GROUND-WATER HYDROLOGY BEFORE, DURING, AND AFTER COAL STRIP MINING OF A SMALL WATERSHED IN COSHOCTON COUNTY, OHIO

By Allan C. Razem

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Dallas L. Peck, Director

For additional information
write to:

District Chief
Water Resources Division
U.S. Geological Survey
975 West Third Avenue
Columbus, Ohio 43212

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION FACTORS

For the benefit of readers who prefer to use the International System of units (SI), conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
gallon per minute (gal/min)	0.00006309	meter^3 per second (m^3/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
micromho per centimeter (umho/cm)	1	microsiemens (us)

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ABSTRACT

Ground-water conditions before, during, and after surface mining of a small watershed are described as part of a study to determine the effects of mining on hydrologic systems. The watershed was underlain by stratified sedimentary rocks containing three aquifers. The top and middle aquifers were perched above clay beds that underlay the major coal seams; the lowermost aquifer is part of a regional aquifer system. Mining involved removing the overburden rocks (including the top aquifer), stripping the coal, and recontouring the overburden spoils to the approximate premining shape of the watershed.

Replacement of the top aquifer by spoils during mining has caused many changes in the land surface, recharge rates, discharge rates, saturated thickness, water-table gradient, hydraulic conductivity, storage, and water quality. Changes in the middle aquifer include: the amount of recharge from precipitation, amount of leakage through the overlying clay bed, and water quality in some areas.

Saturation of the mine spoils during postmining has been slow and irregular; saturated zones have ranged from zero to 5 feet in thickness. Water levels in wells in the middle aquifer have remained virtually unchanged.

The water quality in the mine spoils is significantly poorer than in the original top aquifer. Specific conductance of water in the mine spoils is 2,020 micromhos per centimeter and sulfate as much as 940 milligrams per liter compared to 120 micromhos per centimeter and 11 milligrams per liter in the original aquifer. Water levels and water quality in the deep aquifer have not been affected by mining.

INTRODUCTION

A better understanding of the impact of coal strip-mining on water resources is required because of the growing use of coal. The U.S. Bureau of Mines has sponsored a comprehensive study to assess the effects of strip mining on hydrology of small watersheds (30-50 acres) in eastern Ohio (Hamon and others, 1977). The U.S. Geological Survey is responsible for the ground-water part of the study, which has the following objectives: (1) describe hydrogeology of four small watersheds and a small control watershed; (2) document ground-water flow and water-quality characteristics in premining and postmining periods; and (3) develop models to simulate the movement of ground water in Watersheds CO6 and MO9 before mining and Watershed MO9 after mining.

In this comprehensive cooperative study, the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) at Coshocton, Ohio, is responsible for collecting and analyzing streamflow, sediment, and erosion data. The Ohio State University, Ohio Agricultural Research and Development Center (OSU-OARDC) at Wooster, Ohio, is responsible for studies of depth of topsoil and mulching requirements and for collecting and analyzing soils, core mineralogy, streamflow quality, and economic data. The U.S. Department of Agriculture, Soil Conservation Service described the soils of the study watersheds before mining and after reclamation.

Recent Reports

Earlier reports (U.S. Bureau of Mines, 1978; Hamon and others, 1979; Helgesen and Razem, 1980) include descriptions of premining (Phase 1) ground-water hydrology. The premining ground-water flow model is described by the U.S. Bureau of Mines (1978). Helgesen and Razem (1981) describe the during mining (Phase 2) ground-water conditions at Watersheds CO6 and MO9. This report, which is one of a series of reports that documents hydrologic changes as a result of strip mining of four watersheds in eastern Ohio, describes ground-water conditions after mining (Phase 3) at watershed CO6.

In order to preserve continuity between the different phases in this study, this report (Phase 3) relies and draws heavily on the Phase 1 reports (U.S. Bureau of Mines, 1978) and Phase 2 reports (Helgesen and Razem, 1981 and U.S. Bureau of Mines, 1982) for summarizing conditions before and during mining. Later reports will document changes as data collection and analysis continue.

Watershed and Well Numbering System

Each watershed (fig. 1) is identified by the first letter of the county in which it is located (except watershed A06) and a two-digit number indicating the number of the coal seam mined. A06 will not be mined; it serves as a control watershed in which the USDA-ARS has collected historic data. J11 was mined and the spoils were graded during the summer and fall of 1980. J08 has not been mined. C06, the watershed discussed in this report, was mined from November 1976 to August 1978. M09 was mined and the spoils were graded from January 1977 to August 1978. The last digit of the observation well number represents the aquifer in which the well is completed; that is, 1 = top, 2 = middle, 3 = deep. The "W" prefix refers to premining and the "P" prefix refers to postmining.

STUDIES ON WATERSHED C06 BEFORE AND DURING MINING

Watershed C06 in Natural (Phase 1) Condition

Geology

Watershed C06 is in the unglaciated plateau region of south eastern Ohio. Stratigraphy (fig. 2) consisted of nearly flat-lying interbedded shale, sandstone, limestone, coal, and clay of the Pennsylvanian System (U. S. Bureau of Mines, 1978). Sandstone and shale were the prevailing rock types. The Middle Kittanning No. 6 coal bed of the Allegheny Formation was the only coal bed that cropped out in the watershed.

Review of Phase 1 Ground-Water Hydrology

Relatively impermeable clay beds that underlay the major coal seams formed bases for two major perched saturated zones above the regional ground-water system (fig. 3). The saturated zones are referred to as "aquifers" for convenience, even though they typically yielded less than 1 gal/min (gallon per minute) to wells. Observation wells (fig. 4) were cased so that each was open to only one aquifer.

The top aquifer was above the clay that underlay the Middle Kittanning No. 6 coal bed of the Allegheny Formation. Recharge was from precipitation within the watershed and discharge was downward as leakage through the underclay or laterally (fig. 5) as springflow, seepage, or evapotranspiration at the coal outcrop.

The middle aquifer is above the clay that underlies the Brookville No. 4 coal bed of the Allegheny Formation. Recharge to the middle aquifer is by leakage through the overlying clay and by precipitation where the clay is absent; discharge is

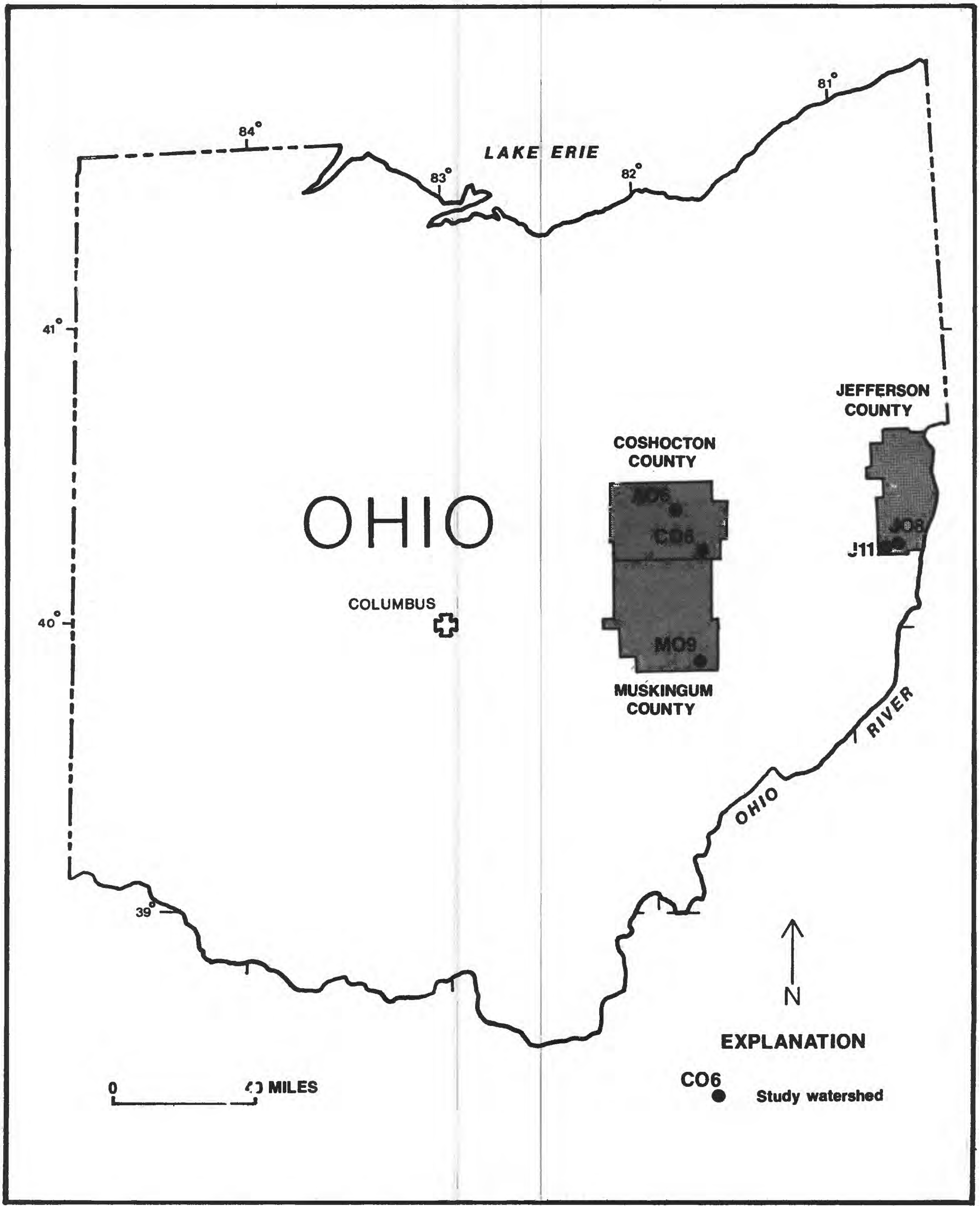
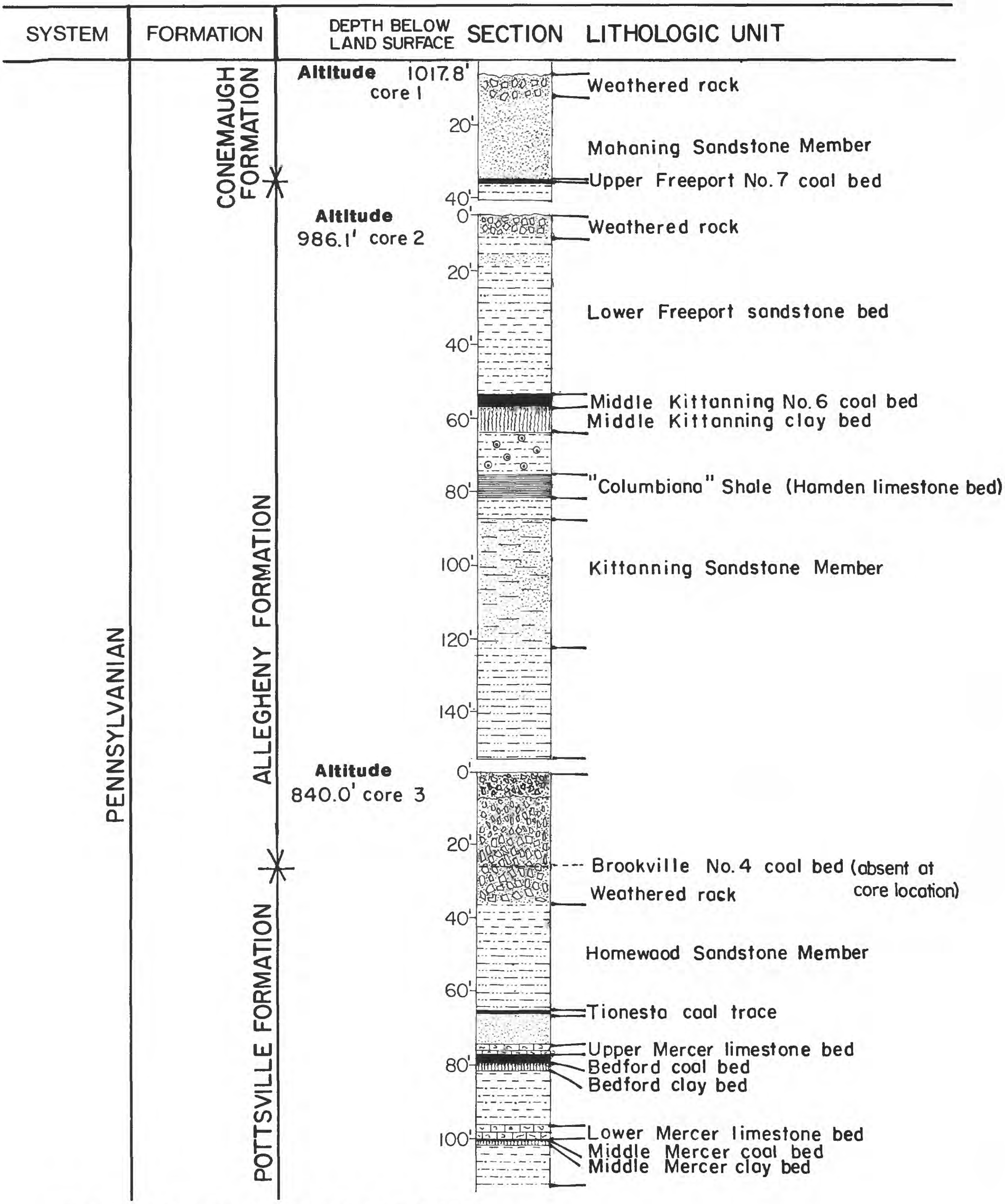
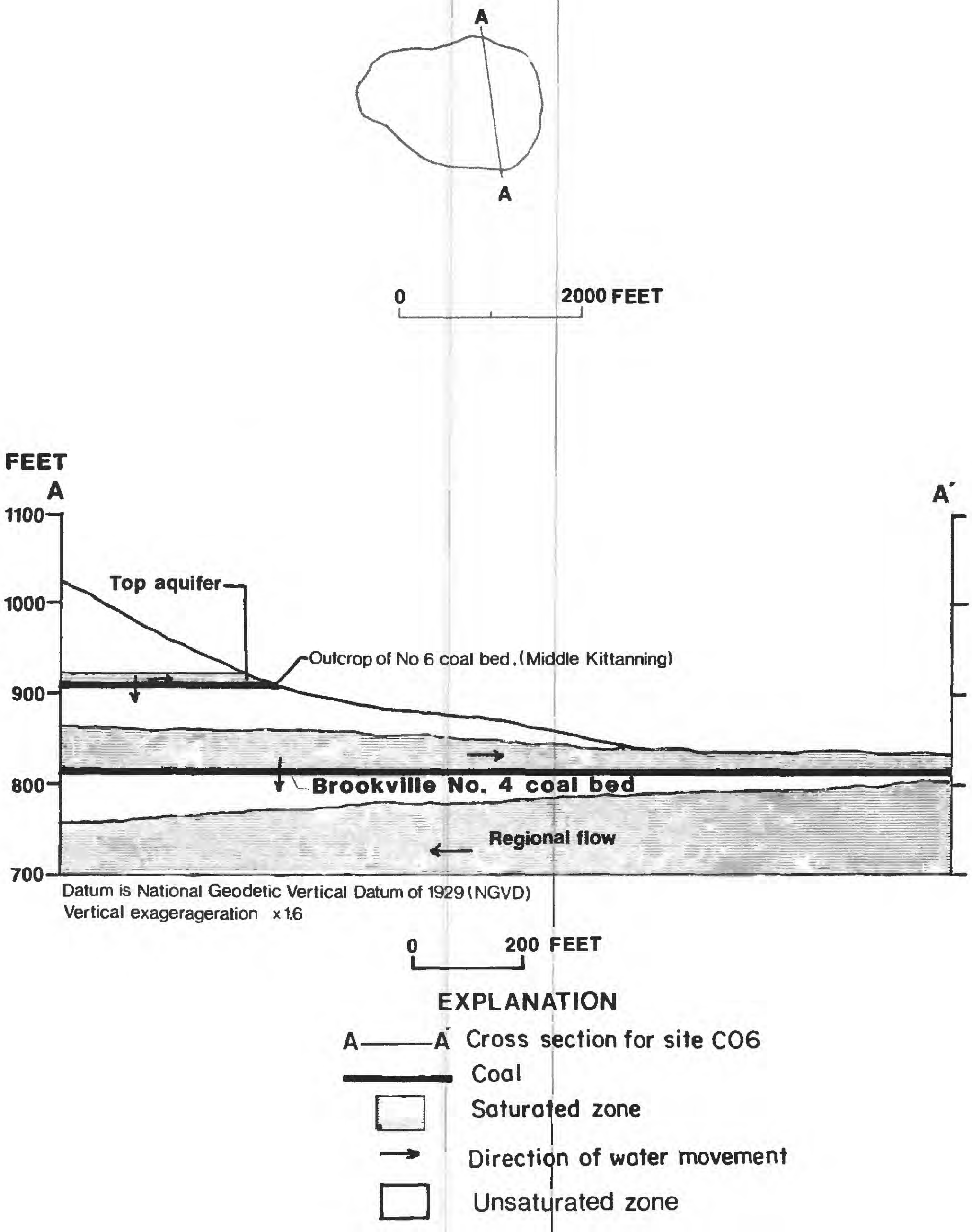


Figure 1. --Location of study watersheds.



National Geodetic Vertical Datum of 1929

Figure 2. --Stratigraphic column for watershed CO6 (Modified from U.S. Bureau of Mines, 1978).



Datum is National Geodetic Vertical Datum of 1929 (NGVD)
Vertical exageragration x 1.6

Figure 3. --Section of watershed CO6 illustrating premining ground-water occurrence and flow.

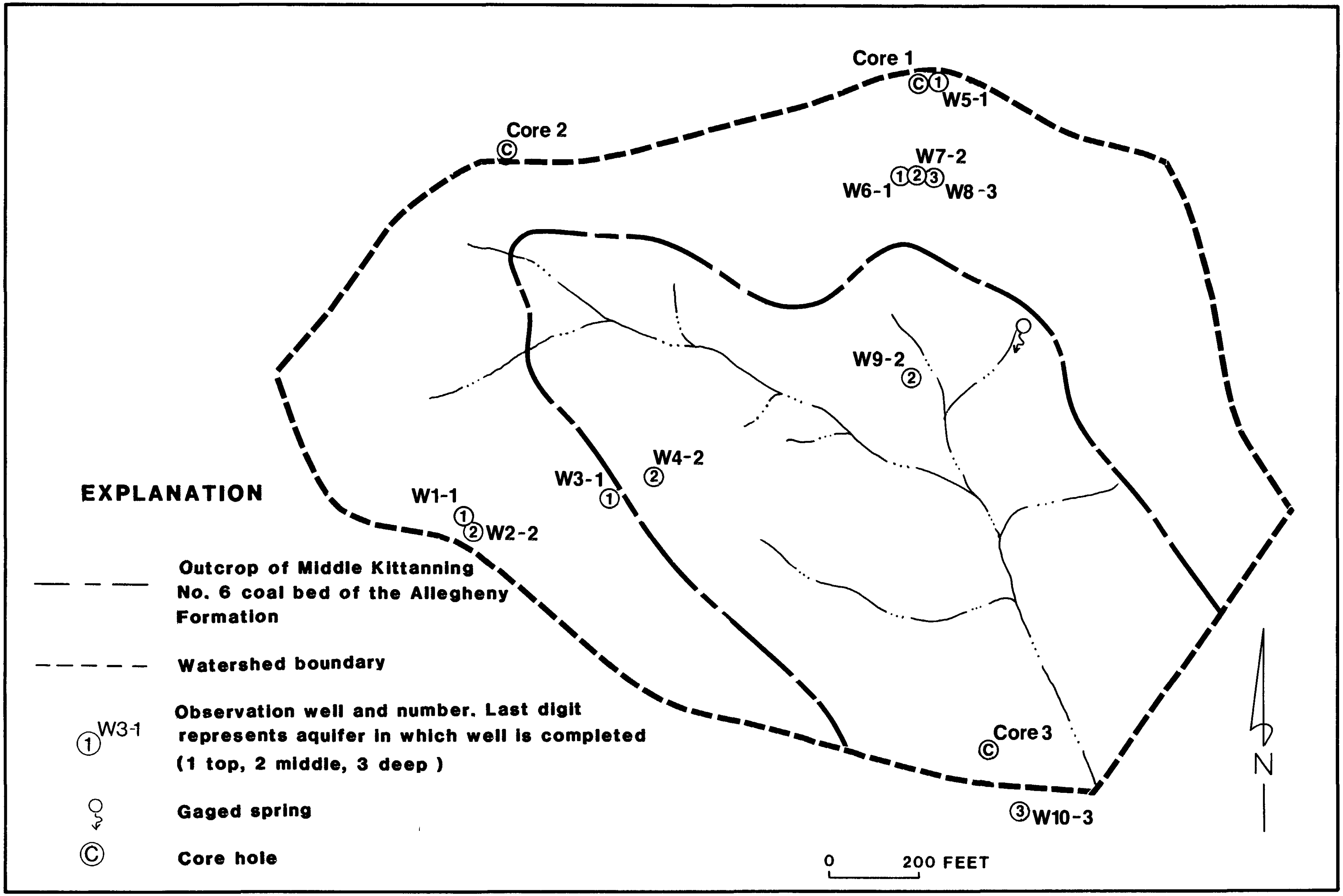


Figure 4. --Premining locations of observation wells, gaged springs, and coal outcrop at watershed CO6.

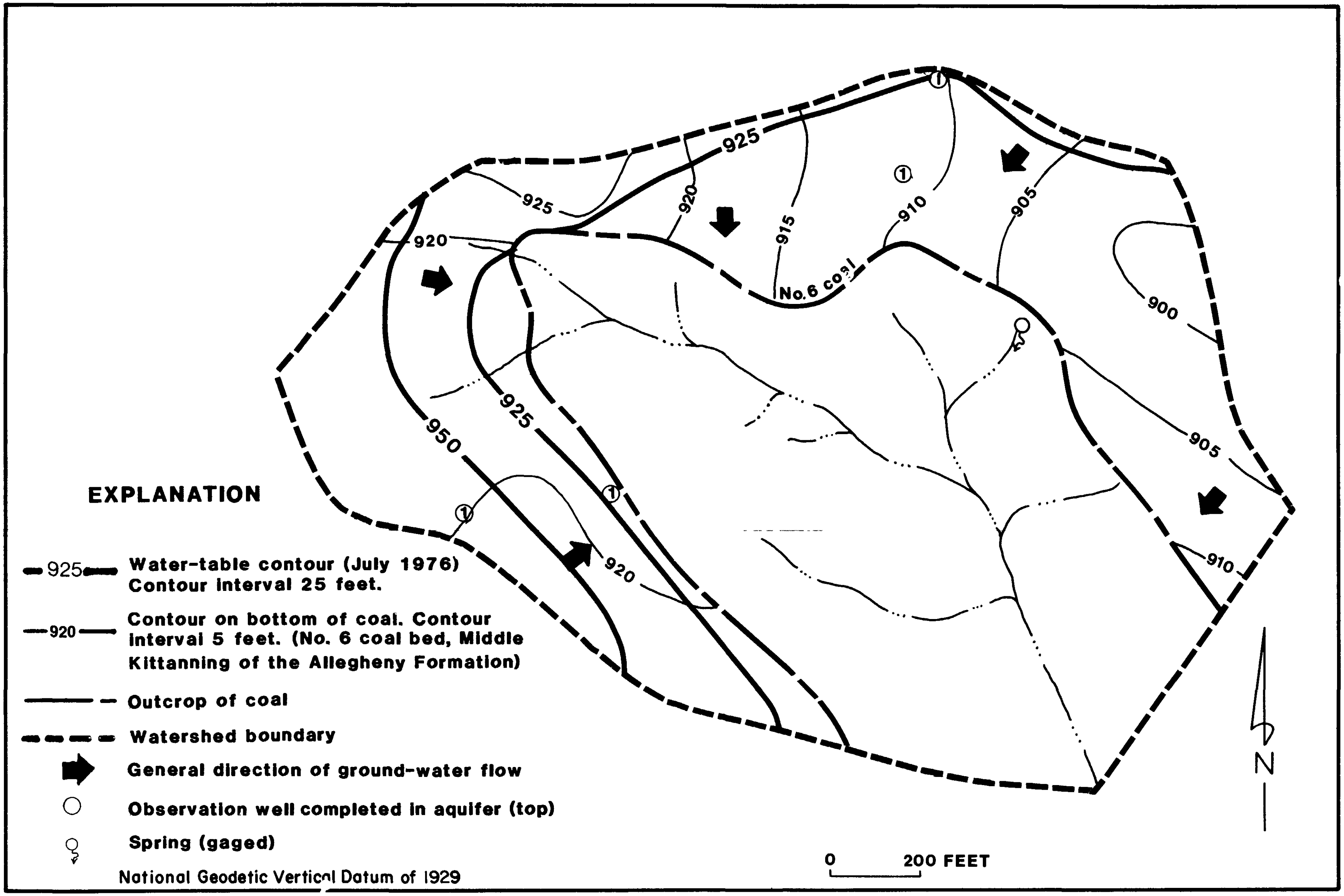


Figure 5. --Potentiometric surface and base of top aquifer at watershed CO6.

downward leakage through the underclay, lateral (fig. 6) as base flow to the stream, or evapotranspiration. The relationships of precipitation, water levels in the top and middle aquifers, springflow, and streamflow are shown in figure 7.

The deep aquifer is part of the regional flow system, which is recharged and discharged mainly outside the watershed.

Review of Phase 1 Ground-Water Quality

Premining ground-water quality at watershed C06 showed considerable variability within and between aquifers (table 1; fig. 8). Ground water was commonly of the calcium bicarbonate type, but calcium sulfate and sodium bicarbonate types were also present. Mineralization of water was greater in the middle and deep aquifers, as indicated by specific-conductance measurements. Specific conductance ranged from 120 to 520 µmho/cm (micromhos per centimeter at 25°C) in the top aquifer, 280 to 905 in the middle aquifer, and 258 to 1,110 in the deep aquifer.

Watershed C06 in Mined (Phase 2) Condition

Geology

Mining entailed stripping of the Middle Kittanning No. 6 coal bed of the Allegheny Formation. Mining began along the coal outcrop. Excavated overburden was placed downslope.

As coal was stripped and the position of the highwall moved toward the watershed divide, additional ridges of overburden material were formed. The underclay and the underlying rocks were left virtually undisturbed. Reclamation included (1) recontouring the spoils to approximate premining watershed shape, (2) replacement of topsoil, and (3) revegetation.

Review of Phase 2 Ground-Water Hydrology

During the fall of 1976, mining of No. 6 coal in the adjacent watershed to the west caused the water table in the top aquifer of C06 to decline (fig. 9; well locations are shown in fig. 4). As rock overburden and coal were removed in the adjacent watershed, the aquifer was narrowed. This change caused an increased hydraulic gradient in the aquifer and increased drainage from the aquifer. Water levels in observation wells nearest the watershed divide, W1-1 and W5-1, declined 8 feet and 10 feet, respectively. Water-level declines in wells nearest the coal outcrop (W3-1 and W6-1) probably reflect only the seasonal trend. Destruction of wells prevented documentation of any water-level decline as mining progressed into watershed C06 in November 1976, but springflow at the gaged site gradually decreased and then ceased on January 3, 1977.

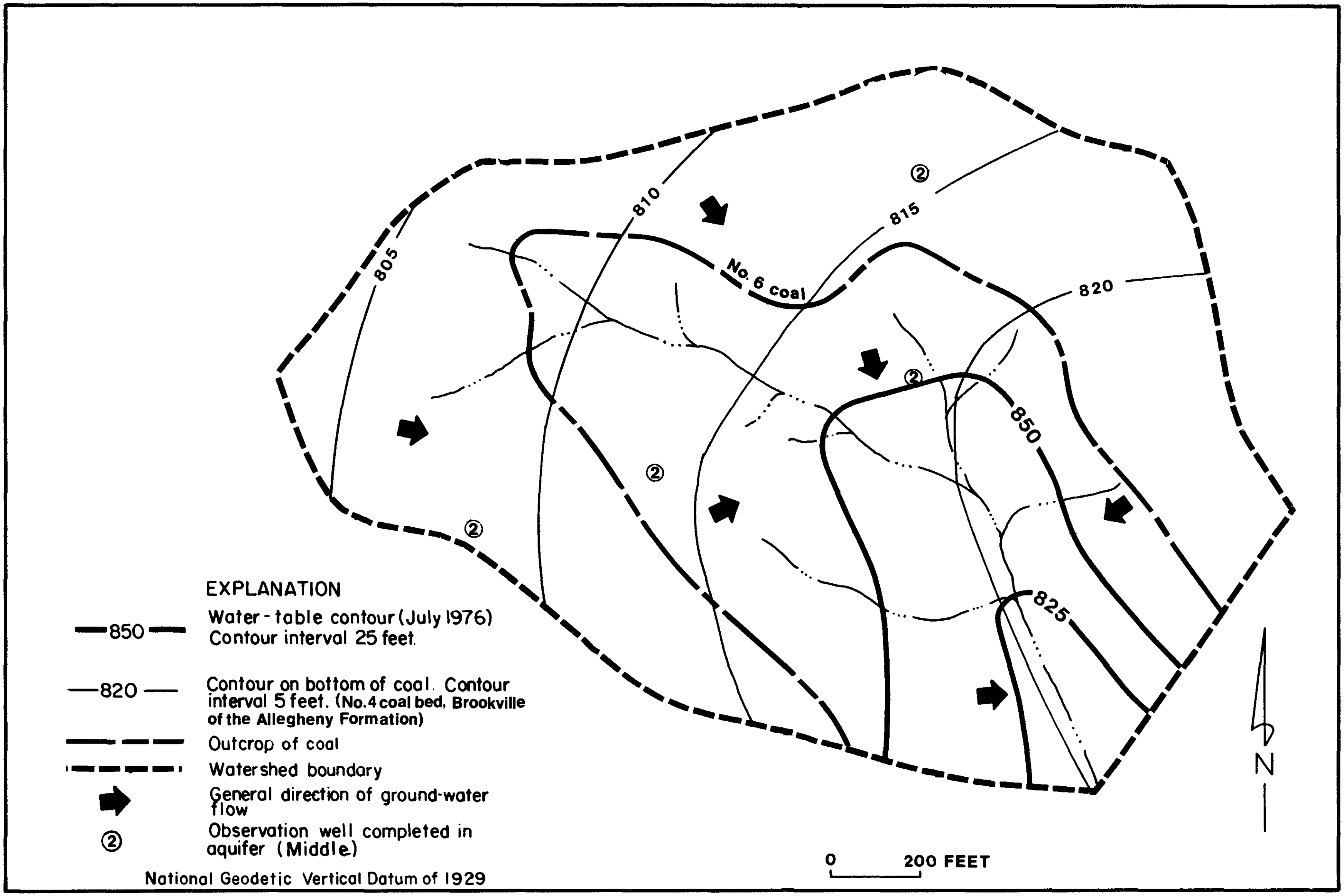


Figure 6. --Potentiometric surface and base of middle aquifer at watershed CO6.

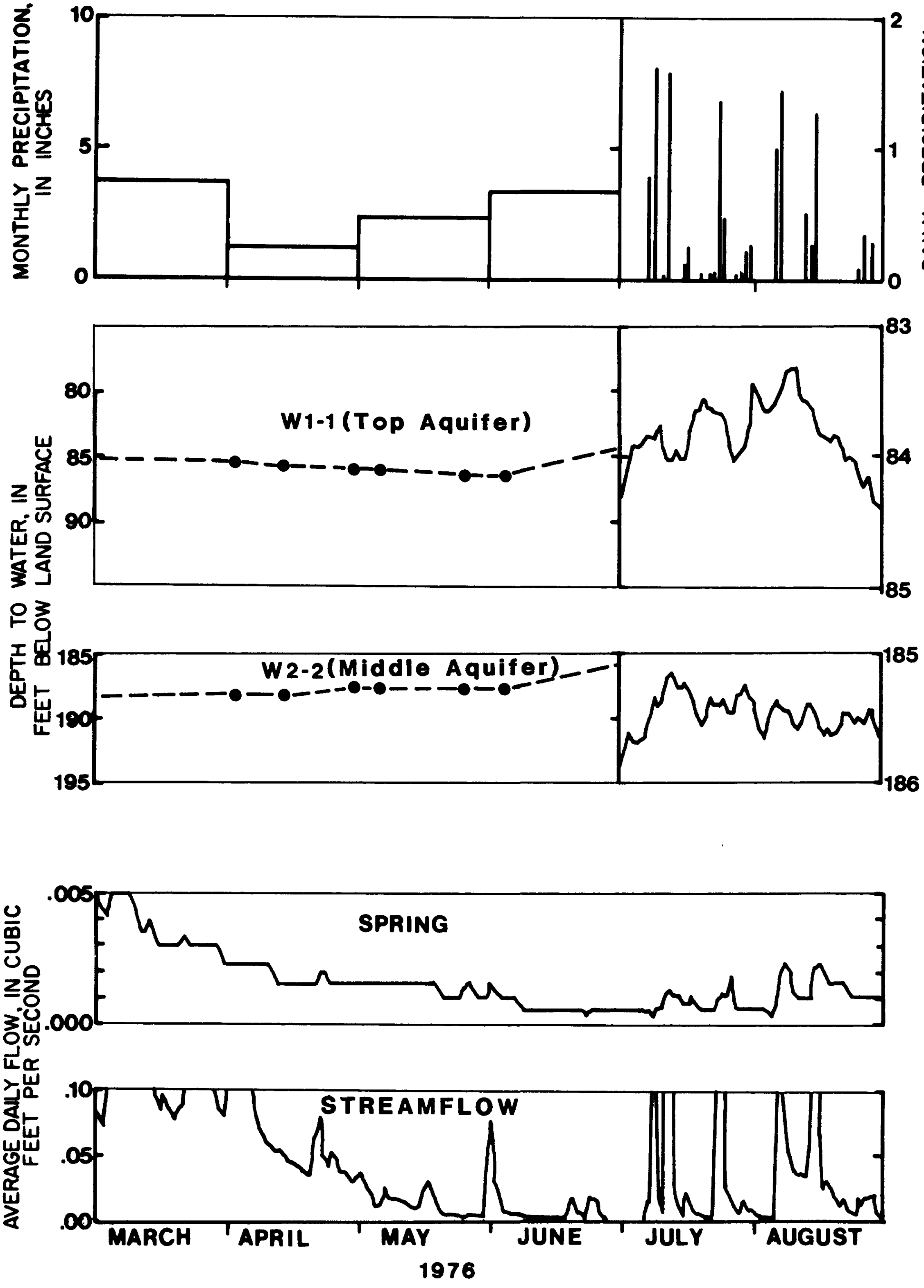


Figure 7. --Graphs of precipitation, ground-water levels, spring flow, and streamflow at watershed CO6 for part of 1976 (Graphs of precipitation, spring flow, and streamflow are based on preliminary data from U.S. Department of Agriculture-Agricultural Research Service).

Table 1.--Chemical analyses of ground water collected from watershed C06, November 1975-October 1976

[mg/L, milligrams per liter; µg/L, Micrograms per liter; Pt-Co, platinum-cobalt units; tons/acre-ft; tons per acre-foot; µmho/cm, micromhos per centimeter at 25°C]

Constituents or properties	Unit	Concentration or other measurement			
		Top aquifer		Middle aquifer	
		Range	Median	Range	Median
Alkalinity, as $CaCO_3$	mg/L	21-135	92	125-284	222
Aluminum, total	µg/L	60-50,000	920	20-5,6000	2,100
Antimony, total	µg/L	0-2	0	0-1	0
Arsenic, total	µg/L	0-43	3	0-5	1
Barium, total	µg/L	0-1,100	100	0-300	100
Bicarbonate	mg/L	25-164	112	152-346	271
Cadmium, total	µg/L	0-62	5	1-34	7
Calcium, dissolved	mg/L	3.1-53	26	3.2-90	38
Carbon dioxide	mg/L	1.7-154	35	13-122	35
Carbon, total organic	mg/L	1.3-27	4.1	0.2-8.6	3.0
Carbonate	mg/L	0-0	0	0-0	0
Chloride, dissolved	mg/L	1.0-91	2.3	1.1-9.0	3.9
Chromium, total	µg/L	0-110	<10	<10-60	<10
Color	Pt-Co	1-46	3	1-8	1
Copper, total	µg/L	0-950	10	0-110	10
Cyanide	mg/L	0.00-0.01	0.00	0.00-0.0	0.00
Fluoride, dissolved	mg/L	0.1-1.6	0.2	0.3-0.9	0.3
Hardness, noncarbonate	mg/L	0-65	32	0-72	36
Hardness, total	mg/L	11-170	115	14-330	190
Hydrogen, sulfide	mg/L	0.0-0.3	0.0	0.0-0.2	0.0
Iron, dissolved	µg/L	10-2,300	130	40-2,000	930
Iron, total	µg/L	120-170,000	5,400	1,200-27,000	7,600
Lead, total	µg/L	0-400	22	2-44	15
Magnesium, dissolved	mg/L	0.8-15	0.9	1.4-26	16
Manganese, dissolved	µg/L	0-930	140	20-710	270
Manganese, suspended	µg/L	0-70,000	360	0-210	120
Manganese, total	µg/L	0-70,000	690	40-840	270
Mercury, total	µg/L	<0.5-<0.5	<0.5	<0.5-2.0	<0.5
Nickel, total	µg/L	2-550	19	1-20	13
Nitrogen, NH_4 as N, total	µg/L	0.00-1.3	0.04	0.00-0.53	0.31
NO_2+NO_3 as N	mg/L	0.02-0.73	0.07	0.01-0.39	0.04
pH (field)		6.0-8.2	6.8	6.3-7.6	7.2
Phenols	µg/L	0-8	0	0-4	0
Phosphorus, total as P	mg/L	0.08-3.8	0.10	0.03-0.12	0.06
Phosphorus, total PO_4	mg/L	0.06-12	0.32	0.09-0.37	0.18
Potassium, dissolved	mg/L	1.0-4.9	1.6	1.7-4.8	3.3
Residue, dissolved (calculated sum)	mg/L	--	--	--	--
Residue, dissolved	tons/acre-ft	--	--	--	--
Sodium adsorption ratio	mg/L	0.1-29	0.2	0.3-14	0.8
Selenium, total	µg/L	0-6	0	0-0	0
Silica, dissolved	µg/L	--	--	--	--
Silver, total	µg/L	0-1	0	0-2	0
Sodium, dissolved	mg/L	1.0-220	6.4	7.7-120	21
Sodium (percent)	%	3-97	11	11-94	21
Specific conductance (field)	µmho/cm	120-520	288	280-905	600
Strontium, total	µg/L	30-240	90	100-920	280
Sulfate, dissolved	mg/L	11-80	36	2.9-160	48
Water temperature	°C	7.0-18	13	11-0-14.0	12.5
Zinc, total	µg/L	10-800	90	20-1,500	220

Table 1.--Chemical analyses of ground water collected from watershed C06, November 1975 - October 1976--Continued

Constituents or properties	Unit	Concentration or other measurement, deep aquifer	
		Range	Median
Alkalinity, as $CaCO_3$	mg/L	97-351	108
Aluminum, total	µg/L	50-9,100	1,000
Antimony, total	µg/L	0-5	1
Arsenic, total	µg/L	0-23	5
Barium, total	µg/L	0-200	200
Bicarbonate	mg/L	118-428	132
Cadmium, total	µg/L	2-14	4
Calcium, dissolved	mg/L	3.0-28	25
Carbon dioxide	mg/L	4.7-49	17
Carbon, total organic	mg/L	0.1-45	2.3
Carbonate	mg/L	0-0	0
Chloride, dissolved	mg/L	1.2-70	3.8
Chromium, total	µg/L	<10-30	10
Color	Pt-Co	1-170	3
Copper, total	µg/L	0-190	10
Cyanide	mg/L	0.00-1.0	0.00
Fluoride, dissolved	mg/L	0.2-1.7	0.3
Hardness, noncarbonate	mg/L	0-31	16
Hardness, total	mg/L	12-130	120
Hydrogen sulfide	mg/L	0.0-0.2	0.0
Iron, dissolved	µg/L	10-630	50
Iron, total	µg/L	1,700-32,000	6,600
Lead, total	µg/L	3-120	13
Magnesium, dissolved	mg/L	1.2-15	14
Manganese, dissolved	µg/L	20-110	60
Manganese, suspended	µg/L	10-500	120
Manganese, total	µg/L	70-540	140
Mercury, total	µg/L	<0.5-1.1	<0.5
Nickel, total	µg/L	2-100	15
Nitrogen, NH_4 as N, total	µg/L	0.00-0.43	0.01
NO_2+NO_3 as N	mg/L	0.05-0.10	0.07
pH (field)		6.6-8.1	7.1
Phenols	µg/L	0-7	0
Phosphorus, total as P	mg/L	0.02-0.54	0.08
Phosphorus, total PO_4	mg/L	0.06-1.7	0.25
Potassium, dissolved	mg/L	0.4-7.4	0.9
Residue, dissolved (calculated sum)	mg/L	--	--
Residue, dissolved	tons/acre-ft	--	--
Sodium adsorption ratio	mg/L	0.1-31	0.1
Selenium, total	µg/L	0.29	0
Silica, dissolved	µg/L	--	--
Silver, total	µg/L	0-3	0
Sodium, dissolved	mg/L	3.3-250	3.8
Sodium (percent)	%	5-97	6
Specific conductance (field)	µmho/cm	258-1,110	278
Strontium, total	µg/L	50-140	70
Sulfate, dissolved	mg/L	8.2-80	20
Water temperature	°C	12.0-17.0	12.5
Zinc, total	µg/L	20-310	90

Based on all premining data: top aquifer, 18 samples from 4 wells and 2 springs; middle aquifer, 9 samples from 4 wells; deep aquifer, 5 samples from 2 wells.

Double dash indicates data are lacking.

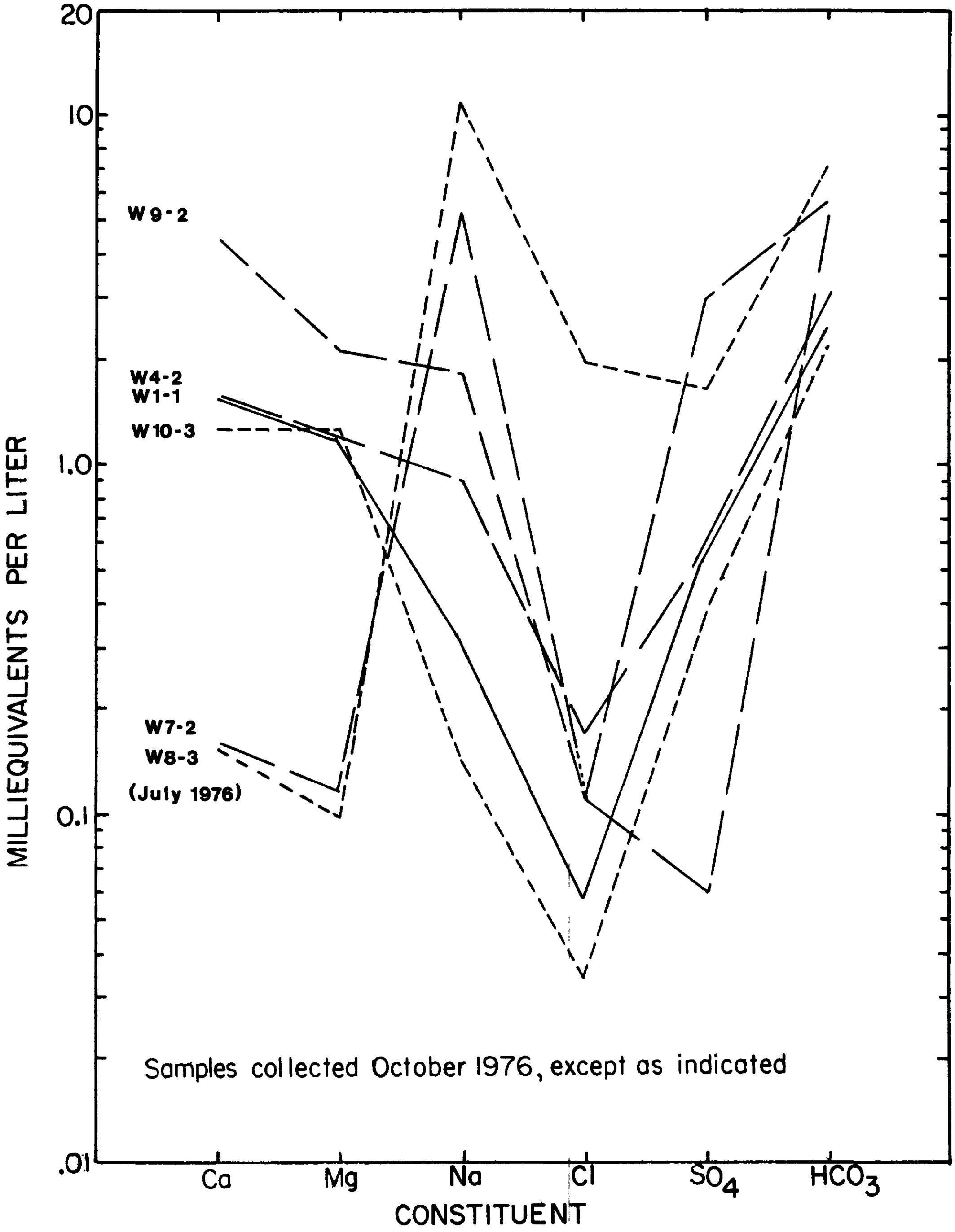


Figure 8. --Concentrations of major ions in ground-water samples from watershed CO6. (The last digit of the well number refers to the aquifer, 1=top, 2=middle, 3=deep.)

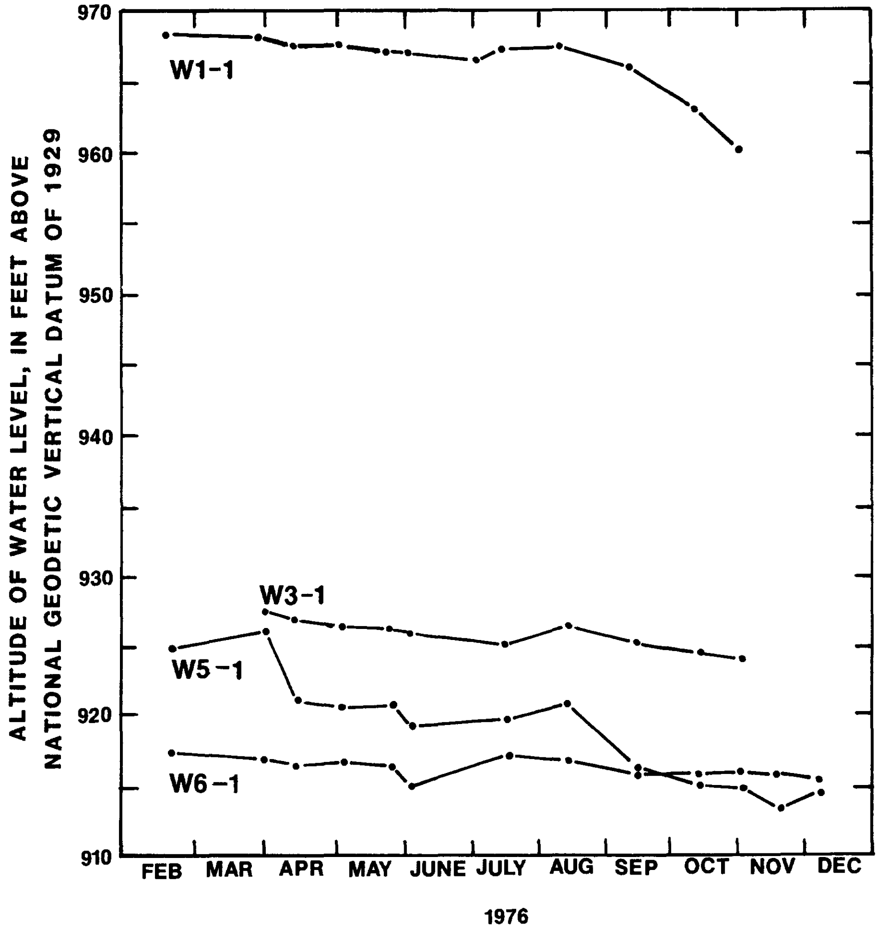


Figure 9. --Hydrographs for premining observation wells completed in top aquifer at watershed CO6.

Most of the water in the top aquifer drained as the rocks were removed and placed into spoil piles. No data are available to indicate the amount of water within the spoils during the mining phase.

The base-flow part of the streamflow hydrograph (fig. 10) reflects ground-water conditions during the mining phase. Relatively low flow during September 1976 to August 1977 was at least partly due to dewatering and destruction of the top aquifer during mining. Base flow decreased until it was supplied mainly by the middle aquifer. Later increases (after August 1977) were probably caused by water that had infiltrated and moved through the overburden spoils.

The hydrograph for well W10-3 (fig. 11) in the lower aquifer is the only water-level record for the mining phase. The hydrograph shows a decline in the water level at about the time mining began and a slow rise toward the end of the mining and reclamation period. This is a result of a decrease in recharge to the lower aquifer during mining. The decrease in recharge during mining may be because heads declined in the top and middle aquifers, which resulted in decreased leakage to the lower aquifer.

Review of Phase 2 Ground-Water Quality

Chemical analyses of water from well W10-3 during the mining phase of C06 (table 2) show no definitive trends, although some constituent concentrations varied from sample to sample.

Base-flow samples collected by USDA-ARS at the mouth of the watershed and analyzed by OSU-OARDC had dissolved-solids concentrations as follows:

Date of sampling:	Milligrams per liter
December 20, 1976	122
February 12, 1977	210
March 18, 1977	112
March 6, 1978	602

The last concentration suggests an increase in dissolved solids over premining base flow, which had a dissolved-solids concentration range of 114 to 141 mg/L (milligrams per liter) (U.S. Bureau of Mines, 1978). This increase reflects a decrease in base-flow contribution from the top aquifer and an increase in contribution from the middle aquifer and overburden spoils.

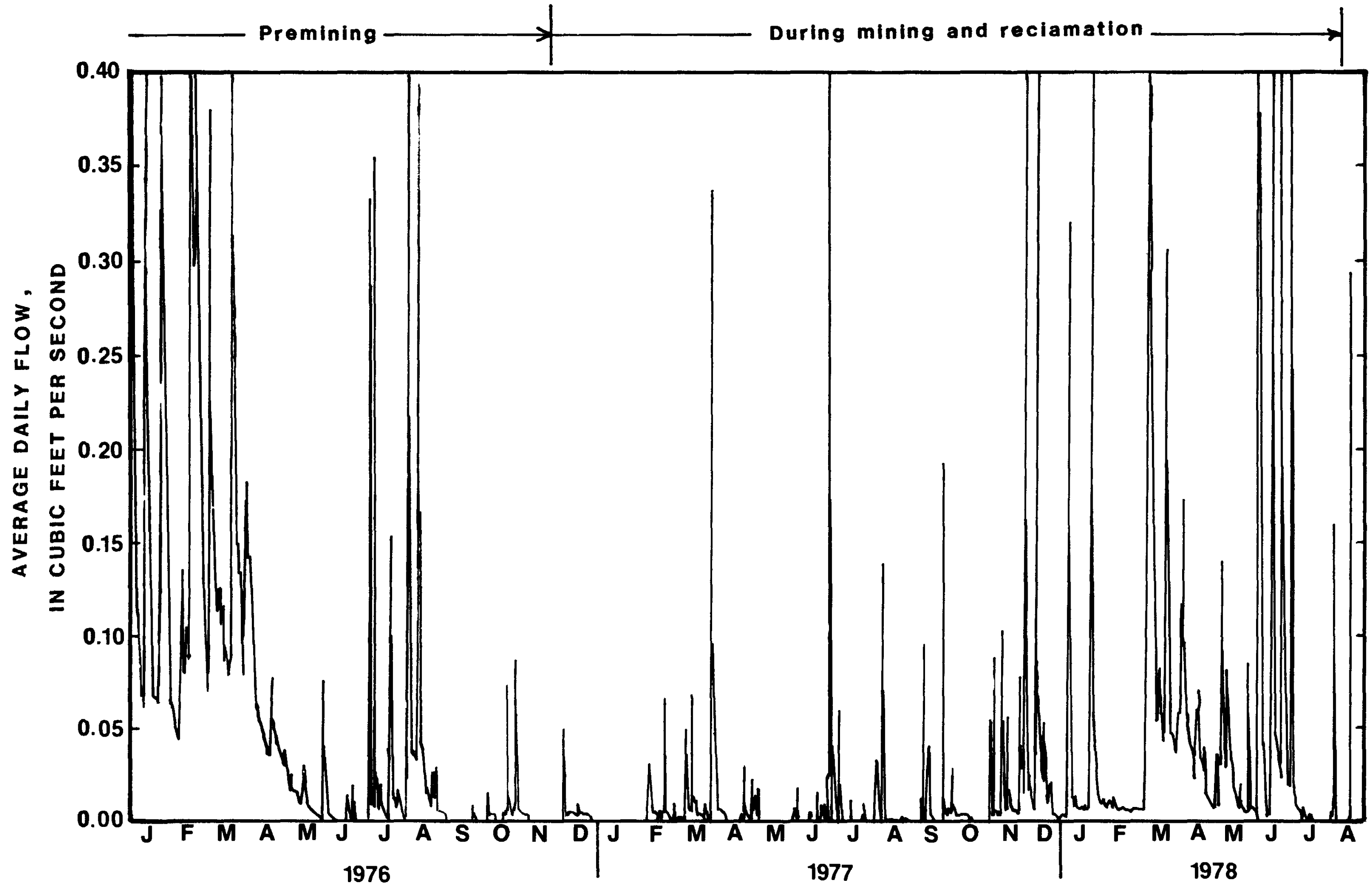


Figure 10. --Hydrograph of streamflow at mouth of watershed CO6 (Based on preliminary data from U.S. Department of Agriculture Agricultural Research Service).

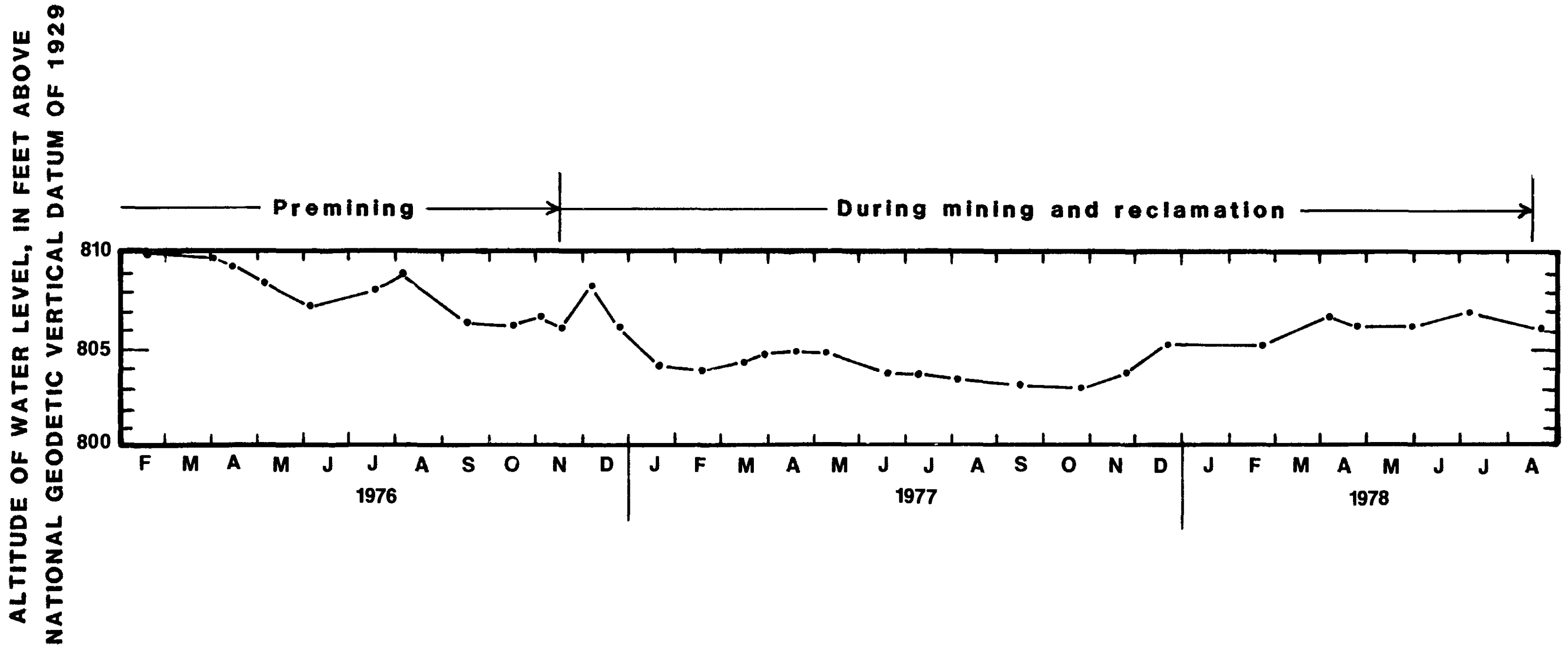


Figure 11. --Hydrograph for well W10-3 in watershed CO6.

Table 2.--Chemical analyses of water collected from well W10-3 at watershed C06 during mining

[ug/L, micrograms per liter; Pt-Co, platinum-cobalt units; tons/acre-ft, tons per acre-foot; umho/cm, micromhos per centimeter at 25°C]

Constituents or properties	Unit	Concentration or other measurement				
		3-16-77	6-17-77	9-15-77	12-27-77	7-6-78
Alkalinity, as $CaCO_3$	mg/L	112	116	115	115	125
Aluminum, dissolved	µg/L	--	--	--	--	20
Aluminum, total	µg/L	30	40	2,900	20	--
Antimony, dissolved	µg/L	--	--	--	--	--
Antimony, total	µg/L	0	0	0	1	--
Arsenic, dissolved	µg/L	--	--	--	--	0
Arsenic, total	µg/L	0	1	0	2	--
Barium, dissolved	µg/L	--	--	--	--	0
Barium, total	µg/L	100	0	100	100	--
Bicarbonate	mg/L	136	141	140	140	152
Cadmium, dissolved	µg/L	--	--	--	--	0
Cadmium, total	µg/L	0	0	0	0	1
Calcium, dissolved	mg/L	25	26	27	--	26
Carbon dioxide	mg/L	22	18	22	28	4.9
Carbon, dissolved organic	mg/L	--	--	--	2.6	0.7
Carbon, total organic	mg/L	8.1	6.3	11	--	--
Carbonate	mg/L	0	0	0	0	0
Chloride, dissolved	mg/L	1.3	1.8	1.1	1.1	1.5
Chromium, dissolved	µg/L	--	--	--	--	0
Chromium, total	µg/L	10	<10	<10	20	--
Color	Pt-Co	0	13	10	31	1
Copper, dissolved	µg/L	--	--	--	--	0
Copper, total	µg/L	2	5	5	8	--
Cyanide	mg/L	0.00	0.00	0.00	0.00	0.00
Fluoride, dissolved	mg/L	0.2	0.2	0.2	0.3	0.2
Hardness, noncarbonate	mg/L	13	3	6	--	0
Hardness, total	mg/L	120	120	120	--	120
Hydrogen sulfide	mg/L	0.2	0.0	0.0	0.0	0.0
Iron, dissolved	µg/L	60	40	20	20	150
Iron, total	µg/L	5,200	18,000	14,000	10,000	10,000
Lead, dissolved	µg/L	--	--	--	--	0
Lead, total	µg/L	4	10	13	8	--

Table 2.--Chemical analyses of water collected from well W1O-3 at watershed CO6 during mining.
--Continued

Constituents or properties	Unit	Concentration or other measurement				
		3-16-77	6-17-77	9-15-77	12-27-77	7-6-78
Magnesium, dissolved	mg/L	15	13	13	--	14
Manganese, dissolved	µg/L	10	20	10	60	30
Manganese, total	µg/L	80	150	60	110	80
Mercury, dissolved	µg/L	--	--	--	<0.5	0.5
Mercury, total	µg/L	0.0	0.0	0.5	<0.5	--
Nickel, dissolved	µg/L	--	--	--	--	0
Nickel, total	µg/L	6	6	6	8	--
Nitrogen (NH_4 as N), dissolved	mg/L	--	--	--	--	0.00
Nitrogen (NH_4 as N), total	mg/L	0.00	0.01	0.01	0.01	--
Nitrogen (organic as N), dissolved	mg/L	--	--	--	--	0.04
NO_2 + NO_3 (as N), dissolved	mg/L	--	--	--	--	0.07
NO_2 + NO_3 (as N), total	mg/L	0.02	0.08	0.10	0.03	--
pH (field)		7.0	7.1	7.0	6.9	7.7
Phenols	µg/L	7	6	2	9	4
Phosphorus (as P), dissolved	mg/L	--	--	--	--	0.00
Phosphorus (as P), total	mg/L	0.00	0.01	0.01	0.01	--
Phosphorus (as PO_4), total	mg/L	0.00	0.03	0.03	--	--
Potassium, dissolved	mg/L	0.7	0.7	0.8	0.7	0.8
Residue, dissolved (calculated sum)	mg/L	151	146	147	--	153
Residue, dissolved	tons/acre-ft	0.21	0.20	0.20	--	0.21
Selenium, dissolved	µg/L	--	--	--	--	0
Selenium, total	µg/L	0	0	0	0	--
Silica, dissolved	mg/L	16	14	15	14	14
Silver, dissolved	µg/L	--	--	--	0	0
Silver, total	µg/L	0	0	0	0	--
Sodium adsorption ratio		0.2	0.2	0.2	--	0.1
Sodium, dissolved	mg/L	5.2	3.8	4.1	4.0	3.6
Sodium (percent)	%	8	6	7	0	6
Specific conductance (field)	µmho/cm	250	245	250	290	246
Strontium, dissolved	µg/L	--	--	--	--	60
Strontium, total	µg/L	80	80	60	40	--
Sulfate, dissolved	mg/L	20	17	17	16	17
Water temperature	°C	12.5	13.0	13.0	11.0	13.5
Zinc, dissolved	µg/L	--	--	--	50	10
Zinc, total	µg/L	50	40	60	60	--

Double dash indicates data are lacking.

POSTMINING GROUND-WATER HYDROLOGY

Data Collected During Phase 3

Ten observation wells were reinstalled in September 1978 after mining and grading were completed. Four wells were completed in the spoils material, five wells were completed in the middle aquifer, and one well was completed in the deep aquifer.

The wells were drilled by cable tool through the replaced overburden materials and by air-rotary through the undisturbed rocks below. Each hole was completed in order to monitor only one of the three major saturated zones. The wells were completed with slotted casing in the replaced materials and open hole in the appropriate intervals in the undisturbed rocks. The reinstalled well network is shown in figure 12. Land surface altitudes were surveyed in at each observation well from nearby benchmarks, and aerial photographs were used for locating wells and defining watershed boundaries.

Water levels in each of the wells have been measured monthly. Digital recorders were used to continuously measure water levels in two top-aquifer wells, one middle-aquifer well, and one deep-aquifer well.

Premining and Postmining Ground-Water Hydrology

The rock above the top underclay has been replaced by spoils, but the material below the Middle Kittanning No. 6 coal bed of the Allegheny formation remains virtually unchanged. In the mining process, the material above the top coal (fig. 13) was blasted and removed, after which the coal was extracted. The spoils were then graded into the approximate premining shape. The intention of the mine operator was to leave the top underclay undisturbed.

Topography and water-table levels within the watershed suggest that the ground-water divides for the top and middle aquifers coincide with the new surface drainage divide. However, a transient divide occurs between wells P6-1 and P5-1 as the saturated zone continues to enlarge. The mine spoils are above the clay that underlay the Middle Kittanning No. 6 coal bed of the Allegheny Formation, and is above the premining land surface where the clay does not exist. The cross section (fig. 14) shows that the areal extent of the mine spoils is greater than that of the premining top aquifer because of the redistribution of spoils during regrading.

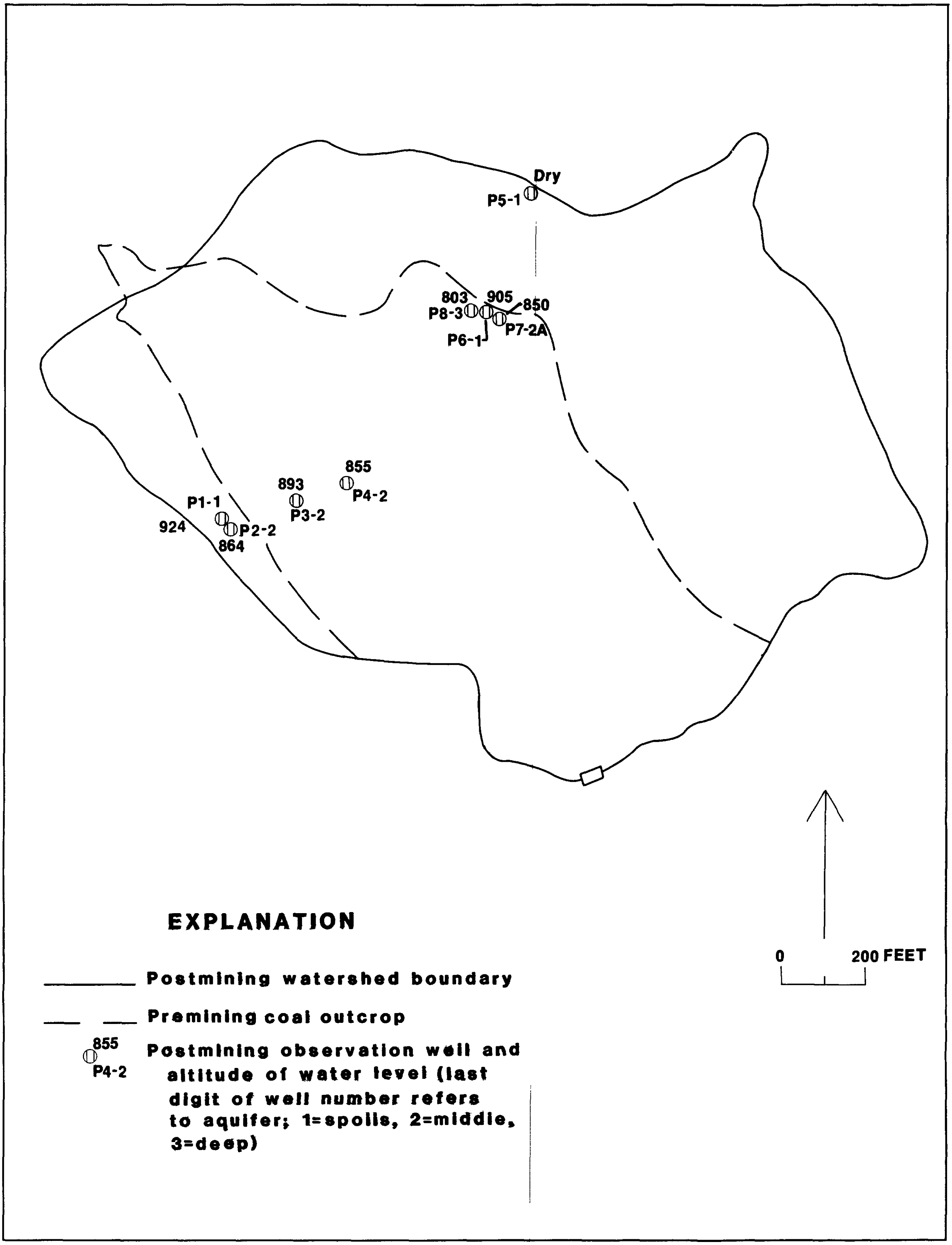


Figure 12. --Postmining observation wells and altitude of water-levels in watershed CO6.

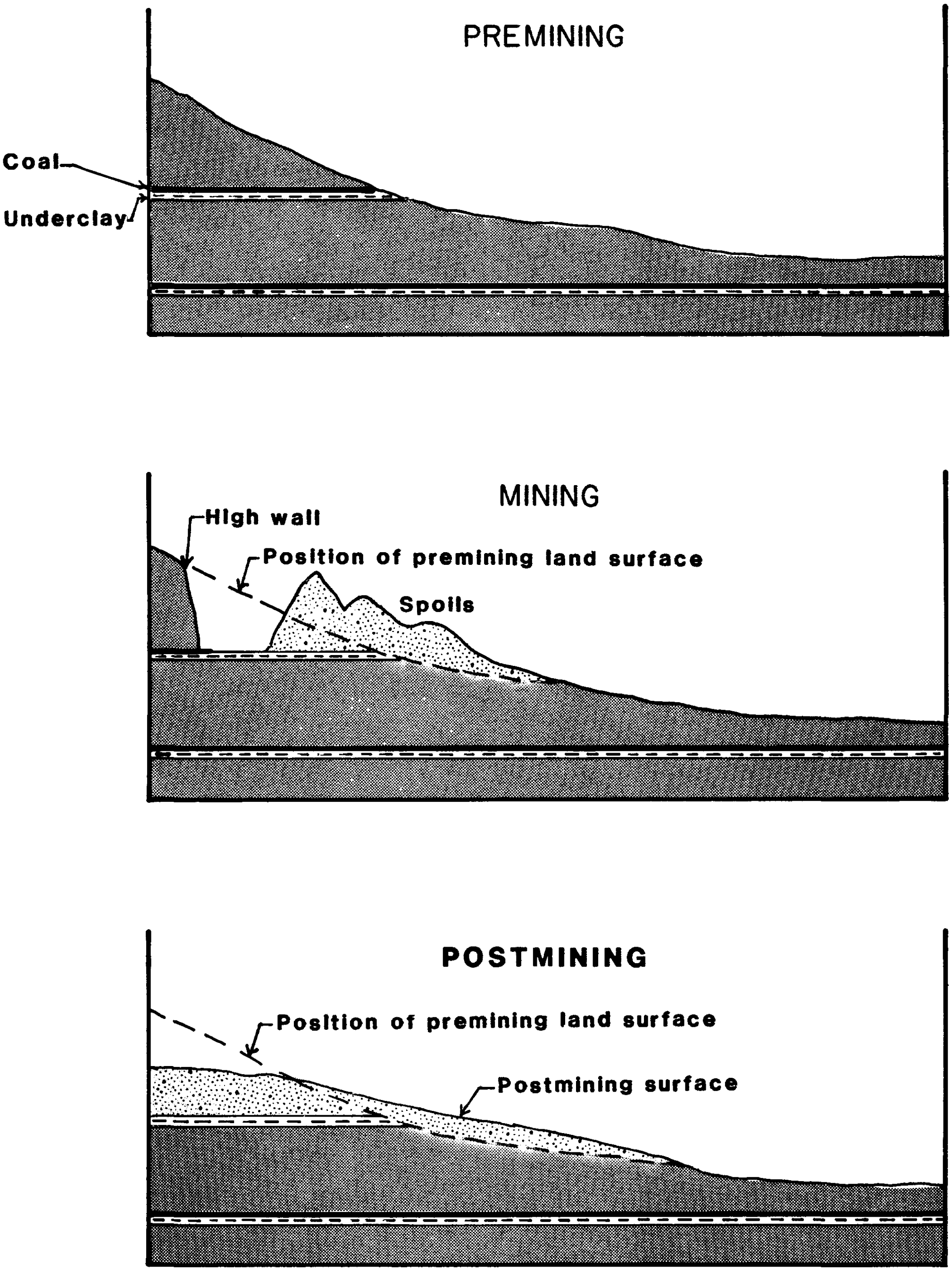


Figure 13. --Schematic sections illustrating strip-mining process. (Heigesen and Razem, 1981)

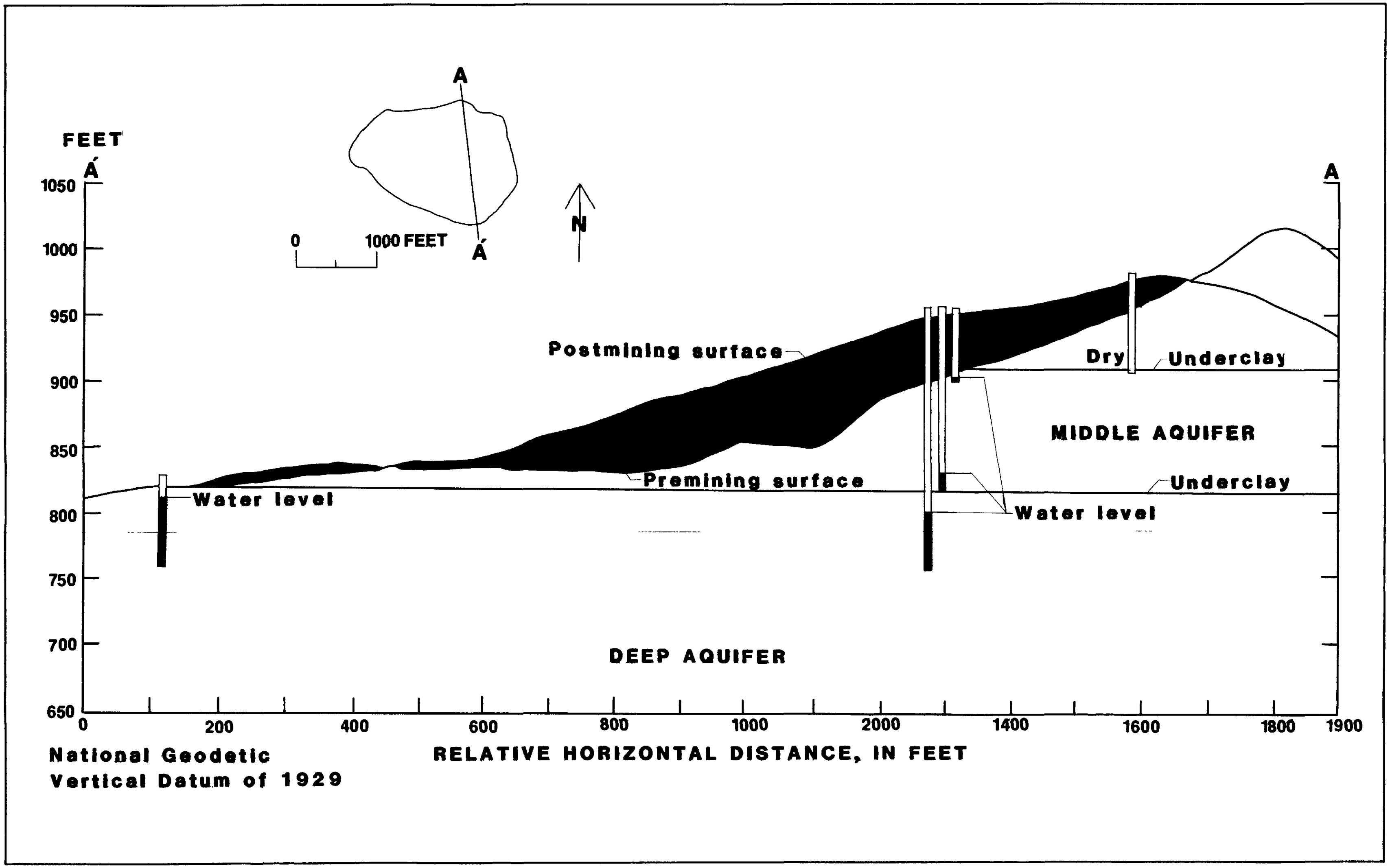


Figure 14. --Geologic and hydrogeologic section showing changes resulting from surface mining at watershed CO6.

As in the premining condition, the mine spoils receive recharge from precipitation that infiltrates to the saturated zone. The rate of recharge to the saturated zone has decreased as a result of the destruction of the soil structure, compaction of the soil, revegetation, and increased storage in the unsaturated zone.

The rate of recharge to the middle aquifer has been slower during the initial postmining period because leakage from the top aquifer is reduced and precipitation must now percolate through the spoils. The recharge rate should become steady after soils, vegetation, and the top aquifer stabilize.

Discharge from the mine spoils includes downward leakage to the middle aquifer (in the areas where sufficient head has developed), flow to springs along the flanks of the spoils material, and evapotranspiration where the water table is near the surface. Discharge from the middle aquifer is downward leakage to the deep regional aquifer and lateral movement to the stream.

Water is stored and transmitted within the intergranular pore spaces of the spoils material and within openings, fractures, and bedding planes in the middle and deep aquifers. Two major perched saturated zones still exist in the postmining watershed. However, the top zone is not completely saturated (well P5-1 is dry) and it appears from the fluctuation shown by the hydrograph of P6-1 (fig. 15) that resaturation is slow and irregular. In December 1980, postmining well P1-1 had 5 feet of water, P6-1 had 2.5 feet, and P5-1 was still dry.

The movement of water in the mine spoils and middle aquifer during postmining is toward the center and mouth of the watershed (fig. 12), whereas the flow in the deep aquifer is to the north as in premining conditions (U.S. Bureau of Mines, 1978). The flow direction and mechanisms for recharge, movement, and discharge of water in the postmining middle aquifer are the same as before mining.

Aquifer testing in the spoils material has been difficult because the saturated zone is too thin to allow for adequate testing. During bailing operations for water-quality sampling, it took many hours for wells to recover enough to obtain samples. This indicates that postmining hydraulic conductivity in the spoils is low, although higher than in the premining overburden. The storage capacity has increased because the handling and breaking of the overburden material has created many more openings, pores, and voids than were present in the premining consolidated rocks. The hydraulic conductivity remains low because fine-grained material has plugged the interconnected openings. The mining operation did not disturb the material below the Middle Kittanning No. 6 coal bed of the Allegheny Formation, so the hydrologic properties of the middle and deep aquifers have not changed.

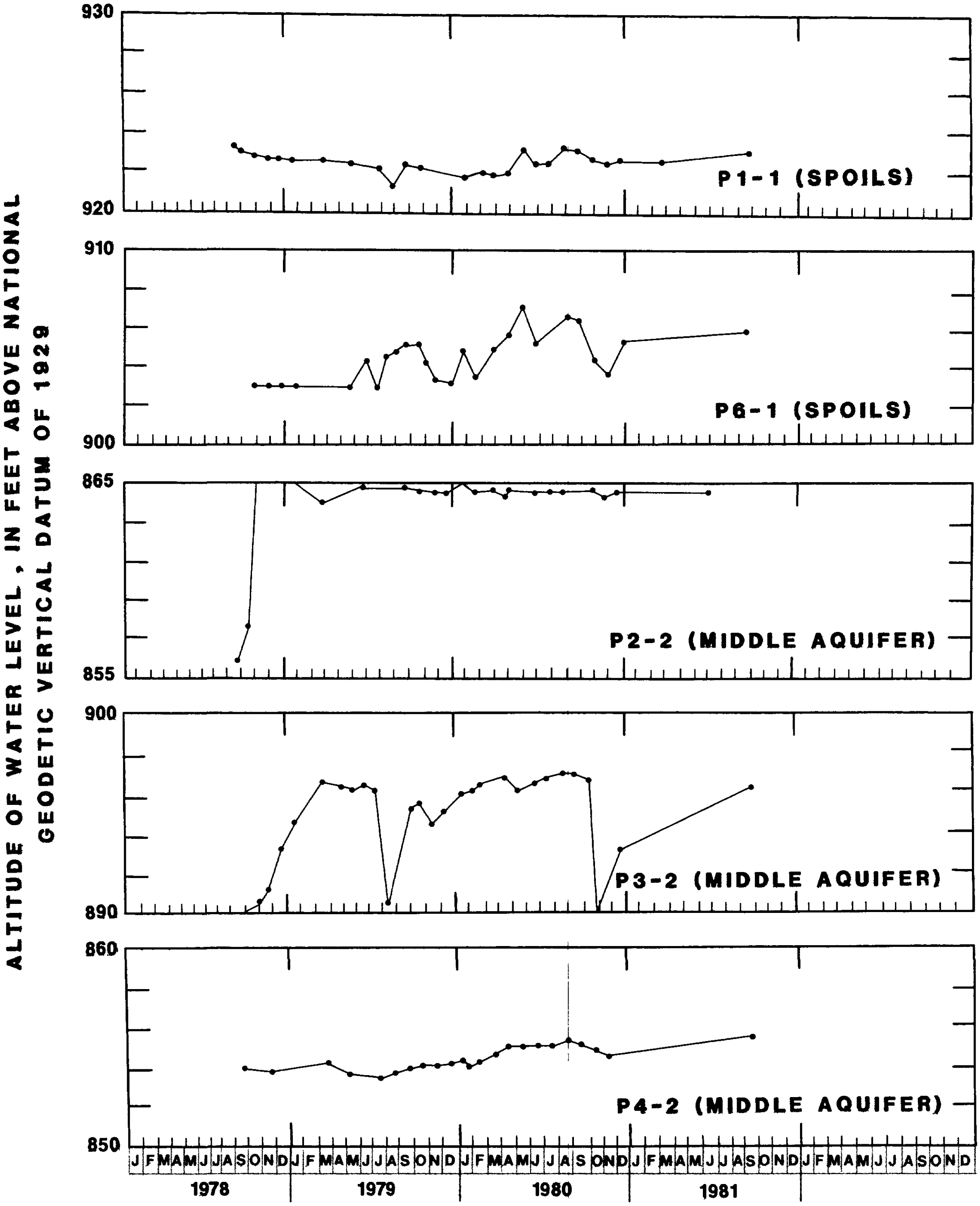


Figure 15.--Hydrographs of postmining water levels from the spoils, middle, and deep aquifers at watershed CO6.

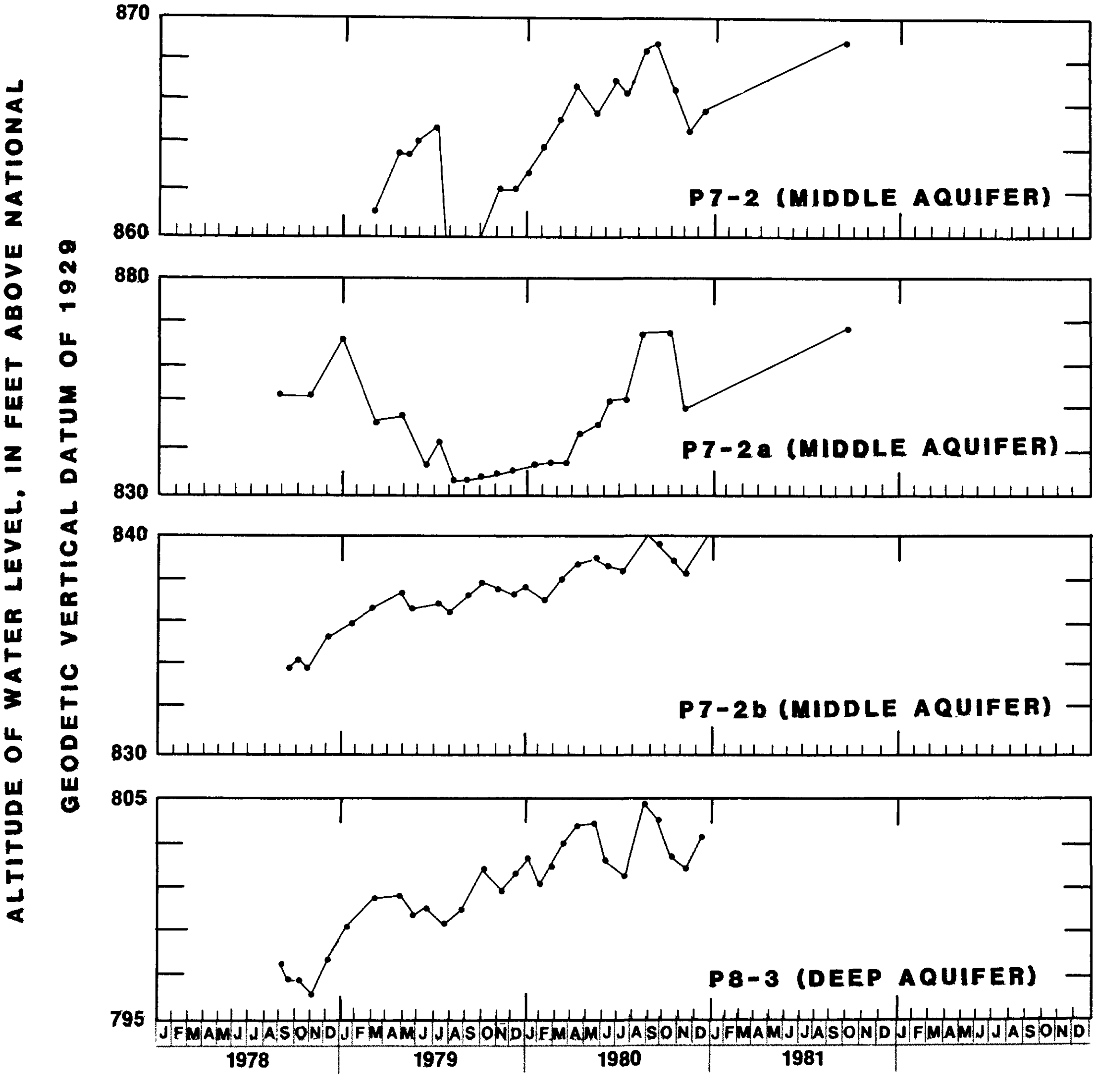


Figure 15.--Hydrographs of postmining water levels from the spoils, middle, and deep aquifers at watershed CO6 --Continued.

The most obvious changes that occurred as a result of the strip mining are the removal of the top aquifer and its replacement by mine spoils. The mine spoils now cover about 30 acres, compared to 23 acres of the top aquifer before mining, and the area has been shifted laterally (compare fig. 4 with fig. 12). The vertical dimensions of the mine spoils are different from the premining top aquifer, some areas gaining 60 feet and other areas losing 70 feet (fig. 14). The premining stratification of the top aquifer has been completely destroyed. The mine spoils consist of heterogeneous rubble that ranges from clay-size particles to large boulders. The saturated thickness of the premining top aquifer, which ranged from 5 to 57 feet before mining, is much more than the saturated thickness of the mine spoils which ranges from 0 to 4 feet. The low water-table gradient in the postmining top aquifer is the result of either (1) incomplete saturation of the mine spoils or (2) a higher hydraulic conductivity.

Recharge, discharge, and movement of ground water in the CO6 postmining watershed are similar to the premining condition. However, the middle aquifer now receives recharge by infiltration through spoils material instead of directly from precipitation because the aquifer is almost entirely covered by spoils material. The strip mining had little or no effect on the middle and deep aquifers' hydraulic characteristics. Water levels and well yields are nearly identical to those before mining.

POSTMINING GROUND-WATER QUALITY

Data Collected During Phase 3

Sixty water samples were collected for water-quality analysis (table 3); 14 from mine spoil wells, 32 from middle-aquifer wells, 11 from deep-aquifer wells, and 3 from springs.

Samples were collected with a nitrogen-gas-operated membrane pump when enough water was present to allow pumping. If only a few feet of water was present, a PVC bailer was used for collecting the sample. In either case, the well was completely evacuated and allowed to recharge before a sample was collected. If the well recharged quickly, the sample was obtained after a volume of water equal to three times the well volume was discharged and after the specific conductance had stabilized.

Temperature, specific conductance, pH, and alkalinity were determined in the field. Samples were chilled until laboratory analyses were made. Dissolved constituents were determined from samples that were filtered in the field with 0.45-micrometer filters. Samples were analyzed at the U.S. Geological Survey laboratory in Doraville, Ga.

Table 3.--Chemical analyses of ground water collected from Watershed C06, during postmining conditions

[mg/L, milligrams per liter; µg/L, micrograms per liter; Pt-Co, platinum-cobalt units; tons/acre-ft; tons per acre-foot; µmho/cm, micromhos per centimeter at 25°C]

Constituents or properties	Unit	Number of samples	Concentration or other measurement, mine spoils	
			Min. - max.	Median
Water temperature	(°C)	5	7.5-12	11
Specific conductance (field)	µmho/cm	5	1,160-2,020	1,600
pH (field)		5	6.4-7	6.5
Carbon dioxide	mg/L	5	135-828	178
Alkalinity, as $CaCO_3$)	mg/L	5	218-1,070	710
Bicarbonate, (mg/L as HCO_3)	mg/L	5	266-1,300	860
Carbonate,	mg/L	5	0.0-0.0	0.0
Nitrogen, as N, dissolved	mg/L	5	0.00-1.2	0.3
Nitrogen, (NH_4 as N), dissolved	mg/L	5	0.02-0.54	0.16
Nitrogen, NH_4 + organic as N, dissolved	mg/L	5	0.06-0.54	0.29
Nitrogen, (organic as N) dissolved	mg/L	5	0.00-0.91	0.01
Phosphorus, (as P), dissolved	mg/L	5	0.01-0.07	0.01
Carbon, total organic	mg/L	3	4-14	12
Carbon, dissolved organic	mg/L	2	2.7-5.3	4.0
Carbon, organic, suspended total	mg/L	1	15-15	15
Cyanide, total	mg/L	3	0-0	0
Hardness, total	mg/L	5	590-1,100	820
Hardness, noncarbonate	mg/L	5	0-870	110
Calcium, dissolved	mg/L	5	100-240	130
Magnesium, dissolved	mg/L	5	65-140	120
Sodium, dissolved	mg/L	5	9.5-19	15
Sodium adsorption ratio	mg/L	5	0.2-0.3	0.2
Sodium, percent	%	5	3-11	4
Potassium, dissolved	mg/L	5	4.3-5.9	5.2
Chloride, dissolved	mg/L	5	3.5-10	8.7
Sulfate, dissolved	mg/L	5	14-940	320
Fluoride, dissolved	mg/L	5	0.1-0.4	0.2
Silica, dissolved	mg/L	5	2.7-26	7.2
Arsenic, dissolved	µg/L	3	1-2	1
Barium, dissolved	µg/L	3	30-100	50
Cadmium, dissolved	µg/L	3	0-3	1
Chromium, dissolved	µg/L	3	10-10	10
Copper, dissolved	µg/L	3	2-12	3
Iron, dissolved	µg/L	5	3,600-140,000	32,000
Lead, dissolved	µg/L	3	1-12	5
Manganese, dissolved	µg/L	5	1,200-7,700	1,800
Nickel, dissolved	µg/L	3	4-16	8
Silver, dissolved	µg/L	3	0-0	0
Strontium, dissolved	µg/L	5	180-700	480
Zinc, dissolved	µg/L	3	10-170	20
Antimony, dissolved	µg/L	3	0-4	0
Aluminum, dissolved	µg/L	3	10-700	50
Selenium, dissolved	µg/L	3	0-0	0
Phenols	µg/L	5	0-4	0
Nitrogen, ammonia as NH_4, dissolved	mg/L	5	0.03-0.7	0.21
Hydrogen sulfide, total	mg/L	5	0.30-9.50	1.40
Mercury, dissolved	µg/L	3	0.2-0.1	0.1
Nitrogen, organic as N, dissolved	mg/L	5	0-0.14	0.04
Solids, sum of constituents, dissolved	mg/L	5	825-1,510	1,060

Table 3.--Chemical analyses of ground water collected from watershed C06 during postmining conditions--Continued

Constituents or properties	Unit	Number of samples	Concentration or other measurement, middle aquifer	
			Min. - max.	Median
Water temperature	(°C)	28	8.5-20	11.5
Specific conductance (field)	µmho/cm	28	220-2,000	590
pH (field)		28	6.2-8.6	6.8
Carbon dioxide	mg/L	28	0.7-809	73
Alkalinity, as $CaCO_3$	mg/L	28	131-1,040	289.5
Bicarbonate	mg/L	28	150-1,270	352
Carbonate	mg/L	28	0-9	0
Nitrogen, as N, dissolved	mg/L	23	0.16-10	0.59
Nitrogen, (NH_4 as N), dissolved	mg/L	28	0.01-6.4	0.41
Nitrogen, NH_4 + organic as N, dissolved	mg/L	27	0.16-10	0.55
Nitrogen, NO_2+ NO_3 as N, dissolved	mg/L	28	0-2.7	0.03
Phosphorus, (as P), dissolved	mg/L	28	0-0.07	0.01
Carbon, total organic	mg/L	5	0.6-126	2.1
Carbon, dissolved organic	mg/L	22	0.2-40	2.3
Carbon, organic, suspended total	mg/L	20	0-2.1	0.2
Cyanide, total	mg/L	23	0-0.01	0
Hardness, total	mg/L	28	43-850	180
Hardness, noncarbonate	mg/L	28	0-47	0
Calcium, dissolved	mg/L	28	9.7-160	43.5
Magnesium, dissolved	mg/L	28	2.5-110	17.5
Sodium, dissolved	mg/L	28	9.4-250	15
Sodium adsorption ratio	mg/L	28	0.2-13	0.5
Sodium, percent	%	28	3-90	15.5
Potassium, dissolved	mg/L	28	2.2-23	3.85
Chloride, dissolved	mg/L	28	1.1-18	1.85
Sulfate, dissolved	mg/L	28	1-400	31
Fluoride, dissolved	mg/L	28	0-1.5	0.3
Silica, dissolved	mg/L	28	1.1-24	12
Arsenic, dissolved	µg/L	24	0-8	2
Barium, dissolved	µg/L	24	90-800	200
Cadmium, dissolved	µg/L	24	0-29	1.5
Chromium, dissolved	µg/L	24	0-30	10
Copper, dissolved	µg/L	24	0-54	1
Iron, dissolved	µg/L	28	10-130,000	1,100
Lead, dissolved	µg/L	24	0-140	0.5
Manganese, dissolved	µg/L	28	50-110,000	665
Nickel, dissolved	µg/L	24	0-28	3
Silver, dissolved	µg/L	24	0-2	0
Strontium, dissolved	µg/L	25	320-2,000	630
Zinc, dissolved	µg/L	24	0-460	25
Antimony, dissolved	µg/L	24	0-4	0
Aluminum, dissolved	µg/L	24	0-4,900	20
Selenium, dissolved	µg/L	27	0-1	0
Phenols	µg/L	27	0-470	2
Nitrogen, ammonia as NH_4, dissolved	mg/L	28	0-8.2	0.53
Hydrogen sulfide, total	mg/L	28	0-170	0
Mercury, dissolved	µg/L	24	0.1-0.5	0.25
Nitrogen, organic as N, dissolved	mg/L	27	0-3.6	0.24
Solids, sum of constituents, dissolved	mg/L	28	143-1,100	340

Table 3.--Chemical analyses of ground water collected from watershed C06 during postmining conditions--Continued

Constituents or properties	Unit	Number of samples	Concentration or other measurement, deep aquifer	
			Min. - max.	Median
Water temperature	(°C)	6	8.5-15	12.75
Specific conductance (field)	µmho/cm	6	1,050-1,780	1,225
pH (field)		6	8.4-8.7	8.6
Carbon dioxide	mg/L	6	2.6-5.6	3.3
Alkalinity, as $CaCO_3$	mg/L	6	673-735	683
Bicarbonate	mg/L	6	764-896	791.5
Carbonate	mg/L	6	0.0-28	20
Nitrogen, as N, dissolved	mg/L	4	0.37-1.4	1.15
Nitrogen, (NH_4 as N), dissolved	mg/L	6	0.05-0.42	0.36
Nitrogen, NH_4 + organic as N, dissolved	mg/L	6	0.35-0.91	0.68
Nitrogen, NO_2 + NO_2 as N, dissolved	mg/L	6	0.02-0.48	0.33
Phosphorus, (as P), dissolved	mg/L	6	0.09-0.17	0.12
Carbon, total organic	mg/L	1	2.3-2.3	2.3
Carbon, dissolved organic	mg/L	5	0.4-13	3.7
Carbon, organic, suspended total	mg/L	5	0.2-2.7	0.4
Cyanide, total	mg/L	5	0-0	0
Hardness, total	mg/L	6	6-9	6
Hardness, noncarbonate	mg/L	6	0-0	0
Calcium, dissolved	mg/L	6	1.5-2.4	1.65
Magnesium, dissolved	mg/L	6	0.4-0.8	0.5
Sodium, dissolved	mg/L	6	300-390	325
Sodium adsorption ratio	mg/L	6	47-68	57
Sodium, percent	%	6	98-99	99
Potassium, dissolved	mg/L	6	1.8-2.2	2.15
Chloride, dissolved	mg/L	6	14-25	19.5
Sulfate, dissolved	mg/L	6	4-150	7.35
Fluoride, dissolved	mg/L	6	1.7-3.1	2.75
Silica, dissolved	mg/L	6	6.4-7.1	6.55
Arsenic, dissolved	µg/L	5	1-2	2
Barium, dissolved	µg/L	5	30-100	50
Cadmium, dissolved	µg/L	5	0-2	2
Chromium, dissolved	µg/L	5	0-30	20
Copper, dissolved	µg/L	6	1-36	6
Iron, dissolved	µg/L	6	10-630	140
Lead, dissolved	µg/L	5	1-37	18
Manganese, dissolved	µg/L	6	6-20	10
Nickel, dissolved	µg/L	5	0-5	3
Silver, dissolved	µg/L	5	0-0	0
Strontium, dissolved	µg/L	5	40-90	50
Zinc, dissolved	µg/L	5	0-20	10
Antimony, dissolved	µg/L	5	0-4	1
Aluminum, dissolved	µg/L	5	20-610	80
Selenium, dissolved	µg/L	5	0-5	1
Phenols	µg/L	6	0-8	2
Nitrogen, ammonia as NH_4, dissolved	mg/L	6	0.06-0.54	0.465
Hydrogen sulfide, total	mg/L	6	0-1.2	0.0
Mercury, dissolved	µg/L	5	0.1-0.5	0.5
Nitrogen, organic as N, dissolved	mg/L	6	0.15-0.67	0.305
Solids, sum of constituents, dissolved	mg/L	6	749-924	796

Premining and Postmining Ground-Water Quality

Water in the postmining mine spoils is a calcium bicarbonate or calcium sulfate type. Some samples of water have magnesium as a codominant cation (fig. 16). Water from the premining top aquifer was predominantly a calcium bicarbonate type (fig. 17). Well P1-1, which has sulfate type water, is finished in the top underclay in the area where coal was removed (fig. 16). Well P6-1, which has bicarbonate type water, is finished beyond the premining underclay outcrop and on top of the premining land surface (fig. 16). The postmining springs that discharge near the point of the premining underclay outcrop are also sulfate type water. From these limited data points, it seems that water derived from areas where the coal was mined is sulfate type, whereas water derived from spoils downslope from the premining coal deposits is bicarbonate type.

The recommended limits (U.S. Environmental Protection Agency, 1977) for drinking water for dissolved-solids concentration (500 mg/L), iron (0.3 mg/L), manganese (0.05 mg/L), and sulfate (250 mg/L) are commonly exceeded in the water from the mine spoils (table 3). Maximum concentrations for selected constituents in water from the mine spoils are as follows (maximum premining concentrations for corresponding well locations are in parentheses): dissolved iron, 140 mg/L (2.3); manganese, 8.9 mg/L (0.89); sulfate, 940 mg/L (80); dissolved-solids concentrations, 1,510 mg/L; and specific conductance, 2,020 µmho/cm (520).

Water in the middle and deep aquifers consists of calcium bicarbonate and sodium bicarbonate types (fig. 16). From the trilinear diagram (fig. 17), the water types from the premining and postmining middle aquifers are the same, except that the postmining field is larger and includes more of the sodium bicarbonate field. The local lithologic conditions and hydraulic conductivity appear to be controls on water quality in the middle and deep aquifers (U.S. Bureau of Mines, 1978). Recommended limits (U.S. Environmental Protection Agency, 1977) of dissolved iron and dissolved manganese are exceeded, but the concentrations are not as high as those found in water from the mine spoils (table 3), and are similar to those found before mining.

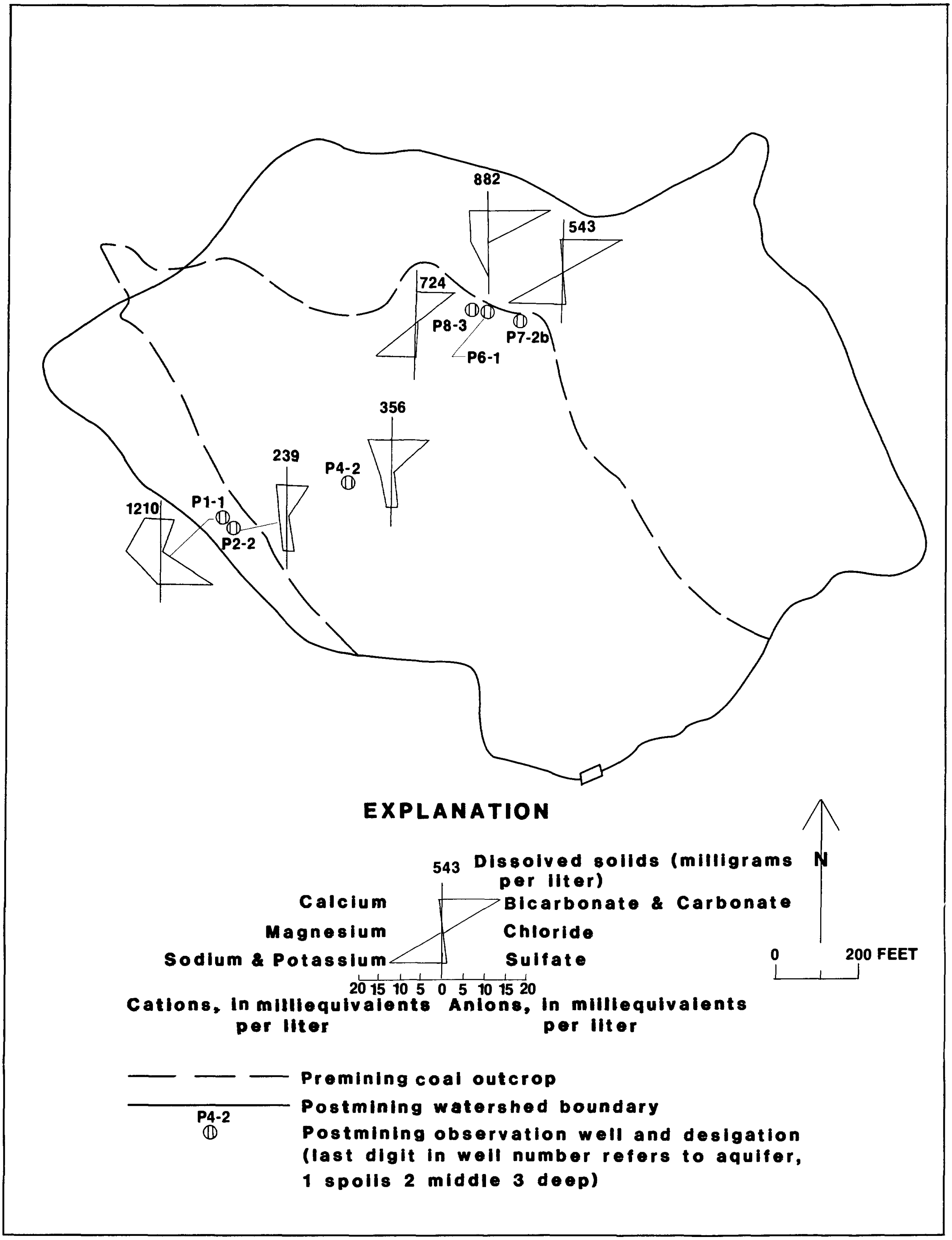


Figure 16.--Stiff (1951) diagrams showing distribution of water types in the postmining condition of the spoils and middle aquifer at watershed CO6.

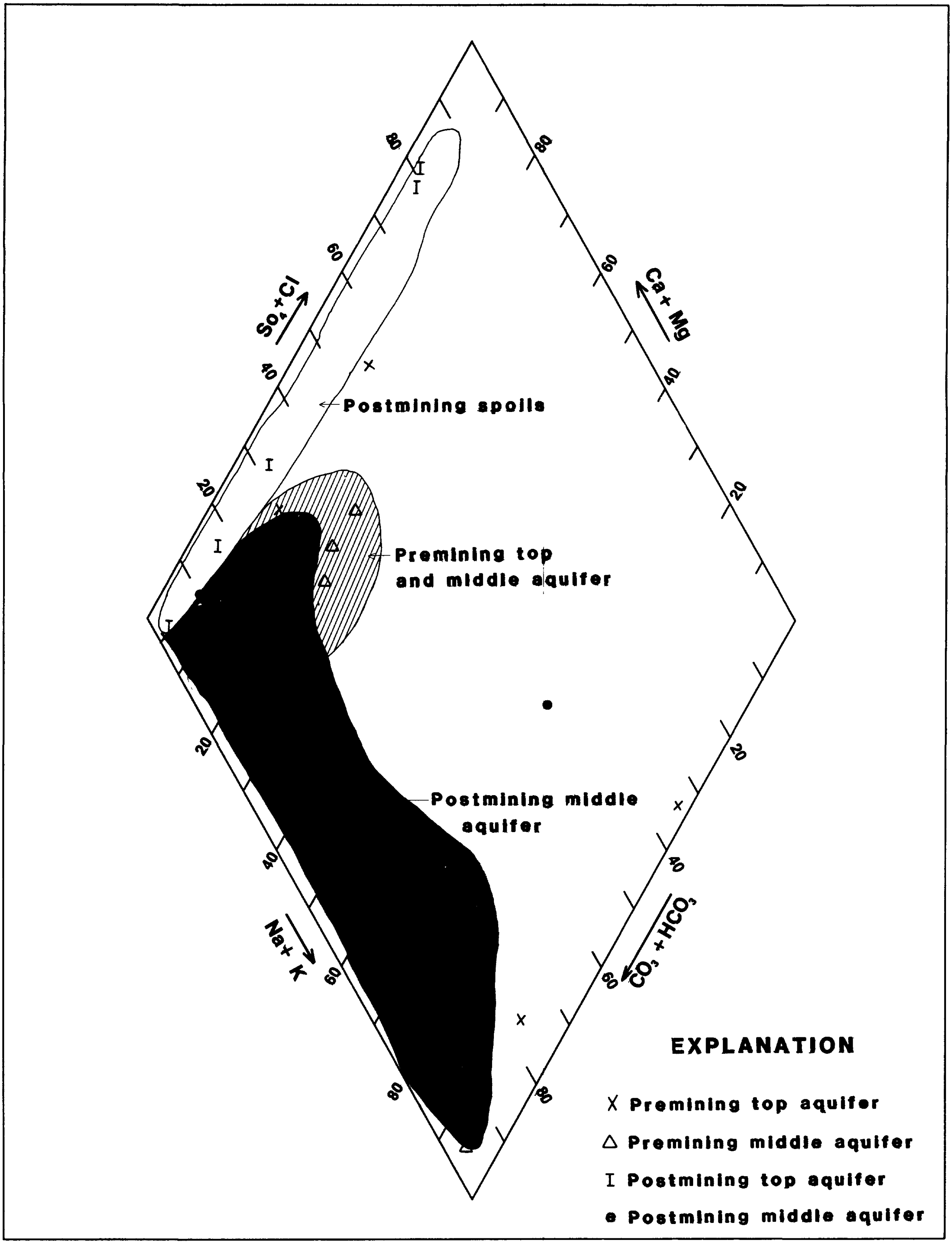


Figure 17. --Water-analysis diagram showing premining and postmining water-quality characteristics of watershed CO6.

SUMMARY

Five small watersheds associated with coal seams in eastern Ohio are being studied to assess the hydrologic effects of strip mining. This report describes ground-water conditions before, during, and after mining in Watershed C06.

The premining watershed was characterized by nearly flat-lying sedimentary rocks of the Pennsylvanian System. Clay beds below the two major coal seams formed bases for perched saturated zones (aquifers). Generally, water in the perched aquifers constituted local flow systems. Premining ground-water quality was generally a calcium or sodium bicarbonate type. Dissolved-solids concentration of water generally increased with depth.

As mining in adjacent watersheds became closer, water levels declined in the top aquifer near the divide of the watershed. Destruction of wells prevented documentation of any continued dewatering during mining. Reduced flow of the stream and an increase in dissolved-solids concentration of the stream base flow resulted from destruction of the top aquifer. The increase in dissolved-solids concentration indicated a change to the middle aquifer and the overburden spoils as the predominant sources of base flow during mining.

Most wells completed in graded overburden spoils were dry at first, although some areas contained a few feet of saturated spoils. Resaturation of the spoils after mining has been slow and irregular; saturated zones have ranged from 0 to 5 feet in thickness. Water levels in the middle aquifer are relatively unchanged.

A comparison of the premining top aquifer with the post-mining spoils shows numerous changes in geometry, recharge rates, discharge rates, saturated thickness, water-table gradient, hydraulic conductivity, storage, and water quality. Changes in the middle aquifer include the quantity of recharge from precipitation, and quantity of leakage through the overlying clay bed.

Recharge rates from precipitation seem to be lower than in the premining top aquifer in some areas owing to lack of soil structure, compaction of the soil, and lack of an established vegetation. The underclay underlying most of the mine spoils is absent in some areas. Leakage rates are higher in areas where the underclay is absent.

The mine spoils do not discharge water to springs or to the base flow of the stream. Differences in water quality between the mine spoils and the premining top aquifer reflects increases in dissolved-sulfate concentrations from 11 to 940 mg/L and increases in specific conductance from 120 to 2,020 µmho/cm. Water quality of the middle and deep aquifers appears unchanged.

REFERENCES CITED

Hamon, W. R., Bonta, J. V., Haghiri, Faz, and Helgesen, J. O., 1979, Research on the hydrology and water quality of watersheds subjected to surface mining, I. Premining hydrologic and water-quality conditions, in Symposium on Surface Coal Mining and Reclamation: Louisville, Kentucky, Coal Age, p. 70-98.

Hamon, W. R., Haghiri, Faz, and Knochenmus, D. D., 1977, Research on the hydrology and water quality of watersheds subjected to surface mining, in Fifth Symposium on Surface Mining and Reclamation: Louisville, Kentucky, National Coal Association and Bituminous Coal Research, Inc., p. 37-40.

Helgesen, J. O., and Razem, A. C., 1980, Preliminary observation of surface-mine impacts on ground water in two small watersheds in eastern Ohio: Proceedings of the Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation, University of Kentucky, Lexington, Kentucky, p. 351-360.

----- 1981, Ground-water hydrology of strip-mine areas in eastern Ohio (Conditions during mining of two watersheds in Coshocton and Muskingum Counties): U.S. Geological Survey Water-Resources Investigations Open-File Report 81-913, 25 p.

Stiff, H. A., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. 3, no. 10, p. 15-17.

U.S. Bureau of Mines, 1978, Research on the hydrology and water quality of watersheds subjected to surface mining, phase I. Premining hydrologic and water-quality conditions: U.S. Bureau of Mines Open-File Report 88-80, 347 p.

----- 1982, Research on the hydrology and water quality of watersheds subjected to surface mining, Phase II. Hydrologic and water-quality conditions during mining and reclamation of a small watershed in Coshocton County, Ohio: U.S. Bureau of Mines Open-File Report, 146 p.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: 256 p.

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