaCO_3$	18	1,970	1,950	1,500	2,500	297
Noncarbonate hardness, as $CaCO_3$	18	1,420	1,400	1,100	1,800	201
Dissolved calcium	18	513	515	390	620	60
Dissolved magnesium	18	164	170	100	220	43
Dissolved sodium	18	91	87	11	150	35
Dissolved potassium	18	5.6	5.9	2.7	8.0	1.8
Bicarbonate as HCO_3^-	18	660	720	370	860	161
Alkalinity, as $CaCO_3$	18	542	591	303	705	132

Table 20.--Summary of selected properties and concentrations of chemical constituents in water from 1940 spoil--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Dissolved sulfate	18	1,640	1,550	1,400	2,000	220
Dissolved cholride	18	7.1	5.15	3.4	18	4.34
Dissoloved fluoride	18	0.5	0.4	0.3	0.7	0.1
Dissolved silica, as SiO_2	18	17	17	12	21	2.3
Dissolved solids, calculated sum	18	2,720	2,700	2,260	3,470	380
Dissolved nitrate, as N	6	0.06	0.00	0.00	0.55	0.11
Dissolved aluminum, in µg/L	18	0.088	0.080	0.00	1.00	2.232
Dissolved iron, in µg/L	18	7.35	3.45	1.10	19.0	6.57
Dissolved manganese, in µg/L	18	5.14	4.20	3.50	8.50	1.75

Table 21.--Summary of selected properties and concentrations of chemical constituents in water from 1952 spoil

[Concentrations in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter at 25° Celsius; µg/L, micrograms per liter; °C, degrees Celsius; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, µS/cm	25	3,160	3,040	2,650	4,040	370
pH, in units	25	--	6.5	4.2	7.2	--
Water temperature, in °C	25	14.6	15.0	10.0	18.0	2.4
Hardness, as $CaCO_3$	25	2,210	2,200	1,600	3,400	448
Noncarbonate hardness, as $CaCO_3$	25	1,920	2,000	1,200	2,900	440
Dissolved calcium	25	517	510	410	650	57.5
Dissolved magnesium	25	223	200	130	420	77.5
Dissolved sodium	25	48	26	9.8	180	53.5
Dissolved potassium	25	6.1	5.0	2.2	13	3.1
Bicarbonate as HCO_3^-	25	353	380	0	630	215
Alkalinity, as $CaCO_3$	25	289	312	0	517	177

Table 21.--Summary of selected properties and concentrations of chemical constituents in water from 1952 spoil--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Dissolved sulfate	25	2,040	2,100	1,500	2,800	334
Dissolved cholride	25	2.9	2.0	1.1	15	2.7
Dissolved fluoride	25	1.1	0.8	0.2	2.8	0.68
Dissolved silica, as SiO_2	25	14	14	1.3	.21	.45
Dissolved solids, calculated sum	25	3,050	2,970	2,500	4,180	415
Dissolved nitrate, as N	8	0.14	0.035	0.00	0.70	0.24
Dissolved aluminum, in µg/L	25	3.15	0.040	0.0	25.0	7.31
Dissolved iron, in µg/L	25	19.4	16	0.25	9.6	22.0
Dissolved manganese, in µg/L	25	7.35	6.3	1.0	18	4.7

Table 22.--Summary of selected properties and concentrations of chemical constituents in water from 1968 spoil

[Concentrations in milligrams per liter unless otherwise indicated; µS/cm, microsiemens per centimeter at 25° Celsius; µg/L, micrograms per liter; °C, degrees Celsius; --, not calculated]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Specific conductance, µS/cm	12	3,290	3,270	2,210	4,680	898
pH, in units	12	--	6.9	6.7	7.4	--
Water temperature, in °C	12	15.1	15.8	10.0	18.5	2.4
Hardness, as $CaCO_3$	12	1,650	1,400	910	2,700	694
Noncarbonate hardness, as $CaCO_3$	12	1,180	960	590	2,000	539
Dissolved calcium	12	372	310	220	580	133
Dissolved magnesium	12	177	145	86	320	89
Dissolved sodium	12	237	270	18	410	122
Dissolved potassium	12	14	14	11	19	2.2
Bicarbonate as HCO_3^-	12	582	545	340	910	215
Alkalinity, as $CaCO_3$	12	477	477	279	746	176

Table 22.--Summary of selected properties and concentrations of chemical constituents in water from 1968 spoil--Continued

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum	Standard deviation
Dissolved sulfate	12	1,790	1,600	1,100	3,000	703
Dissolved cholride	12	5.0	4.15	3.2	8.5	1.9
Dissolved fluoride	12	0.3	0.3	0.2	0.4	0.06
Dissolved silica, as SiO_2	12	11	9.9	7.7	16	2.6
Dissolved solids, calculated sum	12	2,850	2,345	1,890	4,660	1,060
Dissolved nitrate, as N	4	0.16	0.06	0.00	0.51	0.24
Dissolved aluminum, in µg/L	12	0.23	0.025	0.00	1.5	0.49
Dissolved iron, in µg/L	12	16.7	3.3	0.31	61	22.6
Dissolved manganese, in µg/L	12	3.92	2.85	1.2	12	3.2

Table 23.--Saturation indices of selected minerals in water from selected lakes and precipitation

[--, not calculated]

Lake number and identifying letter (figs. 2-4)	Date of sample	Calcite	Dolomite	Gypsum	Amorphous ferric hydroxide	Goethite
101	9-22-83	--	--	-0.282	-2.36	4.48
201	7-26-83	0.190	0.280	-.0586	-1.22	9.08
301	7-25-83	.851	1.81	-.606	1.83	9.09
300 H	8-12-83	.119	-.105	-2.30	2.21	9.39
		PRECIPITATION (see table 5)				
Ashland	12-81 to 4-82	-0.707	-14.6	-5.00	--	--

Lake number and identifying letter (figs. 2-4)	Date of sample	Alunite	Albite	Adularia	Kaolinite	Amorphous ferric hydroxide	Pyrite	Siderite
101	9-22-83	-7.21	--	--	--	-8.22	--	--
201	7-26-83	-2.62	-2.43	-.724	1.54	-1.42	--	-27.7
301	7-25-83	-9.09	-4.40	-3.16	-2.14	-2.57	--	-29.2
300 H	8-12-83	-10.4	-5.38	-3.40	-1.42	-2.14	--	-29.0
				PRECIPITATION (see table 5)				
Ashland	12-81 to 4-82	--	--	--	--	--	--	--

Table 23.--Saturation indices of selected minerals in water from selected lakes and precipitation--Continued

Lake number and identifying letter (figs. 2-4)	Date of sample	Quartz	Illite	Calcium montmorillonite
101	9-22-83	--	--	--
201	7-26-83	0.368	0.535	0.990
301	7-25-83	-.301	-3.66	-3.95
300 H	8-12-83	-.390	-3.46	-3.35
PRECIPITATION (see table 5)				
Ashland	12-81-4-82	--	--	--

Table 24.--Saturation indices of selected minerals in water from wells completed in glacial drift and bedrock not affected by strip mines

[--, not calculated]

Well-identifying letter (fig. 1)	Date of sample	Calcite	Dolomite	Gypsum	Amorphous ferric hydroxide	Goethite
WELLS COMPLETED IN GLACIAL DRIFT						
A	10-11-80	0.160	0.116	-1.65	3.53	10.2
B	10-9-80	-.048	-.485	--	3.46	10.1
C	10-20-80	.092	-.104	-1.11	2.03	8.71
D	10-2-80	-.289	-1.11	-1.31	1.92	8.61
E	10-20-80	.0407	.471	-1.59	3.52	10.2
F	9-2-80	.159	.109	-1.97	2.62	9.30
G	9-23-80	-.192	-.907	-.840	2.91	9.59
H	10-22-80	.0224	-.281	-.926	2.26	8.94
I	9-14-80	.252	-.337	-2.21	2.22	8.90
J	2-26-80	.531	.358	-.394	--	--
K	2-26-80	.688	.990	-1.04	2.35	8.92
L	3-16-66	.419	.517	-1.38	3.25	9.93
M	3-15-66	.599	1.03	-2.20	3.34	10.0
N	4-9-81	.516	.799	-.871	--	--
Q	9-15-81	.817	.023	-.744	2.65	9.33
T	8-24-83	-.428	-1.24	-1.84	1.30	8.06
U	8-24-83	.174	-.241	-1.46	2.20	8.92
V	8-25-83	.456	.603	-2.37	2.55	9.49
WELLS COMPLETED IN BEDROCK						
O	4-9-81	0.428	0.358	-1.31	1.50	8.19
P	4-9-81	1.20	2.68	-2.44	.580	7.31
R	9-15-81	.177	.270	-1.83	1.49	8.18
S	9-15-81	1.05	1.67	-4.31	-.313	6.37

Table 24.--Saturation indices of selected minerals in water from wells completed in glacial drift and bedrock not affected by strip mines--Continued

Well-identifying letter (fig. 1)	Date of sample	Alunite	Albite	Adularia	Kaolinite	Amphorous aluminum hydroxide	Pyrite	Siderite
WELLS COMPLETED IN GLACIAL DRIFT								
A	10-11-80	--	--	--	--	--	--	-3.69
B	10-9-80	--	--	--	--	--	--	-3.66
C	10-20-80	--	--	--	--	--	--	-5.32
D	10-2-80	--	--	--	--	--	--	-5.46
E	10-20-80	--	--	--	--	--	--	-3.89
F	9-2-82	--	--	--	--	--	--	-4.14
G	9-23-80	--	--	--	--	--	--	-3.16
H	10-22-80	--	--	--	--	--	--	-4.14
I	9-14-80	--	--	--	--	--	--	-6.63
J	2-26-80	--	--	--	--	--	--	--
K	2-26-80	--	--	--	--	--	--	-7.15
L	3-16-66	--	--	--	--	--	--	-3.90
M	3-15-66	--	--	--	--	--	--	-4.13
N	4-9-81	--	--	--	--	--	--	--
Q	9-15-81	--	--	--	--	--	--	-1.09
T	8-24-83	-1.62	-3.18	-0.243	2.46	-0.921	--	-27.7
U	8-24-83	-2.92	-2.26	-.738	2.79	-1.14	--	-26.1
V	8-25-83	-5.71	-2.37	.327	2.07	-1.33	--	-26.8
WELLS COMPLETED IN BEDROCK								
O	4-9-81	--	--	--	--	--	--	-6.69
P	4-9-81	--	--	--	--	--	--	-10.3
R	9-15-81	--	--	--	--	--	--	- 5.01
S	9-15-81	--	--	--	--	--	--	-13.8

Table 24.--Saturation indices of selected minerals in water from wells completed in glacial drift and bedrock not affected by strip mines--Continued

Well-identifying letter (fig. 1)	Date of sample	Quartz	Illite	Calcium montmorillonite
WELLS COMPLETED IN GLACIAL DRIFT				
A	10-11-80	--	--	--
B	10-9-80	--	--	--
C	10-20-80	--	--	--
D	10-2-80	--	--	--
E	10-20-80	--	--	--
F	9-2-80	--	--	--
G	9-23-80	--	--	--
H	10-22-80	--	--	--
I	9-14-80	--	--	--
J	2-26-80	--	--	--
K	2-26-80	--	--	--
L	3-16-66	0.578	--	--
M	3-15-66	.401	--	--
N	4-9-81	.910	--	--
Q	9-15-81	.746	--	--
T	8-24-83	.238	1.19	1.54
U	8-24-83	.616	1.11	2.41
V	8-25-83	.492	1.47	1.64
WELLS COMPLETED IN BEDROCK				
O	4-9-81	0.844	--	--
P	4-9-81	.569	--	--
R	9-15-81	.479	--	--
S	9-15-81	-.197	--	--

Table 25.--Saturation indices of selected minerals in water from wells completed in or near spoil

[--, not calculated]

Well number (figs. 2-4)	Date of sample	Calcite	Dolomite	Gypsum	Amorphous ferric hydroxide	Goethite
1	7-21-81	0.174	-0.103	0.038	-4.14	2.04
	12-8-81	-.151	-.684	-.009	-4.87	1.75
	3-24-82	-.052	-.500	.044	-4.64	2.08
	6-7-82	-.236	-.877	.053	-8.72	1.56
	9-1-82	-.037	-.488	.060	-4.84	1.91
2	12-8-81	-0.183	-0.546	-0.044	-6.21	0.399
	3-24-82	.112	.013	.094	-5.51	1.09
	6-7-82	-.018	-.245	.098	-5.82	.898
	9-1-82	.198	.190	.077	-5.32	1.42
3	7-20-81	-0.141	-0.492	0.034	-5.94	0.839
	12-9-81	.235	.235	.131	-5.35	1.22
	3-26-82	.255	.231	.166	-5.67	.835
	6-7-82	-.114	-.441	.174	-6.36	.403
	8-31-82	-.040	-.287	.170	-6.11	.645
	7-26-83	.362	.539	.152	-5.44	1.32
4	12-9-81	0.095	-0.172	0.100	-6.09	0.458
	3-24-82	.043	-.250	.121	-5.60	.986
	6-7-82	.015	-.317	.083	-5.91	.832
	9-1-82	.185	.041	.068	-5.59	1.13
6	7-21-81	0.372	0.636	0.041	-4.24	2.61
	3-25-82	.549	1.02	.186	-2.68	3.96
	6-8-82	.360	.713	.189	-3.20	3.56
	9-2-82	.427	.869	.142	-3.12	3.65
7	7-21-81	0.002	-0.055	0.122	-4.59	2.23
	12-9-81	-.397	-1.54	.192	-4.89	1.64
	3-25-82	-.175	-.529	.145	-3.70	2.88
	6-8-82	-.110	-.321	.145	-.870	3.00
	9-2-82	-.173	-.506	.144	-4.24	2.48
8	7-21-81	-0.122	-0.501	-0.012	-6.65	0.123
	12-9-81	.153	.003	.056	-5.79	.735
	3-25-82	.453	.611	.025	-5.13	1.59
	6-8-82	.197	.137	.052	-5.25	1.58
	9-2-82	.247	.359	.022	-5.20	1.50
	7-26-83	.044	-.178	.013	-1.29	1.45

Table 25.--Saturation indices of selected minerals in water from wells completed in or near spoil--Continued

Well number (figs. 2-4)	Date of sample	Calcite	Dolomite	Gypsum	Amorphous ferric hydroxide	Goethite
9	12-9-81	-0.059	-0.282	0.070	-4.52	2.08
	3-25-82	.533	1.11	.260	-5.23	1.47
	6-8-82	-.279	-.492	.201	-5.91	.829
	9-1-82	-.115	-.157	.206	-5.57	1.21
10	3-25-82	0.220	0.275	0.187	-6.03	0.578
	6-8-82	-.278	-.705	.157	-6.53	.190
	9-1-82	-.298	-.769	.149	-6.43	.400
11	7-21-81	0.002	-0.178	-0.306	-5.15	1.59
12	7-21-81	0.145	0.176	-0.021	-5.16	1.63
	3-25-82	.412	.758	-.026	-4.32	2.27
	6-8-82	.090	.073	-.197	-5.12	1.62
	9-1-82	-.154	-.397	-.158	-5.56	1.21
	7-25-83	.066	.029	-.181	-5.58	1.22
13	3-25-82	0.360	0.425	-0.174	-5.01	1.52
	6-8-82	.162	.096	-.191	-5.69	1.05
	9-1-82	-.103	-.396	-.231	-5.91	.852
14	12-9-81	-0.411	-0.965	0.073	-4.32	2.40
	3-25-82	-2.05	-4.42	.195	-6.70	-.131
	6-8-82	-1.42	-3.03	.171	-6.03	.710
	9-2-82	-.992	-2.21	.151	-5.47	1.28
15	12-9-81	-3.21	-6.59	0.164	-7.51	-0.845
	3-25-82	--	--	.158	-8.52	-1.87
	6-8-82	--	--	.134	-9.09	-2.35
	9-2-82	-3.42	-7.00	.137	-8.09	-1.27

Table 25.--Saturation indices of selected minerals in water from wells completed in or near spoil--Continued

Well number (figs. 2-4)	Date of sample	Alunite	Albite	Adualria	Kaolinite	Amorphous ferric hydroxide	Pyrite	Siderite
1	7-21-81	--	--	--	--	--	-3.60	0.565
	12-8-81	0.543	-2.62	-1.18	1.89	-1.58	10.7	.332
	3-24-82	1.11	-2.10	-.664	2.59	-1.22	10.8	.435
	6-7-82	2.96	-2.12	-.669	3.24	-.872	10.4	.237
	9-1-82	--	--	--	--	--	10.6	.427
2	12-8-81	2.14	-1.89	-0.563	3.17	-1.08	9.51	-0.333
	3-24-82	2.00	-1.69	-.536	3.43	-.976	10.1	-.126
	6-7-82	.513	-2.58	-1.41	2.11	-1.58	9.80	-.202
	9-1-82	--	--	--	--	--	10.1	.156
3	7-20-81	7.45	-1.79	0.400	6.07	0.680	9.60	-0.399
	12-9-81	1.85	-1.64	-.339	3.00	-1.15	10.2	.010
	3-26-82	4.35	-.886	.284	4.65	-.309	10.0	-.351
	6-7-82	--	--	--	--	--	9.34	-.508
	8-31-82	.940	2.69	-1.67	1.71	-1.64	9.53	-.363
	7-26-83	1.41	-1.70	-.619	2.84	-1.10	9.91	.024
4	12-9-81	5.17	-0.769	0.487	5.20	-0.059	9.64	-0.712
	3-24-82	3.80	-1.31	-.247	4.20	-.536	10.1	-.130
	6-7-82	3.45	-1.52	-.389	3.91	-.628	9.09	-.279
	9-1-82	.988	-2.03	-.942	2.66	-1.24	9.87	-.307
6	7-21-81	--	--	--	--	--	11.0	1.30
	3-25-82	2.91	-0.720	0.513	3.87	-0.581	12.5	2.45
	6-8-82	3.01	-1.27	-.078	3.36	-.693	12.1	2.13
	9-2-82	1.75	-1.41	-.353	2.83	-.945	12.0	2.12
7	7-21-81	7.62	-1.28	1.10	6.44	0.820	10.8	0.750
	12-9-81	3.29	-2.88	-.934	2.71	-1.13	11.0	.385
	3-25-82	2.85	-2.60	-.669	3.04	-.927	12.0	1.39
	6-8-82	2.72	-2.83	-.888	2.84	-.870	11.7	1.43
	9-2-82	.930	-3.55	-1.53	1.72	-1.46	11.2	.872
8	7-21-81	1.63	-2.03	0.862	2.60	-1.12	8.75	-1.38
	12-9-81	4.13	-.384	.641	4.91	-.240	9.80	-.660
	3-25-82	1.89	-.941	.071	3.86	-.591	9.95	-.062
	6-8-82	2.86	-1.10	-.117	4.01	-.491	9.98	.098
	9-2-82	1.26	-1.46	-.413	3.12	-.999	10.1	-.002
	7-26-83	.900	-2.00	-.984	2.44	-1.29	10.1	.075

Table 25.--Saturation indices of selected minerals in water from wells completed in or near spoil--Continued

Well number (figs. 2-4)	Date of sample	Alunite	Albite	Adualria	Kaolinite	Amorphous ferric hydroxide	Pyrite	Siderite
9	12-9-81	0.161	-3.19	-1.55	1.75	-1.59	11.0	0.604
	3-25-82	2.81	1.90	-.220	3.99	-.308	9.76	-.342
	6-8-82	.613	-4.25	-2.52	.994	-1.80	9.77	-.357
	9-1-82	-.079	-4.22	-2.53	.778	-1.89	9.99	-.040
10	3-25-82	2.65	-4.90	-3.00	2.06	-0.476	9.25	-1.27
	6-8-82	1.57	-3.51	-1.82	2.44	-1.14	9.03	-1.35
	9-1-82	-2.03	-4.76	-3.11	-.058	-2.35	9.04	-1.10
11	7-21-81	7.78	0.350	1.43	7.03	1.30	9.90	-2.44
12	7-21-82	7.82	-0.629	1.40	6.68	1.03	10.0	0.081
	3-25-82	3.02	-.417	.620	4.21	-.342	10.7	.493
	6-8-82	3.27	-1.24	-.187	3.83	.331	10.0	-.0812
	9-1-82	--	--	--	--	--	9.75	.334
	7-25-83	1.38	-2.02	-.831	2.54	-.934	9.34	-.489
13	3-25-82	3.15	-0.604	0.843	4.61	-0.185	9.86	-0.607
	6-8-82	3.59	-1.05	.296	--	-.041	9.24	-.902
	9-1-82	1.54	-2.24	-.901	2.51	-.920	9.24	-.971
14	12-9-81	2.78	-2.60	-0.575	3.08	-0.950	11.2	0.809
	3-25-82	.261	-4.85	-3.01	.131	-2.67	9.48	-1.75
	6-8-82	2.31	-3.98	-2.10	1.68	-1.72	9.87	-.741
	9-2-82	.070	-4.29	-2.41	.567	-2.26	10.3	-.102
15	12-9-81	7.00	-4.19	-2.21	3.27	-1.00	8.74	-2.54
	3-25-82	4.38	-6.09	-4.21	.488	-2.42	7.90	--
	6-8-82	3.85	-6.97	-5.03	-.385	-2.73	7.26	--
	9-2-82	7.34	-4.63	-2.71	3.04	-.938	8.01	-3.01

Table 25.--Saturation indices of selected minerals in water from wells completed in or near spoil--Continued

Well number (figs.2-4)	Date of sample	Quartz	Illite	Calcium montmor-rillonite
1	7-21-81	0.571	--	--
	12-8-81	.578	-0.077	1.15
	3-24-82	.595	.906	2.07
	6-7-82	.579	1.33	2.73
	9-1-82	.579	--	--
2	12-8-81	0.720	1.36	2.77
	3-24-82	.743	1.67	3.16
	6-7-82	.715	-.037	1.58
	9-1-82	.707	--	--
3	7-20-81	0.446	4.43	5.86
	12-9-81	.690	1.45	2.60
	3-26-82	.662	3.20	4.46
	6-7-82	.633	--	--
	8-31-82	.582	-.567	.924
	7-26-83	.608	1.23	2.41
4	12-9-81	0.698	3.73	5.13
	3-24-82	.681	2.41	3.93
	6-7-82	.663	2.08	3.62
	9-1-82	.647	.785	2.20
6	7-21-81	0.540	--	--
	3-25-82	.577	2.91	3.60
	6-8-82	.461	2.07	2.84
	9-2-82	.452	1.51	2.25
7	7-21-81	0.499	5.30	6.44
	12-9-81	.517	.549	1.90
	3-25-82	.493	1.26	2.36
	6-8-82	.378	1.03	2.07
	9-2-82	.393	-.337	.755
8	7-21-81	0.513	0.787	1.96
	12-9-81	.731	3.67	4.89
	3-25-82	.596	2.60	3.64
	6-8-82	.599	2.52	3.79
	9-2-82	.631	1.62	2.76
	7-26-83	.598	.584	1.89

Table 25.--Saturation indices of selected minerals in water from wells completed in or near spoil--Continued

Well number (figs.2-4)	Date of sample	Quartz	Illite	Calcium montmorillonite
9	12-9-81	0.521	-0.330	0.922
	3-25-82	.377	2.68	3.54
	6-8-82	.374	-1.64	-.205
	9-1-82	.371	-1.76	-.406
10	3-25-82	-0.444	-0.760	0.107
	6-8-82	.434	.061	1.62
	9-1-82	.423	-2.85	-1.28
11	7-21-81	0.300	6.08	6.91
12	7-21-81	0.400	5.73	6.62
	3-25-82	.493	3.30	3.88
	6-8-82	.327	2.38	3.20
	9-1-82	.311	--	--
	7-25-83	.297	.914	1.68
13	3-25-82	0.392	3.80	4.25
	6-8-82	.300	3.19	3.84
	9-1-82	.260	.801	1.57
14	12-9-81	0.568	1.33	2.53
	3-25-82	.781	-3.15	-.977
	6-8-82	.640	-1.12	.785
	9-2-82	.631	-2.15	-.446
15	12-9-81	0.696	-0.273	2.39
	3-25-82	.727	-4.11	-.999
	6-8-82	.614	-5.44	-2.19
	9-2-82	.556	-.802	1.96