GROUND-WATER HYDROLOGY AND QUALITY BEFORE AND AFTER STRIP MINING OF A SMALL WATERSHED IN JEFFERSON COUNTY, OHIO

By Allan C. Razem

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ERRATA

p. 9 -- Table 2; the value for the magnesium (dissolved) range should be 9.1-31, not 9.1-3.1.

p. 11 -- Figure 4; change "Meigs Creek No. 4 coal bed" to "Meigs Creek No. 9 coal bed".

p. 13 -- Figure 6; change well designations "W2-2" and "W7-2" to "W1-1" and "W6-1", respectively.

p. 14 -- Figure 7; well designation "W1-1" should be "W2-2".

p. 15 -- Second paragraph, last sentence should read "... underclay has a hydraulic conductivity about 200 times lower ...."

p. 24 -- Figure 13; Remove the word "spoils" from the top aquifer.

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CONVERSION FACTORS

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

Multiply	By	To obtain
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
micromhos per centimeter (µmho/cm) at 25°C	1	microsiemens (µS)

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ABSTRACT

Ground-water conditions before and after surface mining of a small watershed in Ohio 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 local aquifers above shaley clay beds associated with the major coal seams. A deeper, regional aquifer mined by underground methods is dry. Mining involved removing the overburden rocks, including most of the top aquifer, stripping the coal, and recontouring the overburden spoils to the approximate premining shape of the watershed. Part of the top aquifer coal was removed by augering.

Replacement of the top aquifer by spoils during regrading has created a new aquifer with specific recharge and discharge rates, saturated thickness, aquifer characteristics, and water quality different from the original aquifer. In the middle aquifer there were changes in saturated thickness and water quality. Resaturation of the spoils aquifer during and after reclamation has been slow. Saturated thicknesses have ranged from zero immediately after mining to 4 feet after 1 1/2 years. Water levels in the middle aquifer have risen from a few feet to 40 feet.

Water quality in the spoils material generally has been degraded; concentrations of bicarbonate, calcium, magnesium, chloride, iron, manganese, sulfate, and dissolved solids have increased. Water types remained about the same after mining, except for some changes from bicarbonate type to sulfate type.

INTRODUCTION

Purpose and Scope

A better understanding of the impact of coal strip-mining on water resources will help protect our water resources as the use of coal continues to grow. The U.S. Bureau of Mines has sponsored a comprehensive study to assess the effects of strip mining on the hydrology of small watersheds (30-50 acres) in eastern Ohio (Hamon and others, 1977).

The U.S. Geological Survey (USGS) is responsible for the ground-water part of the study, which involves the following objectives: (1) Description of the hydrogeology of four small watersheds and a small control watershed; (2) documentation of ground-water flow and water-quality characteristics in premining and postreclamation periods; and (3) development of models to simulate the movement of ground water in watersheds C06 and M09 before mining (Helgesen and others, 1982), and in watershed M09 after mining (Weiss, 1982).

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, for collecting and analyzing soils, and for studies of 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.

Watershed A06 will not be mined; it serves as a control watershed in which the USDA-ARS has collected historic data. Watershed J11, the watershed discussed in this report, was mined and recontoured during the summer and the fall of 1980. Watershed J08 has not been mined. Watershed C06 was mined and recontoured between November 1976 and August 1978. Watershed M09 was mined and recontoured from January 1977 to August 1978.

Recent Reports

Earlier reports (U.S. Bureau of Mines, 1978; Hamon and others, 1977; Helgesen and Razem, 1980) include descriptions of premining (Phase 1) ground-water hydrology. The premining ground-water flow model was described by the U.S. Bureau of Mines (1978); modifications of the computer program were described by Helgesen, Larson, and Razem (1983); and ground-water conditions at watersheds C06 and M09 during mining (Phase 2) were described by Helgesen and Razem (1980). Amerman and others (1982) described the premining and postreclamation conditions at watersheds C06 and M09. Cooper (1982) described ground-water quality conditions at watershed A06, and Weiss (1982) described the postreclamation model at watershed M09. This report describes ground water conditions before mining and during mining and reclamation at watershed J11. Similar postreclamation reports have been prepared for watersheds C06 and M09.

Watershed- and Well-Numbering System

Each watershed (locations are shown in figure 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 to be mined. Also, each observation well is identified alphanumerically. 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 postreclamation wells.

PREMINING GROUND-WATER CONDITIONS

Physical Characteristics and Geology

Site J11 was a 29-acre, partially wooded watershed drained by a continuously flowing main stream that was 1,400 feet long. There were several partially developed side channels in addition to the well-defined main channel. The hilly topography of the watershed area is typical of eastern Ohio; J11 had a relief of 145 feet.

Watershed J11 is in the unglaciated Allegheny Plateau region of southeastern Ohio. Stratigraphy (fig. 2) consisted of nearly flat-lying interbedded shale, sandstone, limestone, and coal of the Pennsylvanian and Permian Systems. Weathered rock and soil overlay the bedrock in most places (U.S. Bureau of Mines, 1978). The physical and chemical characteristics of the core taken at watershed J11 (fig. 3) are described by the U.S. Bureau of Mines (1978, p. 344-345). The Waynesburg No. 11 coal bed of the Monongahela Formation cropped out near the middle of the watershed. The No. 9 Meigs Creek (Sewickley) coal bed of the Monongahela Formation did not crop out in the watershed.

Summary of Data Collected

Nine observation wells were installed before mining (fig. 3) during April and May 1976. Four wells were completed in the top aquifer, three in the middle aquifer, and two in the deep zone. The wells were drilled by the air-rotary method, and each was cased such that the open interval spanned only one of the three major zones. A continuous core was obtained in March 1976. Geophysical and driller's logs were obtained from each well and the core hole.

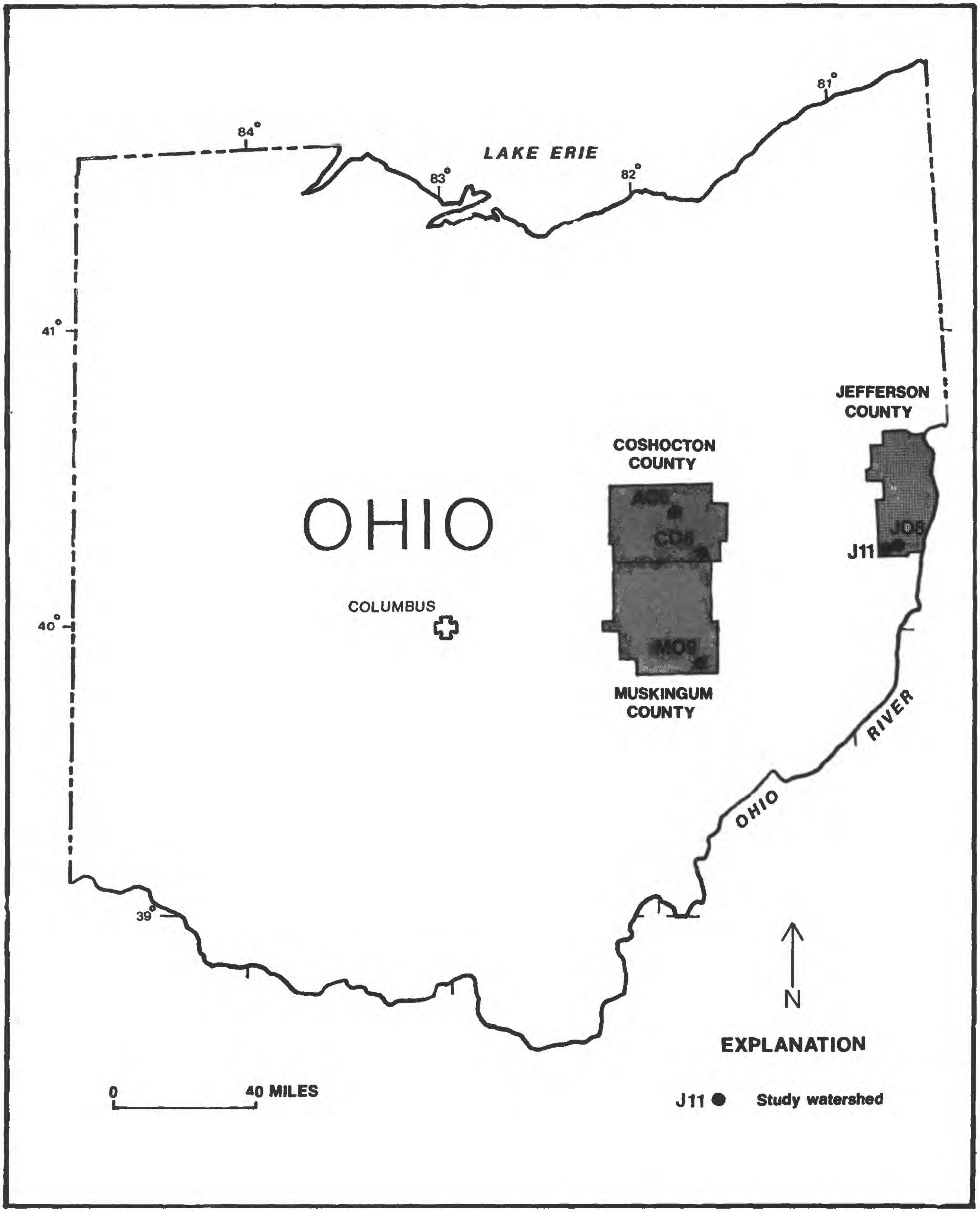


Figure 1.--Location of watersheds studied.

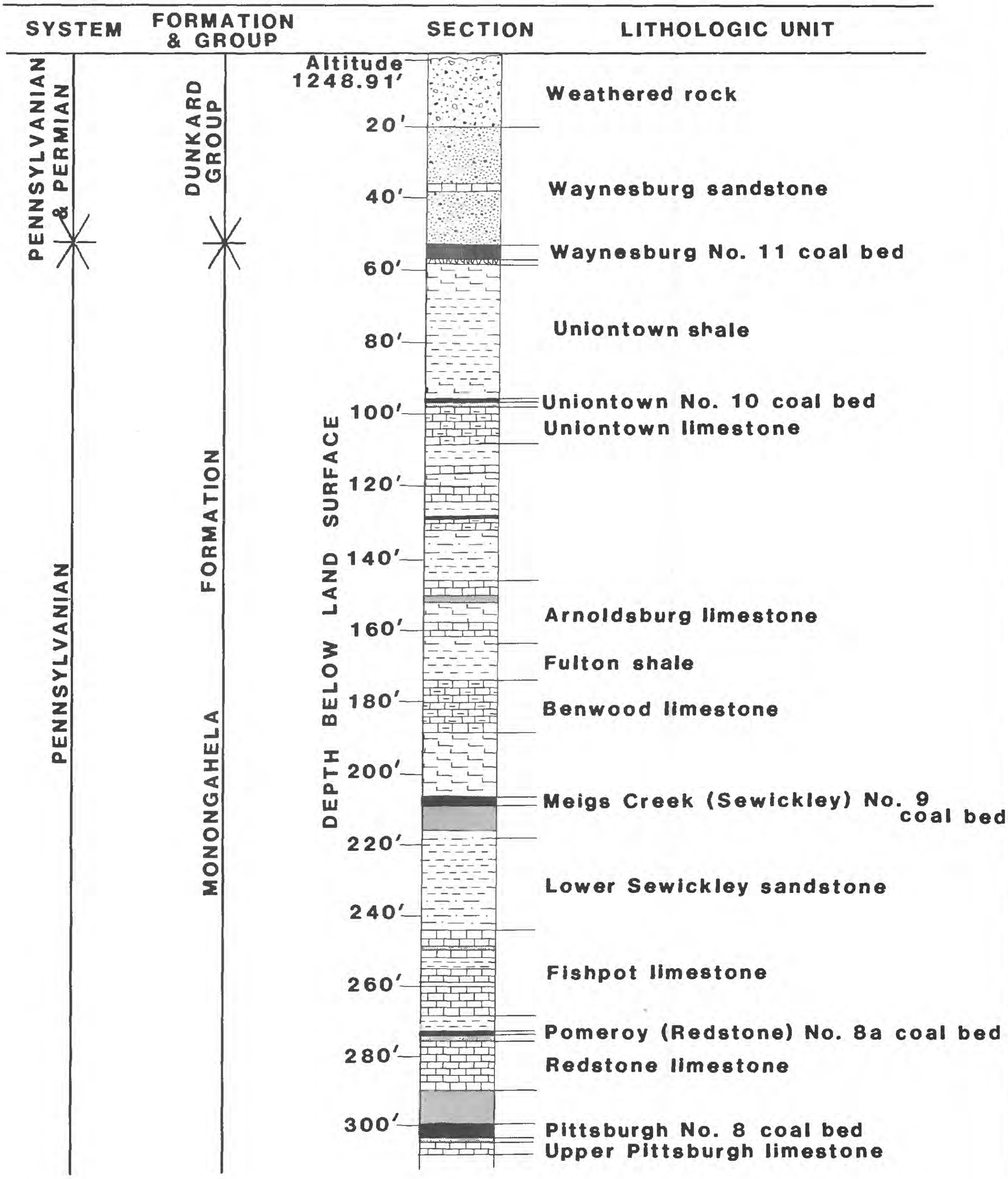


Figure 2.--Stratigraphic column for watershed J11.

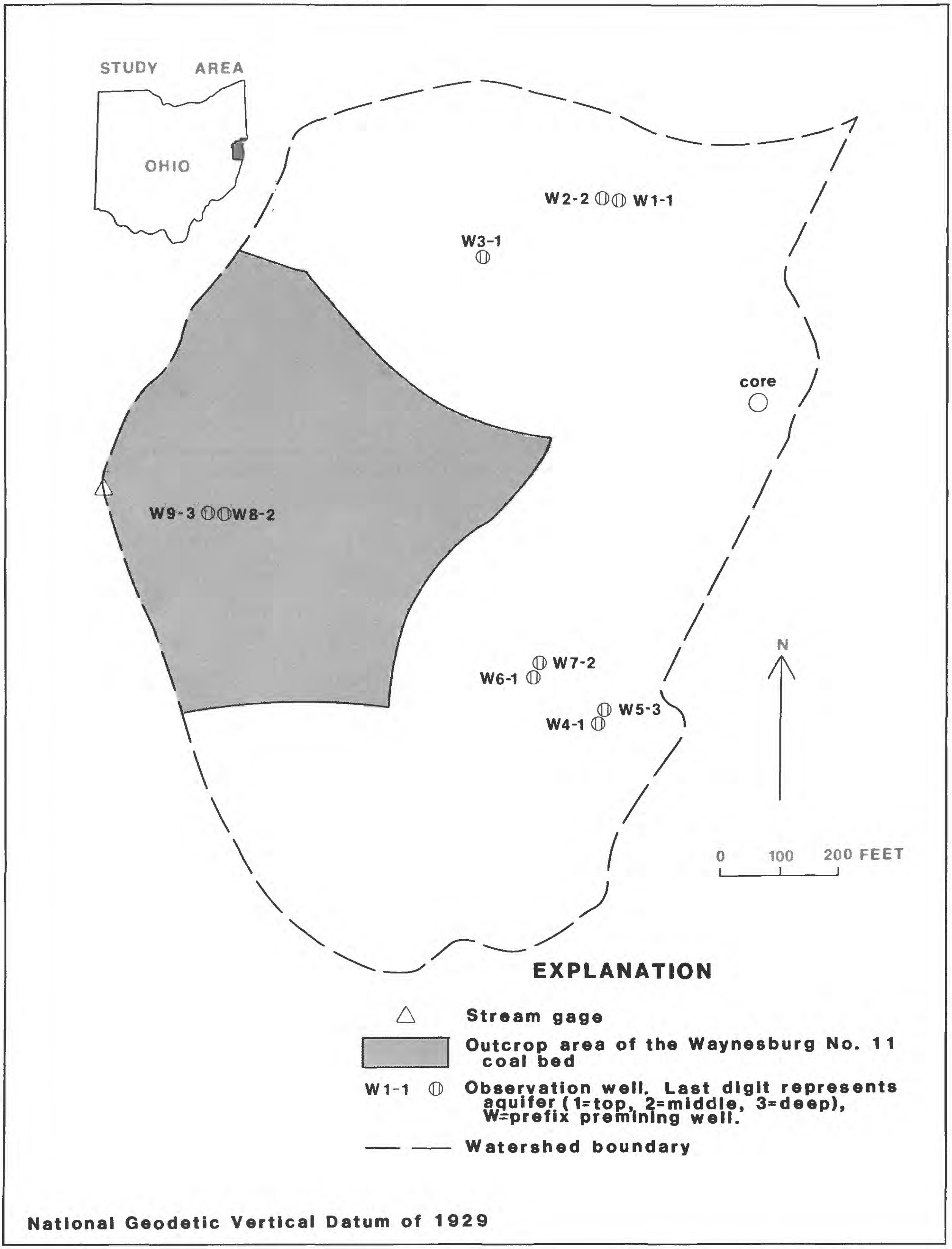


Figure 3.--Premining locations of observation wells, core, and outcrop at watershed J11.

Water levels in the wells were measured monthly, and digital recorders obtained hourly data in selected wells. Table 1 lists the data obtained from each well. Aquifer tests (single-well pumping and slug tests) were made to determine hydraulic properties before mining. Tests of the permeability of the underclay were done in the laboratory. Pumping tests were analyzed according to the methods of Boulton (1963), and slug tests were analyzed by the method described by Cooper and others (1967).

Forty-nine water samples were collected during premining for water-quality analysis (table 2); 35 from top-aquifer wells and 14 from middle-aquifer wells. Samples were collected with either an electrical submersible pump or a nitrogen-gas-operated membrane pump. A PVC bailer was used occasionally. Samples were collected after two to three times the well volume had been discharged and the specific conductance and temperature had stabilized.

Temperature, specific conductance, pH, and alkalinity were determined in the field. Samples were filtered and treated in the field and chilled until laboratory analyses were made. Dissolved constituents were determined from samples that were filtered in the field with 0.45-micrometer filters before treating. Samples were analyzed at the USGS Laboratory in Doraville, Ga.

Ground-water hydrology

Relatively impermeable, shaly clay beds that underlay the major coal seams formed bases for two local perched saturated zones (fig. 4). The saturated zones are referred to as "aquifers" for convenience, even though the wells typically yield less than 1 gal/min (gallon per minute).

The top aquifer was above the shaly clay that underlay the Waynesburg No. 11 coal bed of the Monongahela Formation. Recharge was from percolation from precipitation within the watershed. Figure 5 shows the close relationship between precipitation and water-level rises. Recharge to the middle aquifer is indirectly related to precipitation.

Movement of water in the top aquifer (fig. 6) was from the watershed divide toward the coal outcrop, where it discharged as springflow, seepage, and evapotranspiration. Springflow was the major contributor to base flow of the stream. The remainder of the discharge was leakage downward through the underclay.

The middle aquifer is above the shaly clay that underlies the Meigs Creek (Sewickley) No. 9 coal bed of the Monongahela Formation. Recharge to the middle aquifer is by leakage through the overlying underclay and by precipitation where the underclay is absent. Movement of water in the middle aquifer (fig. 7) is from the watershed divide toward the mouth of the watershed, where it discharges as underflow. Additional discharge is leakage downward through the underclay.

Table 1.--Premining well information at watershed J11

Local Number	Well Location latitude	Well Location longitude	Altitude of land surface (feet)	Date completed	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Remarks
W1-1	401011N	0805216W	1259.5	4/1976	61	18	6	G,Q,L,K
W2-2	401011N	0805216W	1258.7	4/1976	211	64	6	G,Q,L,K
W3-1	401010N	0805218W	1235.2	4/1976	38	18	6	G,Q,L,K
W4-1	401002N	0805218W	1251.4	5/1976	60	18	6	G,Q,L,K
W5-3	401002N	0805218W	1251.7	5/1976	295	218	6	G
W6-1	401004N	0805219W	1237.4	5/1976	46	17	6	G,Q,L,K
W7-2	401004N	0805219W	1237.3	4/1976	192	53	6	G,Q,L
W8-2	401007N	0805224W	1156.7	4/1976	105	20	6	G,Q,L,K
W9-3	401007N	0805224W	1155	4/1976	198	120	6	G

Remarks: G = gamma log
Q - water quality
L = water levels
K = aquifer test

Table 2.--Premining chemical analyses of ground water collected from watershed J11, August 1976-July 1980

Constituents or properties	Unit	No. of samples	Concentration or other measurement, top aquifer	
			Range	Median
Specific conductance	µmho/cm	35	320-830	550
pH		35	5.8-7.7	7.0
Alkalinity, (as $CaCO_3$)	mg/L	35	16-346	148
Bicarbonate, (as HCO_3)	mg/L	35	20-422	180
Nitrogen, (dissolved)	mg/L	11	0.8-11	2.8
Nitrogen, NH_4 (total)	mg/L	18	0-8	0.02
Nitrogen, NH_4 (dissolved)	mg/L	13	0.01-0.21	0.01
Nitrogen, Organic (dissolved)	mg/L	18	0-1.9	0.14
Nitrogen, NO_2+NO_3 (dissolved)	mg/L	18	0.01-11	1.35
Phosphorus (dissolved)	mg/L	18	0-0.71	0.01
Carbon, organic (total)	mg/L	17	2.1-9.2	5.4
Hardness (as $CaCO_3$)	mg/L	35	140-430	270
Hardness, Noncarbonate	mg/L	35	12-210	96
Calcium (dissolved)	mg/L	35	39-120	80
Magnesium (dissolved)	mg/L	35	9.1-3.1	16
Sodium (dissolved)	mg/L	35	5.4-13	7.9
Sodium adsorption ratio		35	0.1-0.4	0.2
Percent sodium		35	3-13	8
Potassium (dissolved)	mg/L	35	1-3.2	1.6
Chloride (dissolved)	mg/L	35	7.5-55	13
Sulfate (dissolved)	mg/L	35	24-190	84
Fluoride (dissolved)	mg/L	35	0.1-0.2	0.1
Silica (dissolved)	mg/L	31	10-19	15
Iron (dissolved)	ug/L	35	10-17,000	30
Manganese (dissolved)	µg/L	35	3-1,400	30
Strontium (dissolved)	µg/L	14	150-470	300
Zinc (dissolved)	µg/L	14	20-60	30
Phenols	µg/L	34	0-44	0.5
Solids, sum of constituents, (dissolved)	mg/L	31	222-471	335

Table 2.--Premining chemical analyses of ground water collected from watershed J11, August 1976-July 1980--Continued

Constituents or properties	Unit	No. of samples	Concentration or other measurement, middle aquifer	
			Range	Median
Specific conductance	µmho/cm	30	475-910	680
pH		30	6.8-8.2	7.5
Alkalinity, (as $CaCO_3$)	mg/L	30	254-417	324
Bicarbonate, (as HCO_3)	mg/L	30	310-508	395
Nitrogen, (dissolved)	mg/L	9	0.1-1.1	0.3
Nitrogen, NH_4 (dissolved)	mg/L	15	0.01-0.21	0.01
Nitrogen, NH_4 (total)	mg/L	11	0.01-0.27	0.03
Nitrogen, Organic (dissolved)	mg/L	15	0-0.75	0.12
Nitrogen, NO_2+NO_3 (dissolved)	mg/L	15	0.03-0.45	0.2
Phosphorus (dissolved)	mg/L	15	0-0.02	0.01
Carbon, organic (total)	mg/L	17	1.7-8.5	5.4
Hardness (as $CaCO_3$)	mg/L	30	56-390	250
Hardness, Noncarbonate	mg/L	30	0-55	0
Calcium (dissolved)	mg/L	30	13-100	61
Magnesium (dissolved)	mg/L	30	5.5-34	23
Sodium (dissolved)	mg/L	30	11-230	48.5
Sodium adsorption ratio		30	0.3-13	1.35
Percent sodium		30	8-90	28.5
Potassium (dissolved)	mg/L	30	1.2-2.7	2
Chloride (dissolved)	mg/L	30	8.8-49	14
Sulfate (dissolved)	mg/L	30	22-87	47
Fluoride (dissolved)	mg/L	30	0.1-2.6	0.25
Silica (dissolved)	mg/L	27	9.4-18	11
Iron (dissolved)	µg/L	30	0-290	10
Manganese (dissolved)	µg/L	30	1-40	10
Strontium (dissolved)	µg/L	10	720-1,900	1,140
Zinc (dissolved)	µg/L	10	0-80	20
Phenols	µg/L	30	0-68	0
Solids, sum of constituents, (dissolved)	mg/L	27	338-588	405

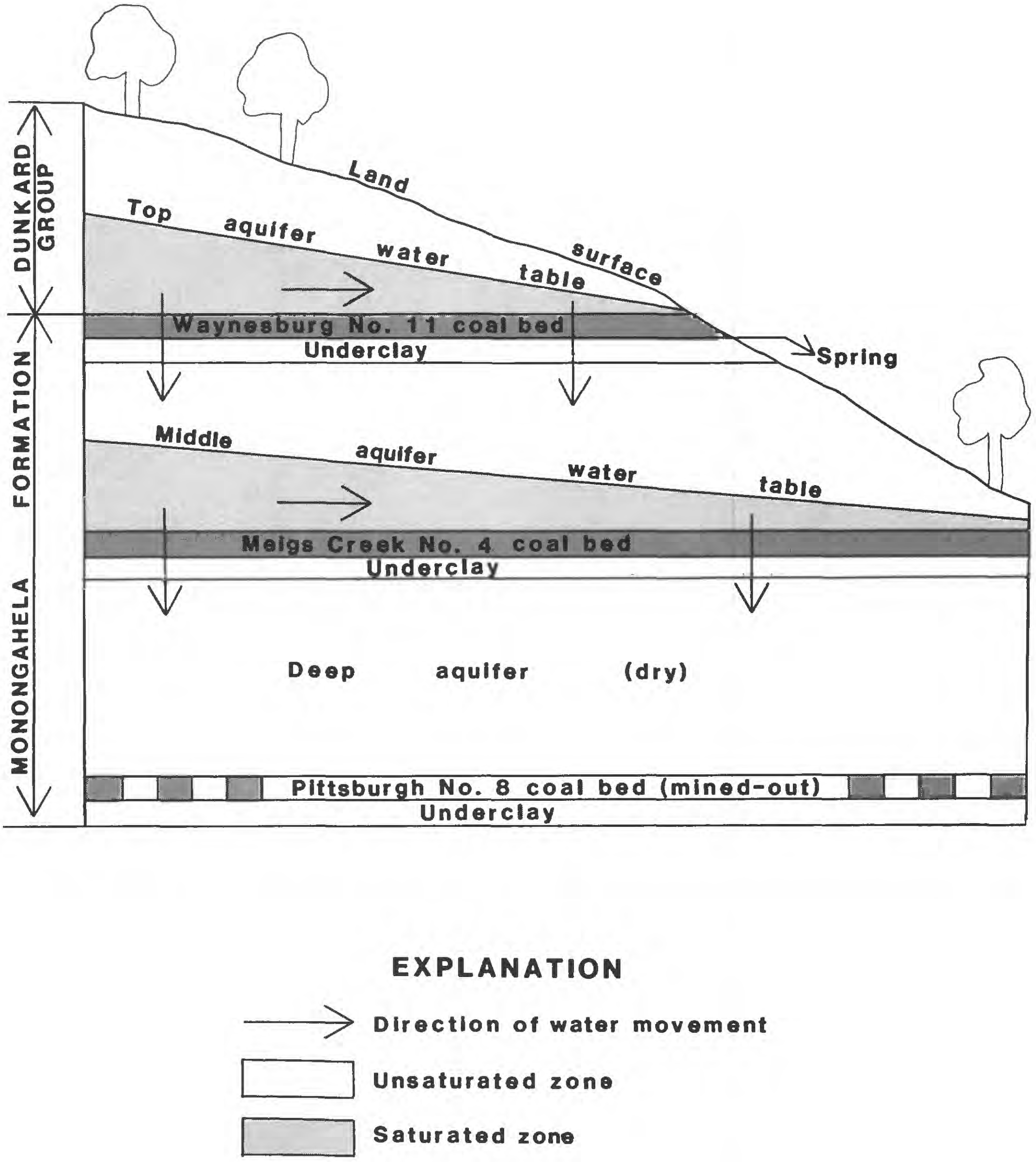


Figure 4.--Schematic section illustrating premining ground water occurrence and flow at watershed J11.

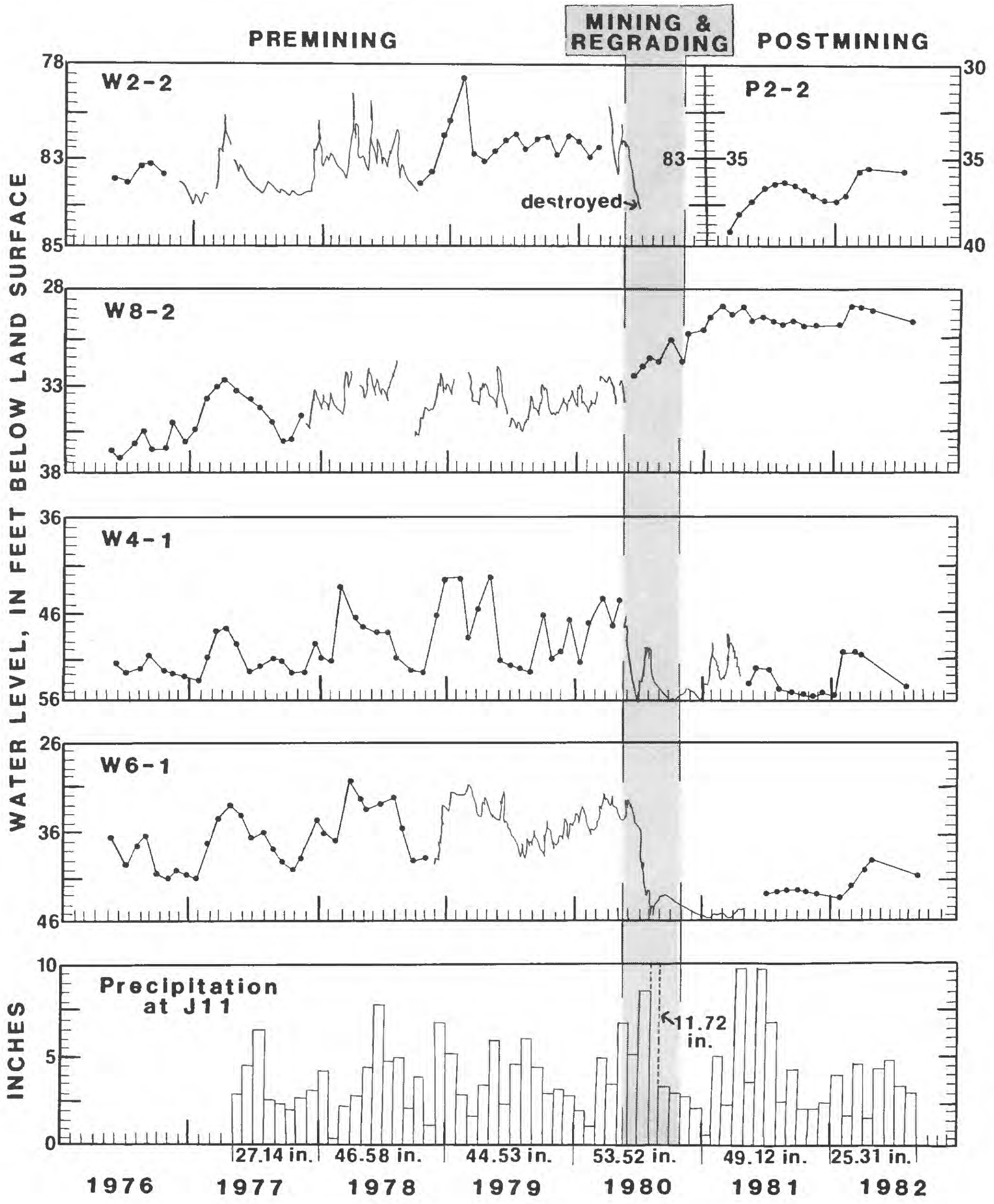


Figure 5.--Hydrographs of water levels from the top and middle aquifers and precipitation watershed J11. Last digit in well number represents aquifers (1=top, 2=middle). Solid circles connected by lines are monthly measurements, continuous lines represent continuously recorded data.

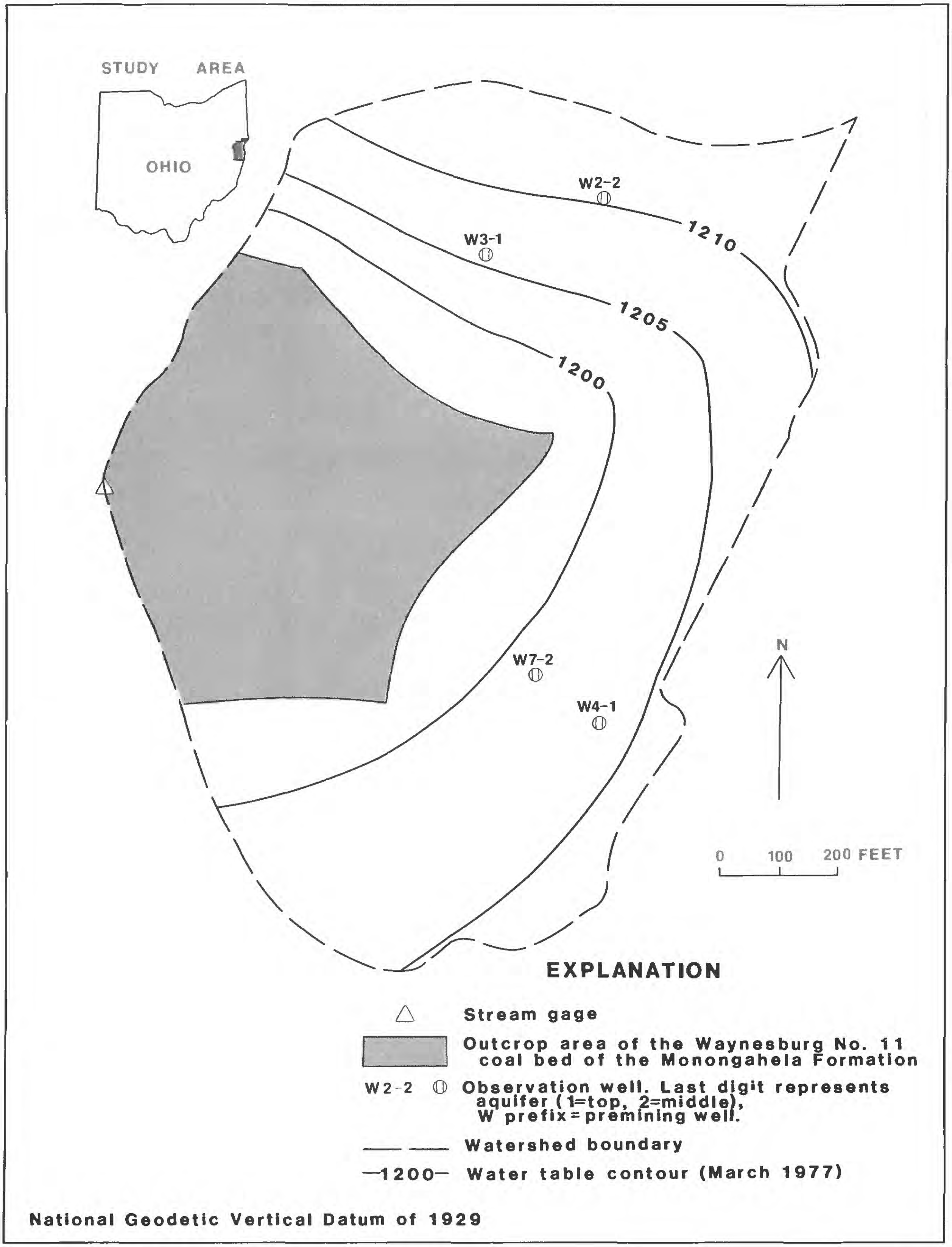


Figure 6.--Premining potentiometric surface of the top aquifer at watershed J11.

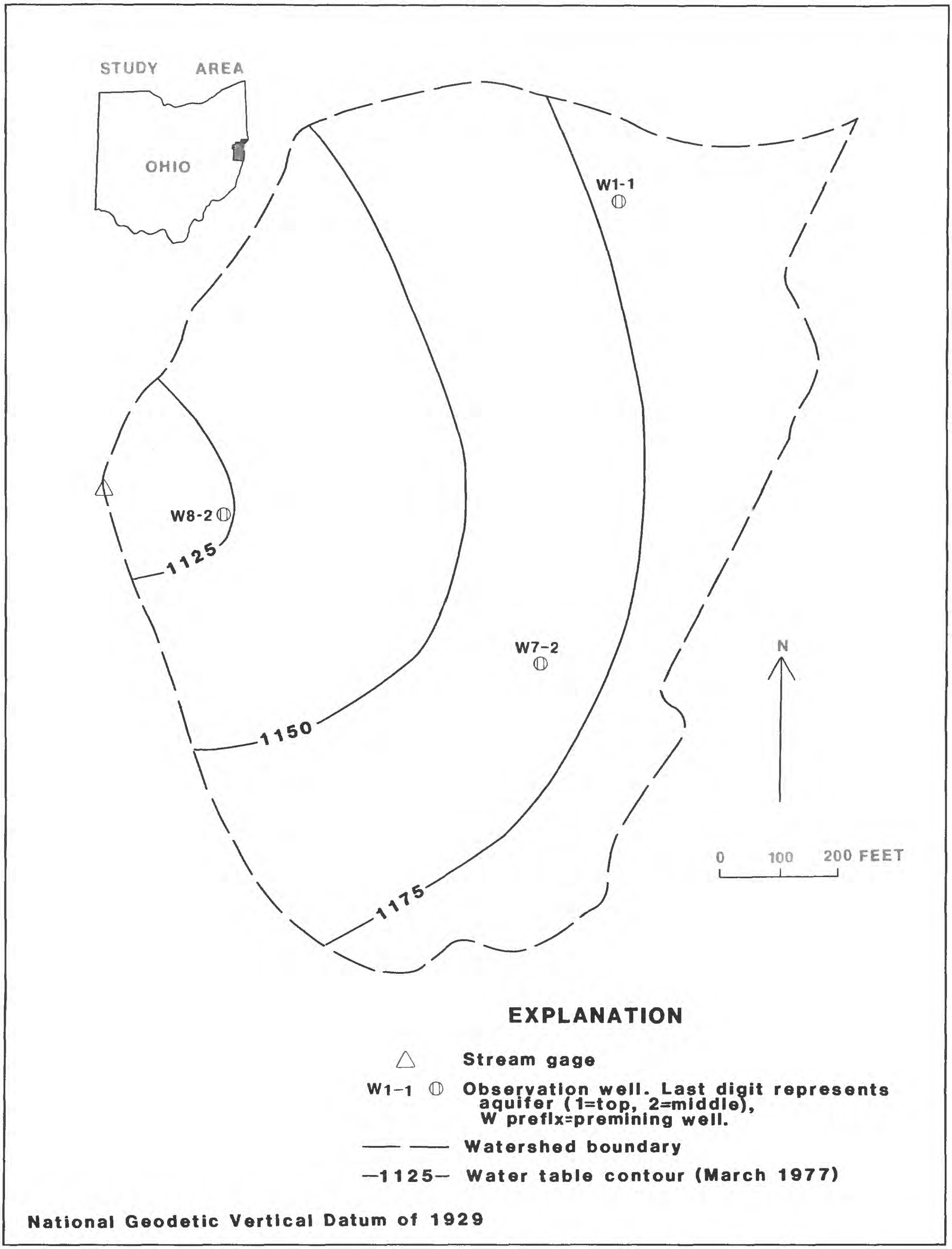


Figure 7.--Premining potentiometric surface of the middle aquifer at watershed J11.

The two deepest wells (W5-3 and W9-3), which are dry, penetrated mined-out openings in the Pittsburgh No. 8 coal bed of the Monongahela Formation. Much of the No. 8 coal bed had been previously removed by underground mining; the bed is apparently drained downgradient from the watershed. Aquifers below the No. 8 coal bed have not been penetrated by drilling.

Ground water is stored and transmitted within open spaces in the rock. The permeability is primary (intergranular pore space) and secondary (fractures and bedding-plane openings). Most of the ground-water movement in the undisturbed rock is probably controlled by fracture-flow hydraulics. Values for the aquifer's horizontal hydraulic conductivity were obtained by slug tests and single-well aquifer tests. The vertical hydraulic conductivity of the underclay was measured by obtaining a sample of underclay from the field and experimentally determining the hydraulic conductivity in a laboratory. The laboratory-determinations were provided by the Ohio State University, Department of Agronomy. Table 3 shows that the hydraulic conductivities of the aquifers were extremely low and that the underclay has a hydraulic conductivity about five-thousandths times lower than that of the aquifer.

Ground-Water Quality

The top aquifer at watershed J11 contained water of calcium bicarbonate and calcium sulfate types (fig. 8). Water from the middle aquifer consisted of sodium bicarbonate and calcium bicabonate types. Results of chemical analyses are shown in table 2.

The premining variations in the chemical constituents were the result of the local geology, paths of flow, and seasonal influences. Local geology was responsible for the high percentage of sulfate in water from the top-aquifer wells, W3-1 and W6-1 (fig. 8). The local geology and the paths of ground-water movement caused water from well W7-2 to have sodium as the dominant cation and water from W8-2 to have calcium as the dominant cation (fig. 8). This was because water recharging the vicinity of W7-2 had to pass through the coal and an underclay, which resulted in cation exchange between sodium and calcium and a net increase of sodium in the water. In the vicinity of W8-2, water originates directly from precipitation and calcium remains the dominant cation.

Changes in chloride content occur seasonally in wells W4-1, W6-1, and W8-2 (figs 9 and 10). Well W4-1, which is the closest to a county road that is salted during the winter, shows increases in chloride content every spring. Wells W6-1 and W8-2, which are farther from the county road, show smaller increases. However, the increases take place during late summer because the chloride, moving with the ground water, takes longer to arrive at these wells.

Table 3.--Results of aquifer and underclay tests at watershed J11

Well	Hydraulic Conductivity (ft/d) Slug test	Hydraulic Conductivity (ft/d) Single-well Pumping test	Hydraulic Conductivity (ft/d) Laboratory Test	Saturated Thickness (ft)
W1-1	0.12			13
W3-1	0.096			8
W4-1	0.302			10
W6-1	0.058			9
Average for top aquifer	0.144			10
W2-2	0.48	0.017		123
W8-2	0.04	0.33		65
Average for middle aquifer	0.26	0.174		94
Underclay			.00038	
Underclay			.00035	
Underclay			.00207	
Average for underclay			.00093	

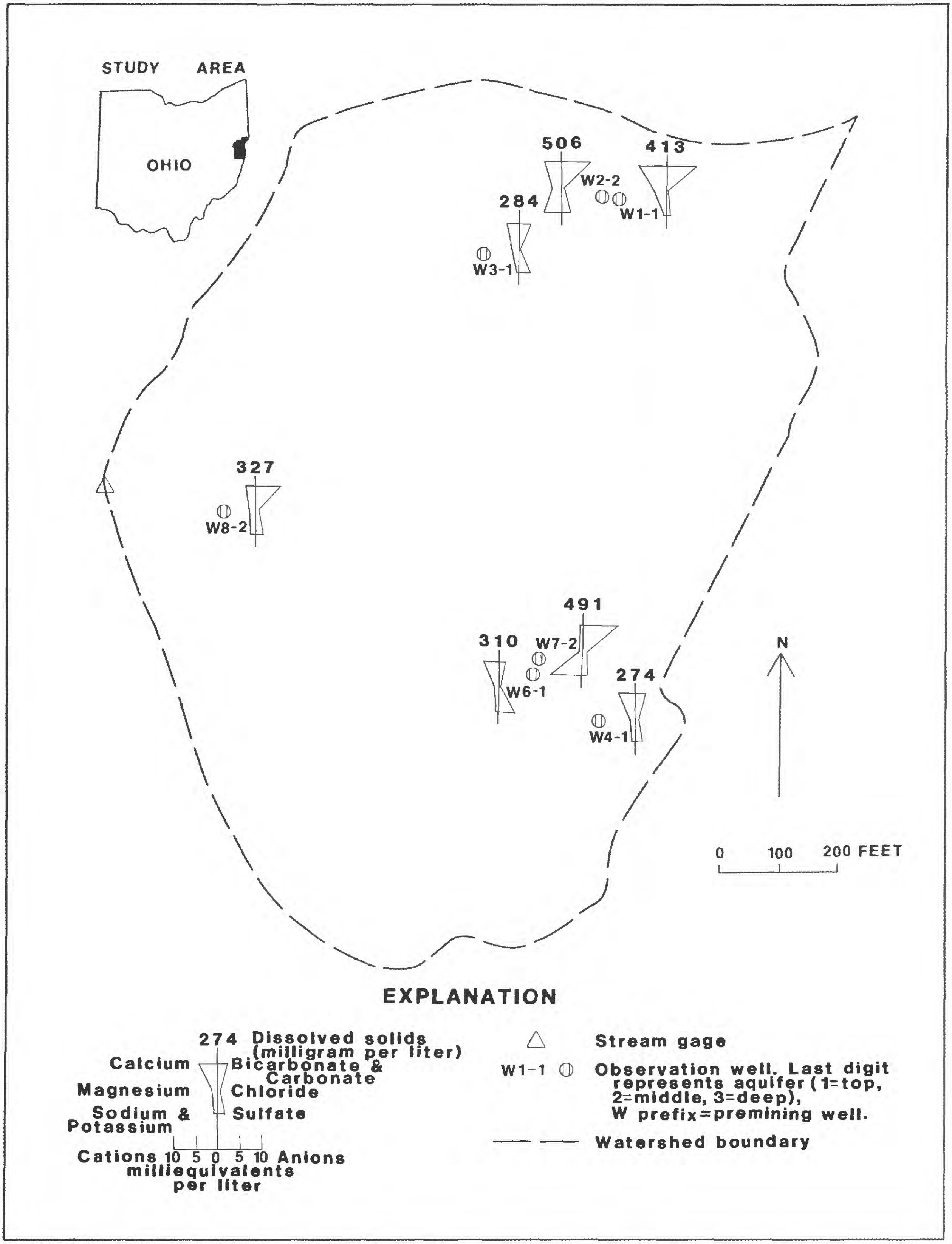


Figure 8.--Stiff (1951) diagrams showing distribution of water types in the premining condition at watershed J11.

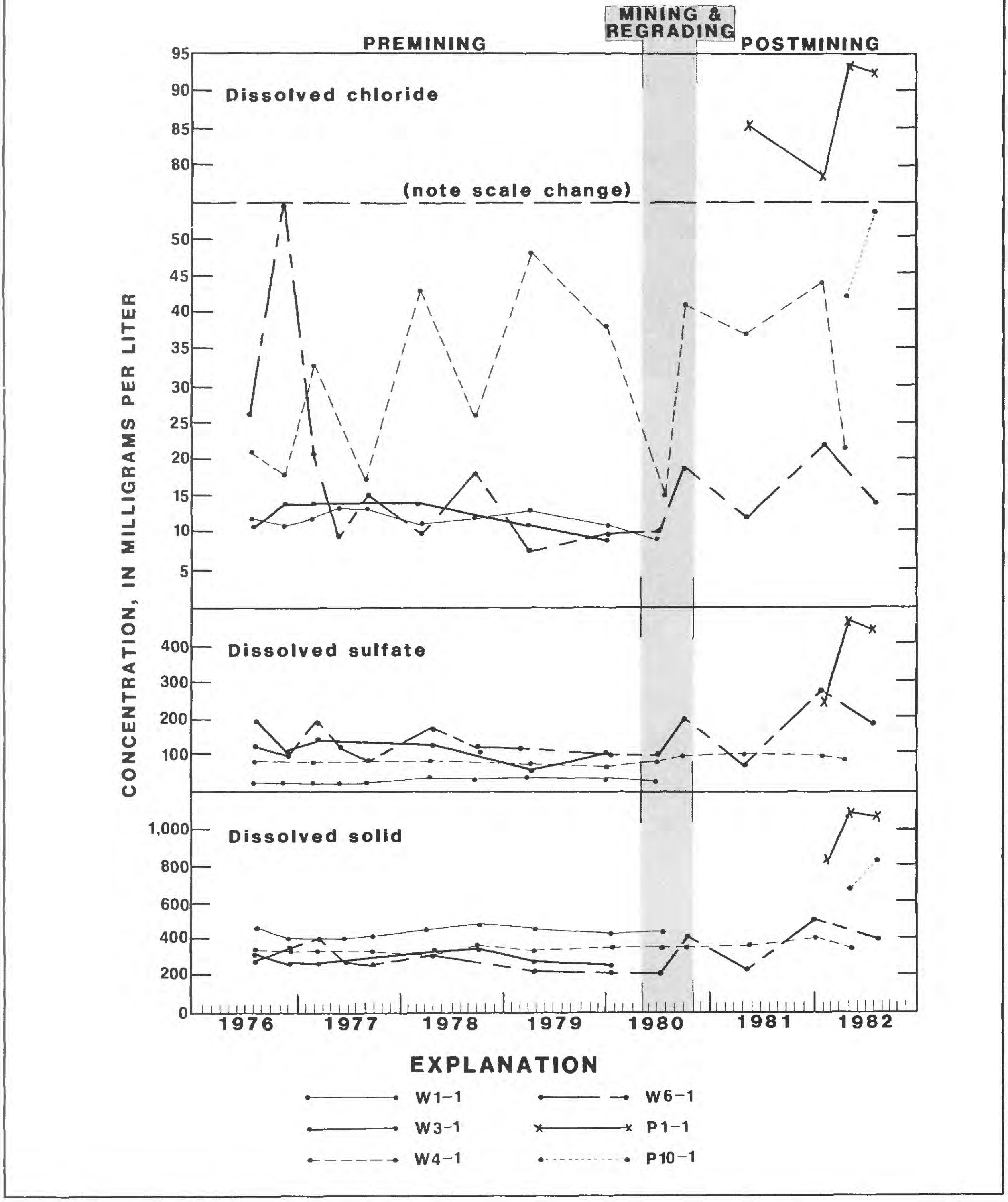


Figure 9.--Variations of selected contituents in the top aquifier at watershed J11 (W prefix=premining well, P prefix=postmining well).

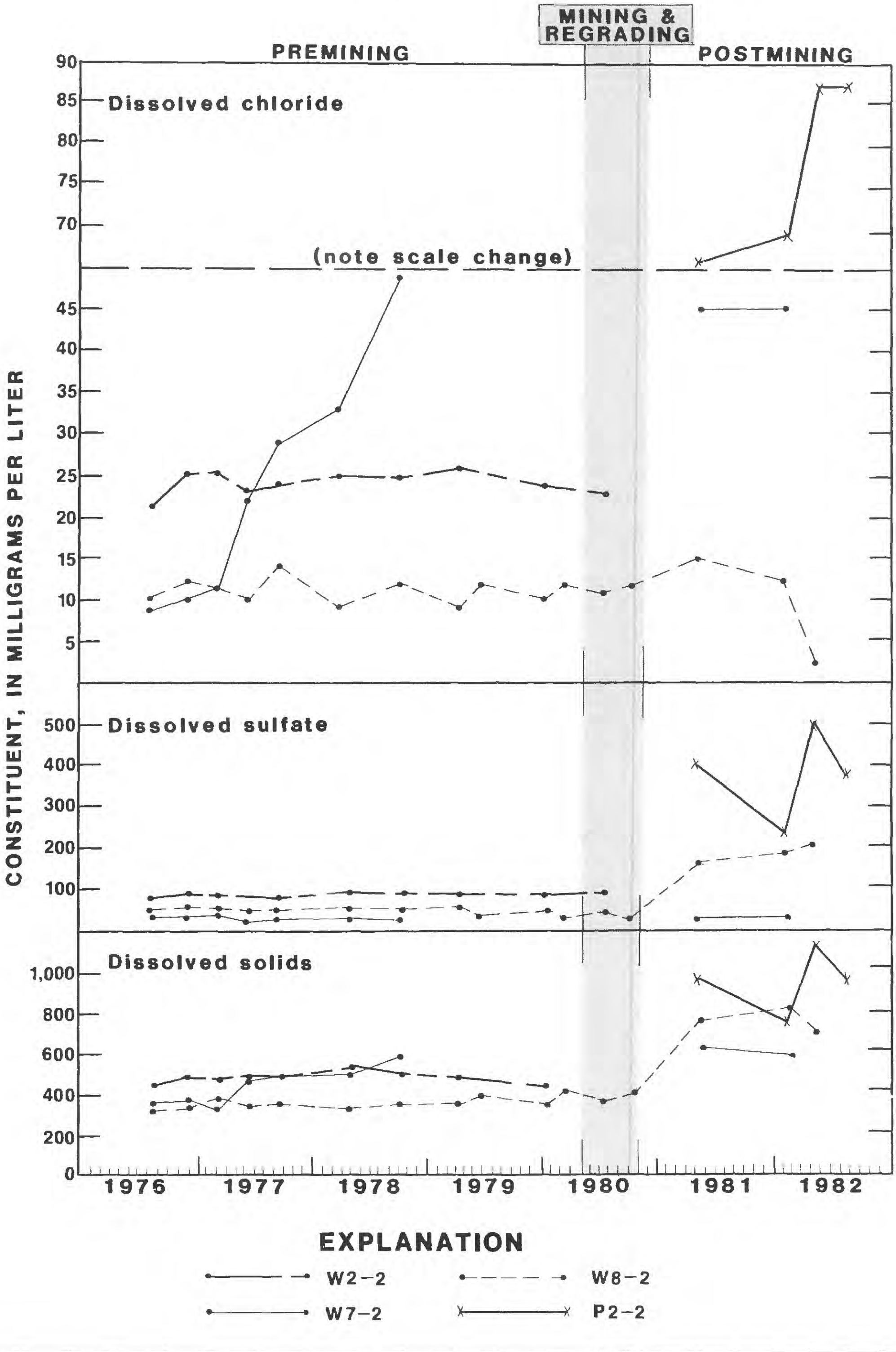


Figure 10.--Variations of selected constituents in the middle aquifier at watershed J11 (W prefix=premining well, P prefix=postmining well).

The water-quality diagram (fig. 11) shows that the base-flow water quality and the top-aquifer water quality closely resemble each other. This indicates that premining base flow was entirely supplied by spring discharge from the top aquifer. The water level in the middle aquifer was 18 feet below the stream bottom and was not supplying water to the stream.

POSTRECLAMATION GROUND-WATER CONDITIONS

Physical Characteristics and Geology

Active mining began in the watershed near the end of May 1980 and continued until the beginning of October 1980, at which time the postreclamation ground-water study began. After mining, the area of the watershed varied slightly from time to time because of changes in diversion ditches, but was about 32 acres. Surface runoff was handled mostly by diversion ditches and the remnants of the main stream channel. The stream, which is now about 300 feet long, is ephemeral. Although the total relief is unchanged, the topography has been smoothed and contoured.

Mining involved stripping the overburden, removing the coal, and replacing the overburden to the approximate premining configuration (fig. 12). Topography and water-table elevations within the watershed suggest that the ground-water divides for the top and middle aquifers reflect the new drainage divide. The entire top aquifer was not destroyed, however, because nearby houses and roads restricted the mining area. In the vicinity of wells W6-1 and W7-2, the coal was removed by augering, which did not disturb the overburden material. After mining, the section consisted of a top aquifer of spoils material on top of the shaly underclay and undisturbed bedrock in the unmined and augered areas (fig. 13). The middle aquifer below the Waynesburg No. 11 coal bed of the Monongahela Formation was undisturbed, except that some areas were covered with a layer of spoils material.

Summary of Data Collected

Four observation wells were installed in March 1981 to replace wells destroyed by mining. Three of the postreclamation wells were completed in the top aquifer (spoils) and one was completed in the middle aquifer. The wells were drilled by the cable-tool method and cased so that they were open to only one of the aquifers. The three top aquifer (spoils) wells were finished with slotted PVC casing, and the middle-aquifer well was constructed with steel casing to seal off the top aquifer and the open hole below. The completed well network is shown in fig. 14. Altitudes of each observation well were surveyed, and aerial photographs were used for locating wells and defining watershed boundaries.

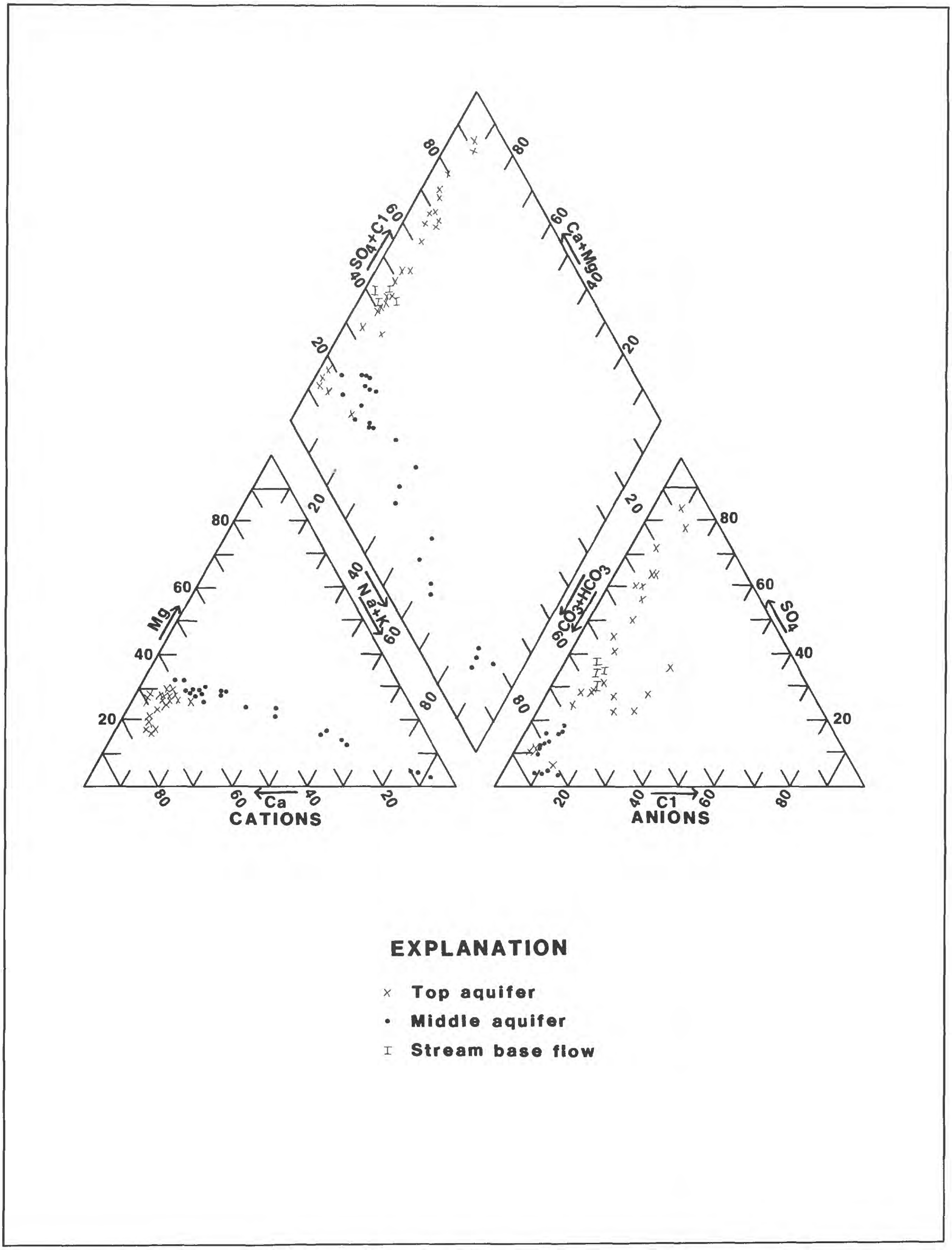


Figure 11.--Water-analysis diagram showing premining water-quality characteristics at watershed J11.

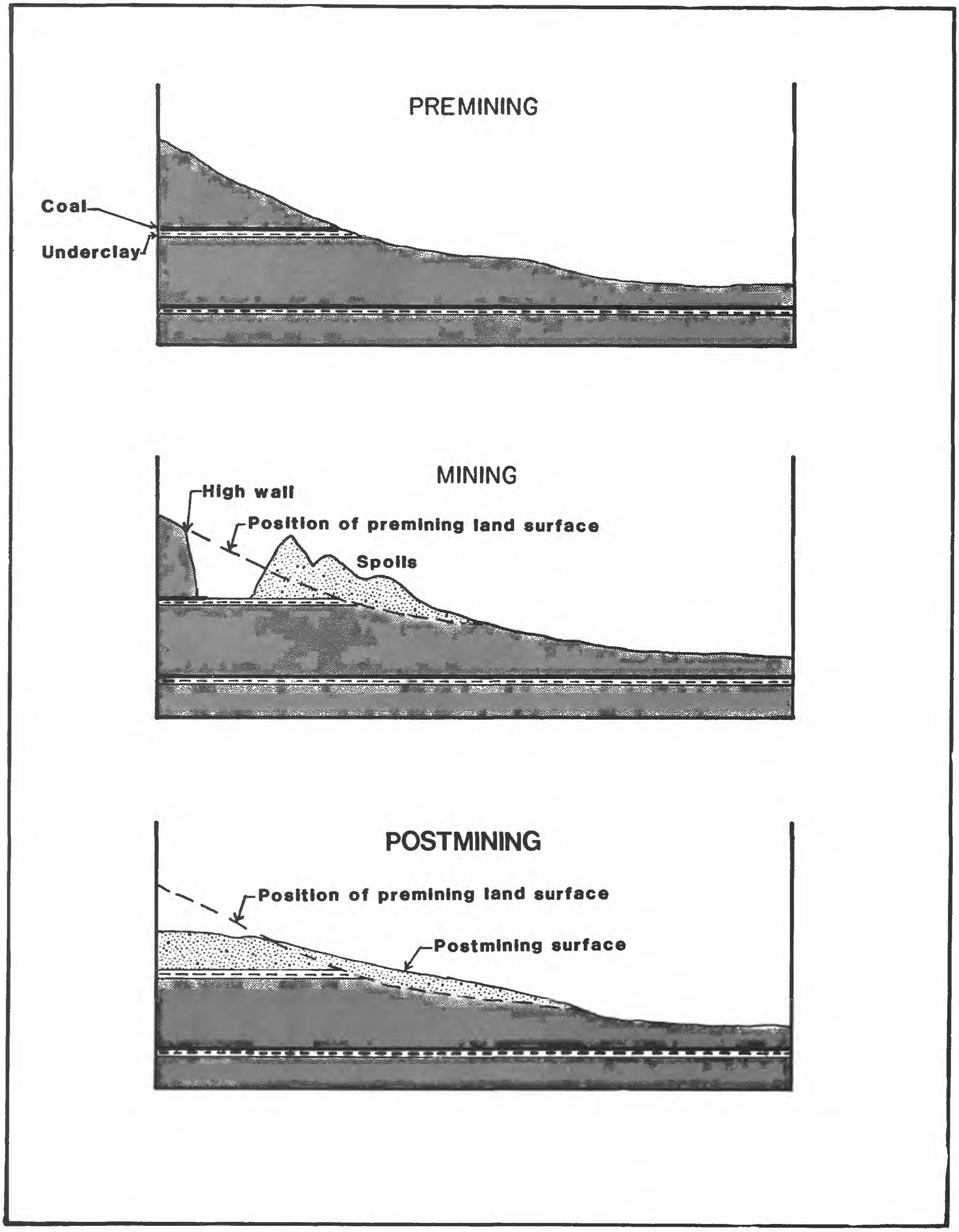


Figure 12.--Schematic section illustrating strip-mining process. (Helgesen and Razem, 1981)

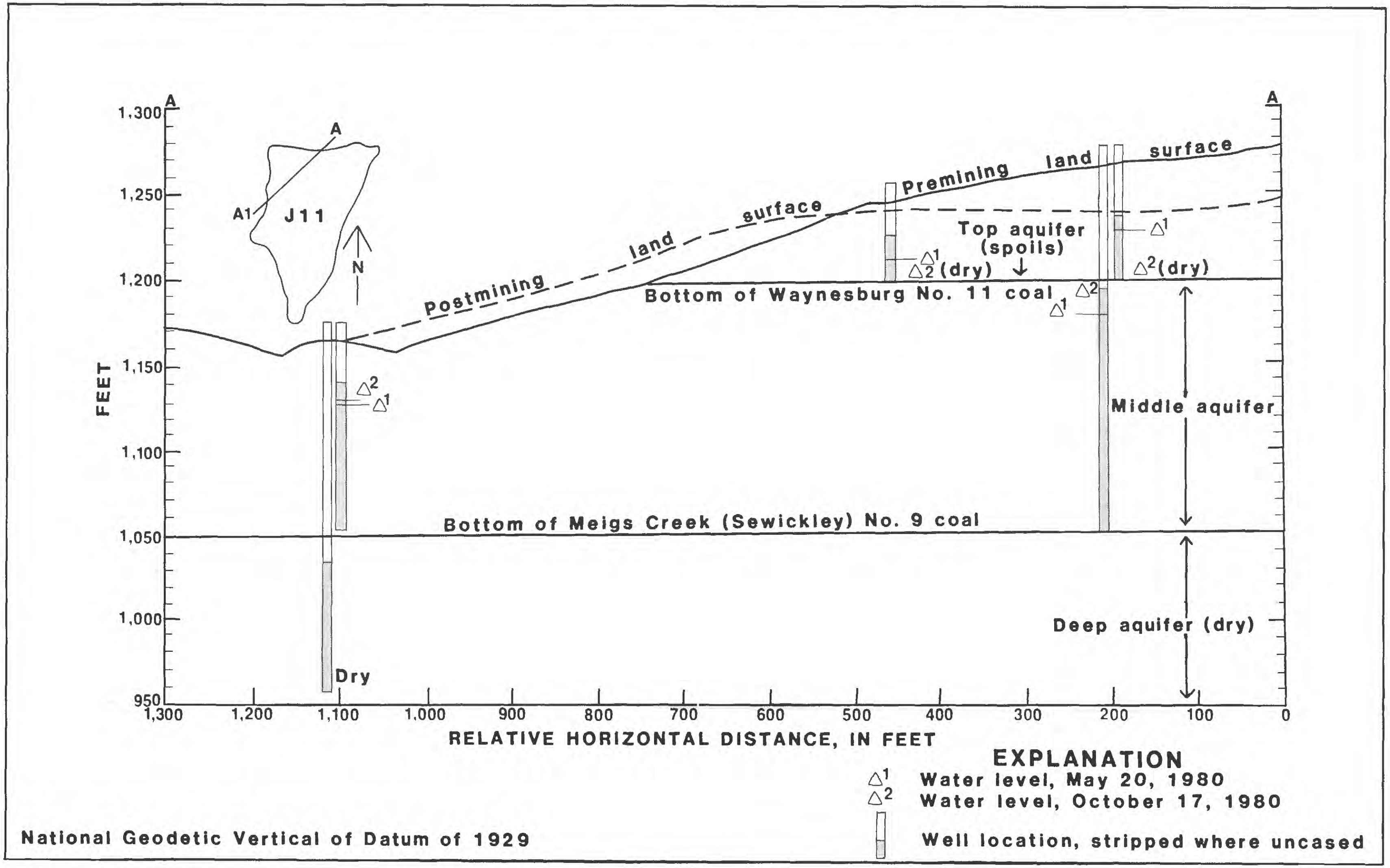


Figure 13.--Hydrogeologic section A-A1 showing changes resulting from surface mining at watershed J11.

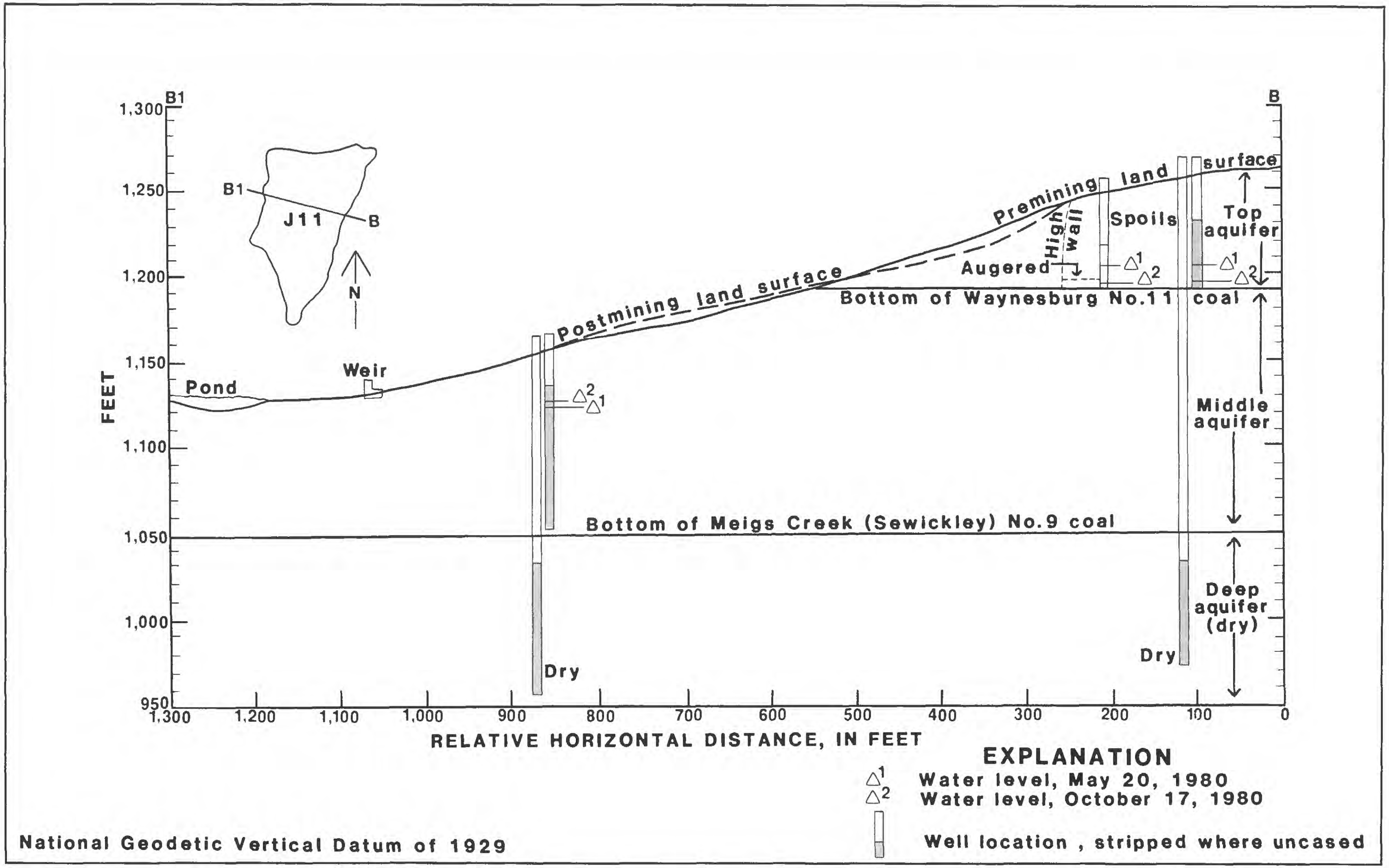


Figure 13.--Hydrogeologic section B-B1 showing changes resulting from surface mining at watershed J11.--Continued.

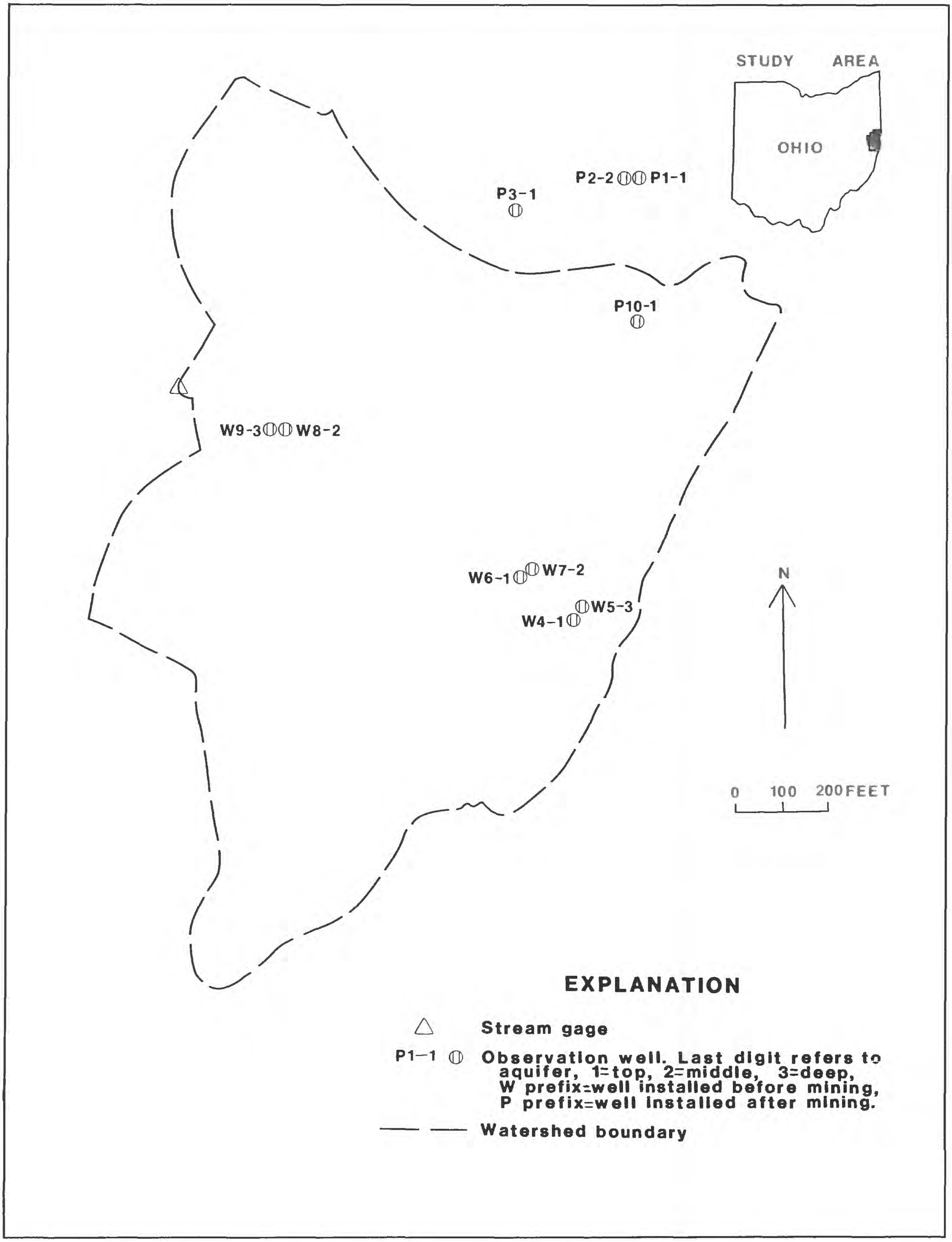


Figure 14.--Postreclamation location of top- and middle-aquifer wells at watershed J11.

Water levels in the wells were measured monthly. Digital recorders obtained hourly data on selected wells. Aquifer tests were not done at any of the postreclamation top aquifer (spoils) wells because the saturated thickness was too thin. Table 4 shows the postreclamation well information and data collected from each well.

Twenty-five samples were collected after mining for water-quality analysis (table 5), 14 from top-aquifer (spoils) wells and 11 from the undisturbed middle aquifer. Samples were collected with an electrical submersible pump if the well yield permitted, or with a PVC bailer if the saturated thickness was small or well yield was low. Samples were collected after the well volume had been discharged two to three times and the specific conductance and temperature had stabilized. Water samples were collected, treated, and analyzed by the same methods as described for the premining samples.

Ground-Water Hydrology

As in the premining condition, the postreclamation top aquifer receives recharge from precipitation that infiltrates to the saturated zone. However, preliminary artificial infiltration tests suggest that the recharge rates in the area covered by spoils have decreased (C. R. Amerman, U.S. Department of Agriculture, Agricultural Research Service, oral commun., 1982). This decrease has been caused by the destruction of the soil structure and compaction of the soil. With time, the recharge rate should increase as soil structure develops.

The middle aquifer receives recharge from precipitation (where the aquifer is exposed), from leakage through the overlying shaly clay bed, and from percolation through the overlying spoils material where the clay is absent.

Discharge from the top aquifer includes downward leakage to the middle aquifer in the areas where sufficient head has developed. Discharge from the top aquifer has decreased substantially in the postreclamation condition. No springs or seeps have been observed, and the streamflow is solely the result of direct runoff following precipitation. Discharge from the middle aquifer occurs as downward leakage and underflow out of the western part of the watershed, as in the premining condition.

Water is stored and transmitted in the intergranular pore spaces of the spoils and in openings, fractures, and bedding planes in the bedrock of the middle aquifer and the part of the top aquifer that was not disturbed. After mining and reclamation, all of the wells reinstalled in the spoils were dry in March 1981. In March 1982, well P3-1 was still dry and wells P1-1 and P10-1 contained only 4 feet and 3 feet of water, respectively (fig. 15). The slow development of a saturated zone in the spoils is a result of the increased storage and increased hydraulic conductivity. The development of the saturated zone was

Table 4.--Postreclamation well information at watershed J11

Local Number	Well Location latitude	Well Location longitude	Altitude of land surface (feet)	Date completed	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Remarks
P1-1	401011N	0805216W	1236.2	3/1981	39	39	4	Q,L
P2-2	401011N	0805216W	1236.2	3/1981	187	46	6	Q,L
P3-1	401010N	0805218W	1236.7	3/1981	38	38	4	L
P10-1	401009N	0805215W	1236.1	3/1981	39	39	4	Q,L

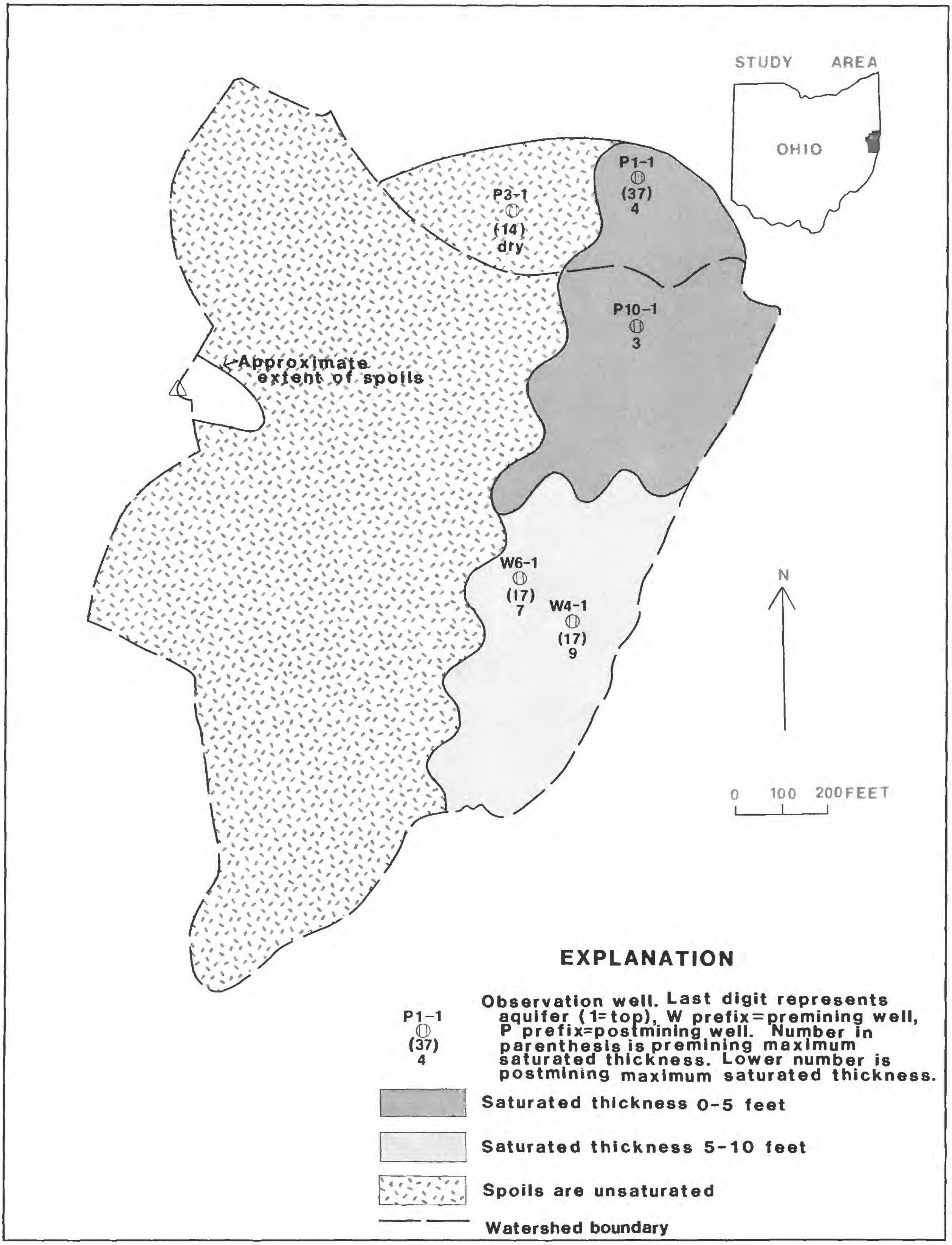
Remarks: Q = water quality
L = water levels

Table 5--Postreclamation chemical analyses of ground water collected from watershed J11, October 1980-August 1982

Constituents or properties	Unit	No. of samples	Concentration or other measurement, top aquifer	
			Range	Median
Specific conductance	µmho/cm	14	374-1,500	716.5
pH		14	6.6-7.1	6.85
Alkalinity, (as $CaCO_3$)	mg/L	14	72-394	196
Bicarbonate, (as HCO_3)	mg/L	14	88-480	239
Nitrogen, (dissolved)	mg/L	10	0.17-10	0.63
Nitrogen, NH_4 (dissolved)	mg/L	11	0.03-10	0.19
Nitrogen, Organic (dissolved)	mg/L	11	0-0.57	0.14
Nitrogen, NO_2 + NO_3 (dissolved)	mg/L	11	0.01-1.5	0.1
Phosphorus, dissolved	mg/L	11	0.01-0.68	0.01
Carbon, organic, as C	mg/L	14	1.2-26	3.3
Hardness (as $CaCO_3$)	mg/L	14	170-770	335
Hardness, Noncarbonate	mg/L	14	63-440	225
Calcium, (dissolved)	mg/L	14	53-210	103.5
Magnesium, (dissolved)	mg/L	14	8.9-61	18.5
Sodium, (dissolved)	mg/L	14	8-32	14
Sodium adsorption ratio		14	0.2-0.6	0.3
Percent sodium		13	6-11	8
Potassium (dissolved)	mg/L	13	1.4-3.6	1.8
Chloride (dissolved)	mg/L	14	12-92	41
Sulfate, (dissolved)	mg/L	13	71-460	200
Fluoride, (dissolved)	mg/L	14	0-0.2	0.1
Silica, (dissolved)	mg/L	13	11-20	14
Iron, (dissolved)	µg/L	13	11-4,300	150
Manganese, (dissolved)	µg/L	14	39-910	400
Strontium, (dissolved)	µg/L	14	250-1,000	490
Zinc, (dissolved)	µg/L	2	30-80	55
Phenols	µg/L	14	0-20	1
Solids, sum of constituents, (dissolved)	mg/L	13	236-1,070	405

Table 5.--Postreclamation chemical analyses of ground water collected from watershed J11, October 1980-August 1982--Continued

Constituents or properties	Unit	No. of samples	Concentration or other measurement, middle aquifer: Range	Concentration or other measurement, middle aquifer: Median
Specific conductance	µmho/cm	10	702-1,600	1,185
pH		10	6.8-7.8	7.05
Alkalinity, (as $CaCO_3$)	mg/L	10	333-591	402
Bicarbonate, (as HCO_3)	mg/L	10	406-720	490
Nitrogen, (dissolved)	mg/L	7	0.2-2.2	0.5
Nitrogen, NH_4 (dissolved)	mg/L	9	0.03-0.46	0.11
Nitrogen, Organic (dissolved)	mg/L	9	0-0.38	0.21
Nitrogen, NO_2 + NO_3 (dissolved)	mg/L	9	0.01-1.5	0.05
Phosphorus, dissolved	mg/L	9	0.01-0.06	0.01
Carbon, organic, as C	mg/L	9	1-5.2	1.8
Hardness (as $CaCO_3$)	mg/L	10	37-810	640
Hardness, Noncarbonate	mg/L	10	0-470	94.5
Calcium, (dissolved)	mg/L	10	9.3-216	166
Magnesium, (dissolved)	mg/L	10	3.2-66	53.5
Sodium, (dissolved)	mg/L	10	11-250	32
Sodium adsorption ratio		10	0.2-17	0.6
Percent sodium		10	3-93	9.5
Potassium (dissolved)	mg/L	10	1.2-3.5	2.2
Chloride (dissolved)	mg/L	10	2.4-86	45
Sulfate, (dissolved)	mg/L	10	21-500	190
Fluoride, (dissolved)	mg/L	10	0.1-3	0.2
Silica, (dissolved)	mg/L	10	8.3-15	12.5
Iron, (dissolved)	µg/L	10	3-1,500	18
Manganese, (dissolved)	µg/L	10	5-1,500	220
Strontium, (dissolved)	µg/L	10	430-2,000	1,600
Zinc, (dissolved)	µg/L	1	0-0	0
Phenols	µg/L	10	0-1	1
Solids, sum of constituents, (dissolved)	mg/L	10	404-1,120	770



EXPLANATION

P1-1 (37) 4 — Observation well. Last digit represents aquifer (1=top), W prefix=premining well, P prefix=postmining well. Number in parenthesis is premining maximum saturated thickness. Lower number is postmining maximum saturated thickness.

▨ Saturated thickness 0-5 feet

░ Saturated thickness 5-10 feet

⁘ Spoils are unsaturated

— — Watershed boundary

Figure 15.--Postreclamation top-aquifer saturated thickness at watershed J11, March 1982.

also slowed down because the spoils materials were partially dried. In the part of the top aquifer not disturbed by mining near wells W4-1 and W6-1, the amount of water in storage has been less than during premining. This can be best seen by comparing premining and postreclamation water levels (fig. 5).

Water levels responded almost immediately to the mining operation. Water-level declines were seen in all wells soon after mining began, except in W8-2, which is in the middle aquifer in an area not overlain by mining and reclamation activity (fig. 5). The water-level decline resulted directly from mining, as evidenced by the magnitude of the declines, by the fact that no other stresses were occurring, and by the fact that precipitation during July and August 1980 was significant compared to the same periods in 1978-82 (fig. 5).

As in premining conditions, there are two major saturated zones in the area not disturbed by mining (near wells W6-1 and W4-1). However, in the spoils material (near wells P1-1 and P10-1), there is no longer an unsaturated zone between the top aquifer (spoils) and the middle aquifer. Water levels in well P2-2 in the second aquifer are up to 40 feet higher than during premining, and are equal to those in well P1-1. This, along with the discovery that the shaly underclay was not observed during drilling after mining, indicates that either the aquifers are directly connected or that only one aquifer now exists in this area.

Water in the top postreclamation aquifer moves along a nearly flat gradient from the watershed divide toward the buried highwall that separates the bedrock from the spoils (fig. 13). Discharge from the top aquifer to the middle aquifer probably occurs at the point of the buried highwall because the underclay is absent. Water in the middle aquifer moves from the watershed divide toward the mouth of the watershed (fig. 16), the same as during the premining condition. However, the gradient has increased slightly as a result of the water-level rise in well P2-2 (fig. 13). The deep zone remains dry, as it was during the premining condition.

Aquifer testing in the spoils has not been possible because the saturated zone has been too thin. Indications from bailing during water-quality sampling are that the yield of the spoils is higher than the yield of the premining top aquifer. This presents a situation where the hydraulic conductivity of the downgradient top-aquifer materials (spoils) is probably one to two orders of magnitude higher than the hydraulic conductivity of the upgradient bedrock. This will retard or prevent the top-aquifer water levels from rebounding to the premining levels because the material of higher hydraulic conductivity will drain faster than the water level can rise in the lower hydraulic-conductivity material. That is, a new steady-state situation will be attained that results in lower water levels in the bedrock part of the top aquifer. Aquifer tests were not feasible in the bedrock part of the top aquifer because of the low yields and the thin saturated zone, but aquifer characteristics should be the same as before mining.

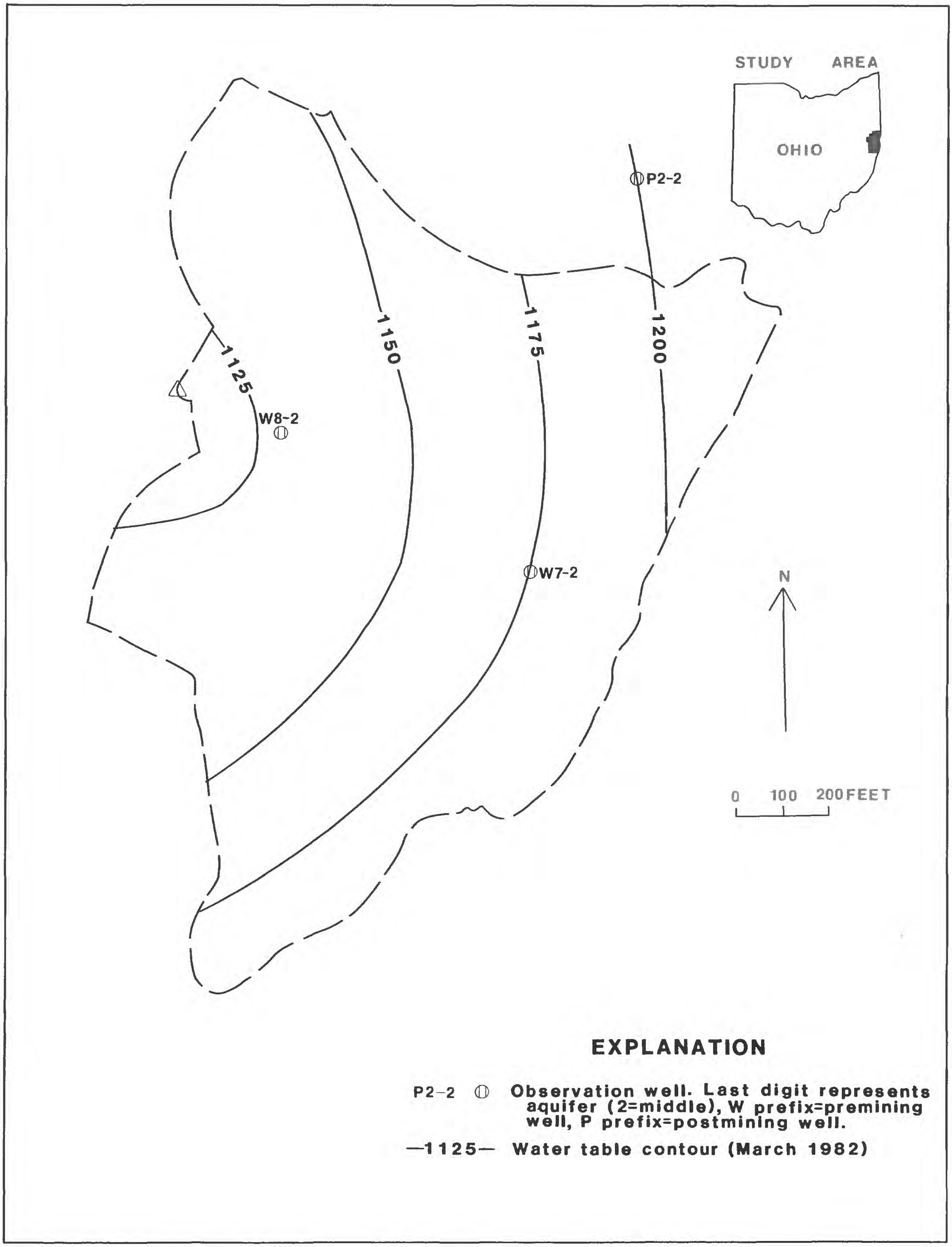


Figure 16.--Postreclamation potentiometric surface of the middle aquifer at watershed J11.

Aquifer tests were not conducted in the middle aquifer because the material was undisturbed by mining. However, because of the increased saturated thickness (30 feet), the transmissivity has increased about 20 percent. Observations during postreclamation drilling and water-quality sampling suggest that primary permeability is the major factor controlling water movement in the spoils part of the top aquifer. As in the premining condition, secondary permeability controls water movement in the bedrock part of the top aquifer and in the middle aquifer after mining.

Storage capacity has increased in the spoils 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 quantity of water in storage in the bedrock part of the top aquifer has decreased because the extent of the bedrock aquifer has decreased and the saturated thickness of the remaining bedrock is thinner than during premining. This decrease in storage is a result of the partial removal of coal by augering. The augering has created large drains that have lowered the water table.

The mining operation did not disturb the material below the underclay beneath the Waynesburg No. 11 coal bed of the Monongahela Formation. Thus, the hydrologic properties of the middle aquifer are not expected to have changed. However, blasting and heavy equipment traffic could have fractured or stressed the aquifer.

Ground-Water Quality

Water in the postreclamation top aquifer is a calcium sulfate type, except at well W4-1 which yielded calcium bicarbonate type water (figs. 17 and 18). Although water types have not changed much between premining and postreclamation (fig. 18), the median concentrations of most of the individual constituents have increased (tables 2 and 5). These increases are the result of the mining operation that broke the bedrock and exposed materials susceptible to solution. Median concentrations of constituents in the top aquifer that increased significantly from premining to postreclamation conditions are dissolved iron (0.03 mg/L (milligrams per liter) to 0.15 mg/L), dissolved manganese (0.03 mg/L to 0.4 mg/L), dissolved sulfate (84 mg/L to 200 mg/L), dissolved chloride (13 mg/L to 41 mg/L), and noncarbonate hardness (96 mg/L to 225 mg/L). Only the median concentration of dissolved manganese (0.4 mg/L) exceeds the recommended limit of 0.05 mg/L for domestic water supplies (U.S. Environmental Protection Agency, 1976). However, concentrations of some constituents at specific well sites did exceed recommended limits, as can be seen in the ranges from table 5.

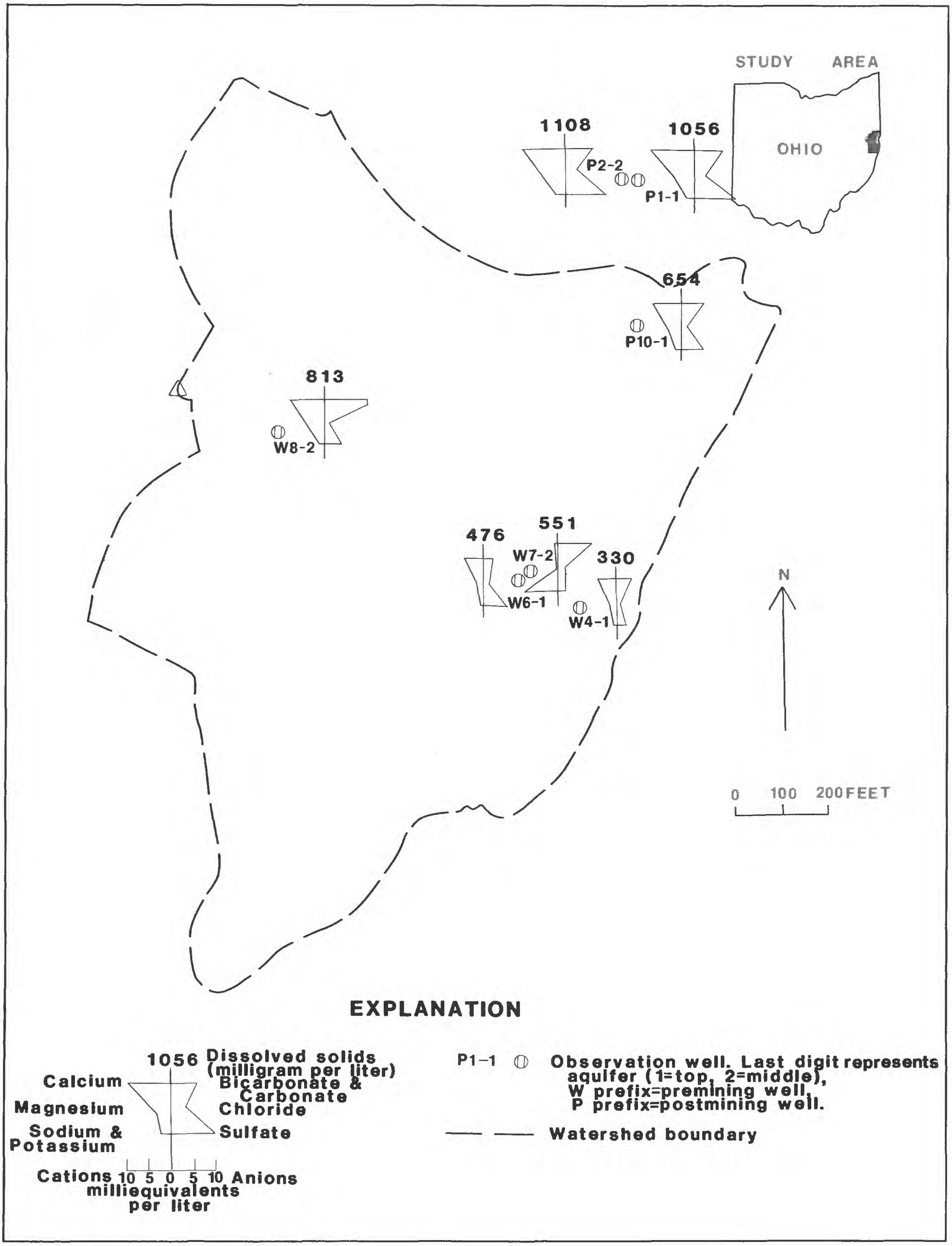


Figure 17.--Stiff (1951) diagrams showing distribution of water types in the postreclamation condition at watershed J11.

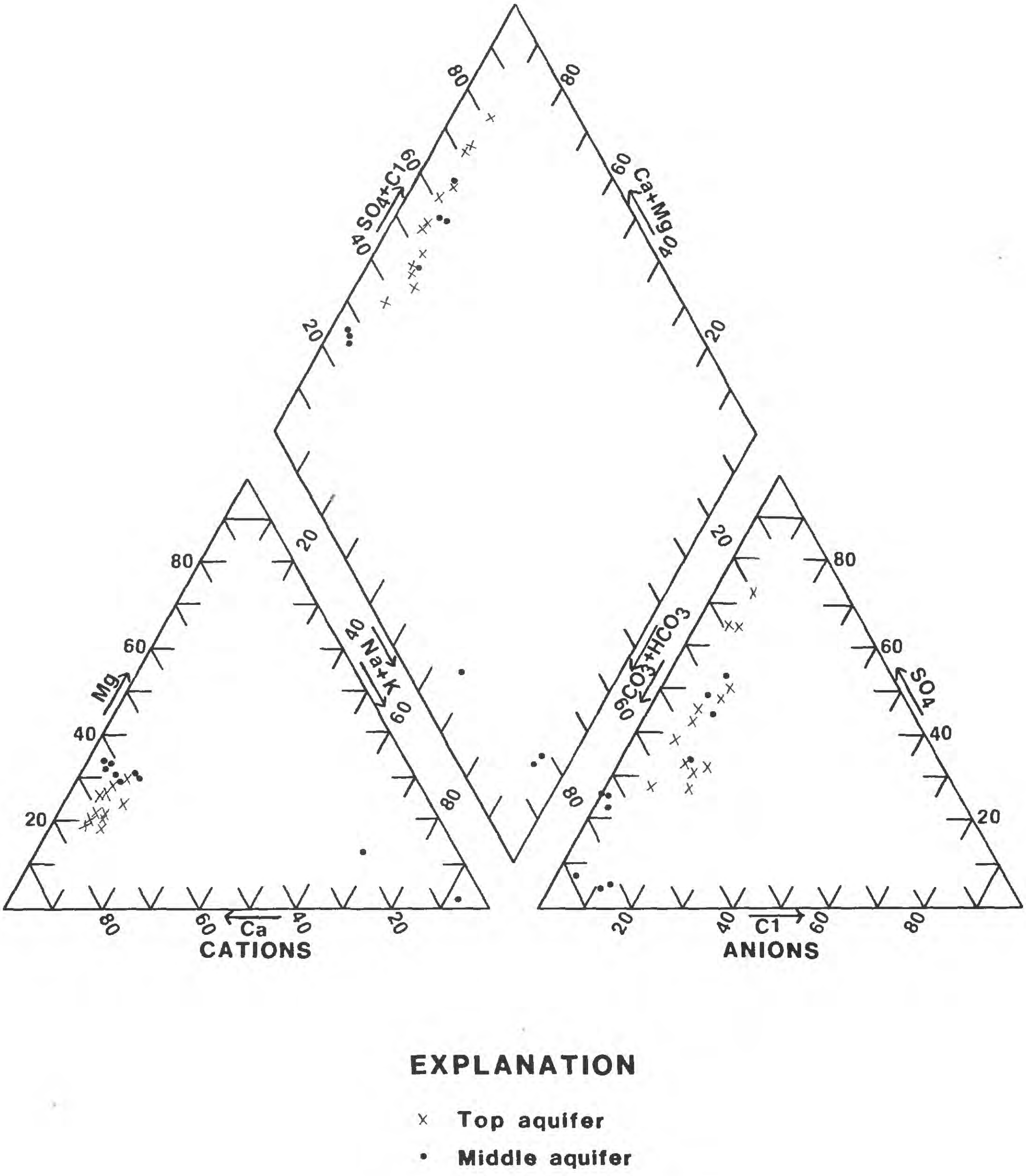


Figure 18.--Water-analysis diagram showing postmining water-quality characteristics at watershed J11.

Water in the second aquifer consists of a sodium bicarbonate type (W7-2), a calcium bicarbonate type (W8-2), and a calcium sulfate type (P2-2) (figs. 17 and 18). The types of water from W8-2 and W7-2 are the same as during prereclamation, though the median of the total dissolved solids content of water at well W8-2 has increased from 358 mg/L to 765 mg/L. The water-quality changes at W7-2 are small in comparison to W8-2 and P2-2 because the area near W7-2 was not disturbed by mining and the well location is upgradient from the mining activity. Water-quality changes in the middle aquifer are most dramatic at P2-2, at which calcium bicarbonate type water has changed to calcium sulfate type. This site was in the middle of the mining activity, and the shaly underclay was disturbed. The similarities in water quality (fig. 17) and water levels in wells P1-1 and P2-2 show that the top aquifer and the middle aquifer react as one in the area of the spoils.

Concentrations of some constituents at specific well sites exceeded recommended limits for domestic water supplies, as can be seen in the ranges in table 5. Dissolved manganese and dissolved solids are the only constituents whose median concentrations exceed recommended limits of 0.05 mg/L and 500 mg/L, respectively (U.S. Environmental Protection Agency, 1976; U.S. Public Health Service, 1962). Although few constituents in the middle aquifer exceed recommended limits, many increased significantly from premining to postreclamation conditions. Some of the median concentrations of constituents in the middle aquifer that increased are: hardness (250 mg/L to 640 mg/L), noncarbonate hardness (0 mg/L to 94.5 mg/L), calcium (61 mg/L to 166 mg/L), magnesium (23 mg/L to 53.5 mg/L), sulfate (47 mg/L to 190 mg/L), manganese (10 µg/L to 220 µg/L), dissolved solids (405 mg/L to 770 mg/L), and chloride (14 mg/L to 45 mg/L). Oddly, the median concentration of sodium decreased from 48.5 mg/L to 32 mg/L, even though chloride increased.

The increases of median concentrations of constituents in the top aquifer (spoils) result from more surface area along mineral-water contacts, which allows for more mineral dissolution. Dissolution of limestones and carbonate cements caused the rise in calcium, magnesium, bicarbonate, and hardness. Manganese is derived from oxides and hydroxides in the soil and rock; sulfates and iron are derived from reduced minerals, particulary pyrite. Breaking and disintegration of the marine shales has released chlorides that were entrapped in the fine-grained sediments when they were deposited.

The introduction of oxygen and its contact with reduced minerals (pyrite), will cause dissolution of these minerals to yield iron and sulfates. The increase in concentrations of constituents in the middle aquifer is the result of leakage from the overlying spoils and introduction of oxygen from the oxygenated spoils. When springs and seeps eventually return, the base flow of the stream will be considerably reduced in quality compared to that before mining.

In the premining condition, median concentrations of dissolved iron and dissolved manganese were equal for both the top and middle aquifers. In the postmining condition, the median concentrations of dissolved manganese are many times higher than those of dissolved iron, which is unusual for most ground waters (Hem, 1970, p. 130). This imbalance is caused by the dissolution of reduced minerals in the presence of oxygen. For example, iron will tend to go into solution, but the iron-bearing water will precipitate ferric hydroxide when dissolved oxygen is present and the Eh rises (Hem, 1970, p. 118). That is, iron will go into solution from the pyrite dissolution, but then precipitate out in the presence of oxygen. On the other hand, manganese goes into solution and stays in solution even in the presence of oxygen (Hem, 1970, p. 129). The net result is that both dissolved iron and manganese increase, but manganese increases much more.

SUMMARY

Five small watersheds associated with coal seams in eastern Ohio were studied to assess the hydrologic effects of strip mining. This report describes ground-water conditions before and after mining in watershed J11. The premining watershed was characterized by nearly flat-lying sedimentary rocks of the Pennsylvanian and Permian Systems. Shaley clay beds below two major coal seams formed bases for perched saturated zones (aquifers). Generally, water in the perched aquifers constituted local flow systems. Premining ground-water was generally a calcium bicarbonate type if overlying clay beds were absent or a sodium bicarbonate type if overlying clay beds were present. Some calcium sulfate type water was present in the premining top aquifer. Dissolved-solids concentration of water generally increased with depth.

As mining began along the outcrop of the Waynesburg No. 11 coal bed of the Monongahela Formation, water levels in top and middle aquifer wells declined abruptly. Springflow from the top aquifer, which supplied the base flow to the stream, decreased and eventually ceased completely.

All wells reinstalled in the spoils after mining and initial regrading were dry at first. One well remains dry, and the others have 3 to 4 feet of saturated thickness after 1 1/2 years. In the part of the top aquifer that was not destroyed by mining, water levels in wells declined during mining and have not recovered to premining levels. Water levels in a middle-aquifer well reinstalled after regrading are up to 40 feet higher than during premining, and are equal to those in the top aquifer spoils. Because of the equal water levels, the nearly identical water quality, and the absence of the shaly underclay during postmining drilling, the spoils and the middle aquifer in the area of the spoils material are assumed to be hydraulically interconnected.

A comparison of the premining top aquifer with the post-reclamation spoils shows marked differences in geometry, recharge rates, discharge rates, saturated thickness, aquifer characteristics, and water quality. Changes in the middle aquifer include saturated thickness, recharge and water quality.

Water types in the middle aquifer generally did not change, except for a few changes from bicarbonate types to sulfate types. Water in the spoils is also of similar quality to the premining top aquifer. Median concentrations of dissolved constituents in the middle aquifer generally increased; however, only dissolved manganese and dissolved-solids concentrations exceeded recommended limits for domestic water supplies. Medium concentration of dissolved constituents in the spoils is higher than in the original top aquifer. Higher concentrations of calcium, magnesium, and bicarbonate are attributed to dissolution of limestone and carbonate cements. Iron and sulfate concentrations result from dissolution of reduced minerals (pyrite). Increases in manganese are the result of dissolution of manganese oxides and hydroxides in the soil and shales. Increases in chloride are attributed to the release of chloride ions that had been trapped in shales during deposition of the fine grain deposits in a marine environment.

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