EFFECTS OF SURFACE COAL MINING AND RECLAMATION ON GROUND WATER IN SMALL WATERSHEDS IN THE ALLEGHENY PLATEAU, OHIO

By Michael Eberle and Allan C. Razem

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 85-4205

Columbus, Ohio

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

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

Copies of this report can
be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 236-7476)

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For the convenience of readers who prefer to use metric (International System) units, conversion factors for inch-pound units used in this report are listed below:

Multiply Inch-Pound units	By	To Obtain Metric Units
foot (ft)	0.3048	meter (m)
acre	0.4047	square hectometer (hm^2)

To convert hardness from milligrams per liter to grains per gallon, multiply by 0.05841.

ABBREVIATIONS

mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemen per centimeter (at 25° C)

EFFECTS OF SURFACE COAL MINING AND RECLAMATION ON GROUND WATER IN SMALL WATERSHEDS IN THE ALLEGHENY PLATEAU, OHIO

By Michael Eberle and Allan C. Razem

ABSTRACT

The hydrologic effects of surface coal mining in unmined areas is difficult to predict, partly because of a lack of adequate data collected before and after mining and reclamation. In order to help provide data to assess the effects of surface mining on the hydrology of small basins in the coal fields of the eastern United States, the U.S. Bureau of Mines sponsored a comprehensive hydrologic study at three sites in the Ohio part of the Eastern Coal Province. These sites are within the unglaciated part of the Allegheny Plateau, and are representative of similar coal-producing areas in Kentucky, West Virginia, and Pennsylvania. The U.S. Geological Survey was responsible for the ground-water phase of the study.

The aquifer system at each watershed consisted of two localized perched aquifers (top and middle) above a deeper, more regional aquifer. The premining top aquifer was destroyed by mining in each case, and was replaced by spoils during reclamation.

The spoils formed new top aquifers that were slowly becoming resaturated at the end of the study period. Water levels in the middle aquifers were about the same after reclamation as before mining, although levels rose in a few places. It appears that the underclay at the base of the new top aquifers at all three sites prevents significant downward leakage from the top aquifer to lower aquifers except in places where the layer may have been damaged during mining.

Water in the new top aquifers is a calcium sulfate type, whereas calcium bicarbonate type water predominated before mining. The median specific conductance of water in the new top aquifers was about 5 times greater than that of the original top aquifers in two of the watersheds, and 1 1/2 times the level of the original top aquifer in the third. Concentrations of dissolved sulfate, iron, and manganese in the top aquifers before mining generally did not exceed U.S. and Ohio Environmental Protection Agency drinking-water limits, but generally exceeded these limits after reclamation. Water-quality changes in the middle aquifers were minor by comparison. Water levels and water quality in the deeper, regional aquifers were unaffected by mining.

INTRODUCTION

Background

The Eastern Coal Province of the United States (fig. 1) has been one of the world's leading coal-producing areas in recent years. In 1981, the amount of coal produced in Ohio, Kentucky, Pennsylvania, and West Virginia alone was 47 percent of the total production in the United States and more than 9 percent of the total world production (U.S. Bureau of the Census, 1984). Much of the coal in the Eastern Coal Province is surface mined.

The effects of surface mining on ground water have been a matter of concern ever since surface mining became widespread around the middle of the twentieth century. Ground-water quality is of major concern because it is a primary determinant of the water quality of base flow in streams, and because many rural residents in the eastern coal province depend on ground water for their domestic water supplies. Moreover, the hydrologic effects of surface mining are of particular concern to mine operators and regulatory officials because the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) requires that every application for a surface-mining permit contain a determination of the "probable hydrologic consequences" of the mining operation both on and off the mine site.

Unfortunately, the relations between surface mining and the impacts on ground water are not understood well enough to be adequately predicted in many cases. An example of this is the lack of data documenting ground-water quality before and after surface mining and reclamation at specific sites.

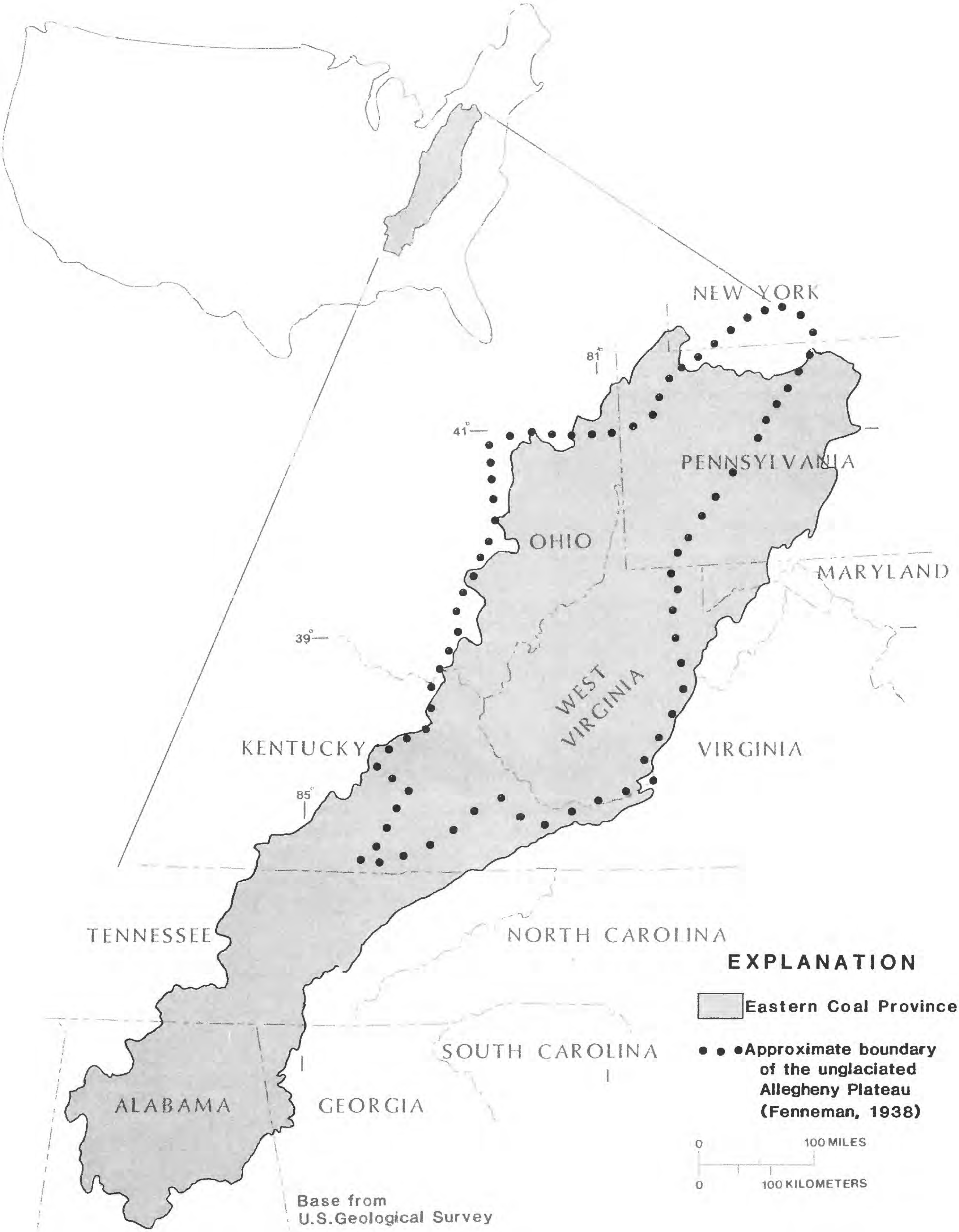


Figure 1.--Location of Eastern Coal Province and the unglaciated Allegheny Plateau.

In order to obtain data necessary for understanding relations between surface mining and the effects on hydrologic systems, the U.S. Bureau of Mines sponsored a comprehensive study to assess the effects of surface mining and reclamation on the hydrology of small watersheds (30-50 acres) in Muskingum, Coshocton, and Jefferson Counties in Ohio (fig. 2). The geology of the study watersheds (referred to as watersheds M09, C06, and J11, respectively) is similar to that in the coal-producing areas in much of eastern Ohio, eastern Kentucky, West Virginia, and western Pennsylvania (Brant and DeLong, 1960, p. 21). This region is in the unglaciated Allegheny Plateau section of the Appalachian Plateaus physiographic province (Fenneman, 1938; fig. 1).

Four agencies--the U.S. Department of Agriculture, Agricultural Research Service; The Ohio State University, Ohio Agricultural Research and Development Center; the U.S. Soil Conservation Service; and the U.S. Geological Survey--were responsible for the design of the study and for the collection and analysis of data. Topics of study included erosion and sedimentation, surface-water quantity and quality, ground-water quantity and quality, and the economics of mining and reclamation.[1] The U.S. Geological Survey was responsible for the ground-water phase of the study.

Purpose and Scope

The purpose of this report is to provide an overview of the effects of surface coal mining and reclamation on ground-water systems of small watersheds in order to illustrate some typical hydrologic systems in the Eastern Coal Province. The report presents background information on geology in Ohio's coal region, and summarizes data on ground-water quantity and quality at three watersheds before and after mining and reclamation.

The three study watersheds were underlain by three major coal seams, one of which was exposed within each watershed. In watersheds C06 and J11, the coal beds to be mined were associated with sandstone and shale strata. The coal beds in watershed M09 were in limestone and shale strata. The watersheds were mined beginning with C06 in November 1976. Reclamation was completed at M09, C06, and J11 in that order (table 1).

This summary, which is not solely for a technical audience,[2] is based primarily on reports by Razem (1983, 1984) and on data from the U.S. Department of Agriculture, Agricultural Research Service. Detailed information on these watersheds can be found in these and other works listed in the selected references. The information presented in this report should be useful to coal-mine operators, government officials, residents of the Eastern Coal Province, and others who are interested in issues related to coal production, land reclamation, and ground water.

Hydrogeologic Setting of Ohio's Coal Region

Coal-bearing strata of eastern Ohio (fig. 2) consist of sedimentary rocks that range in age from the Mississippian Period (360-330 million years ago) to the Permian Period (290-240 million years ago). Most of the rocks cropping out in the study area, however, were deposited during the Pennsylvanian Period (330-290 million years ago).

The Pennsylvanian rocks of Ohio consist of cyclical sequences of shale, sandstone, thin limestone, coal, and clay (fig. 3). Water-bearing characteristics differ considerably among these strata, owing primarily to differences in the size and number of pores and fractures in the rocks. Clay and shale layers, which commonly underlie the coal beds, considerably restrict the downward movement of ground water (Norris, 1969, p. 30-1; Ohio Department of Natural Resources, 1978, p. 168-72). Under these conditions ground water generally moves laterally and discharges at hillside springs or seeps, although there is some downward leakage through the underclay to deeper water-bearing zones. The presence of clay and shale layers commonly causes series of perched aquifers to form in some places (fig. 4).

Local geology considerably influences the quality of ground water in Ohio's coal region--particularly, concentrations of bicarbonate and sulfate. In eastern Ohio, dissolved bicarbonate in ground water generally is derived from limestone (calcium carbonate) and carbonate cements. Sulfate is derived primarily from pyrite--an iron sulfide mineral--which commonly is associated with coal and coal-bearing rocks in the eastern United States.

---

[1] Further information on the surface-water, sedimentation, revegetation, and economics phases of the study may be obtained from:

USDA - Agricultural Research Service
North Appalachian Experimental Watershed
P.O. Box 78
Coshocton, Ohio 43812

or:

Bureau of Mines
U.S. Department of the Interior
Washington, D.C. 20241

[2] Technical terms are defined in a glossary at the back of this report.

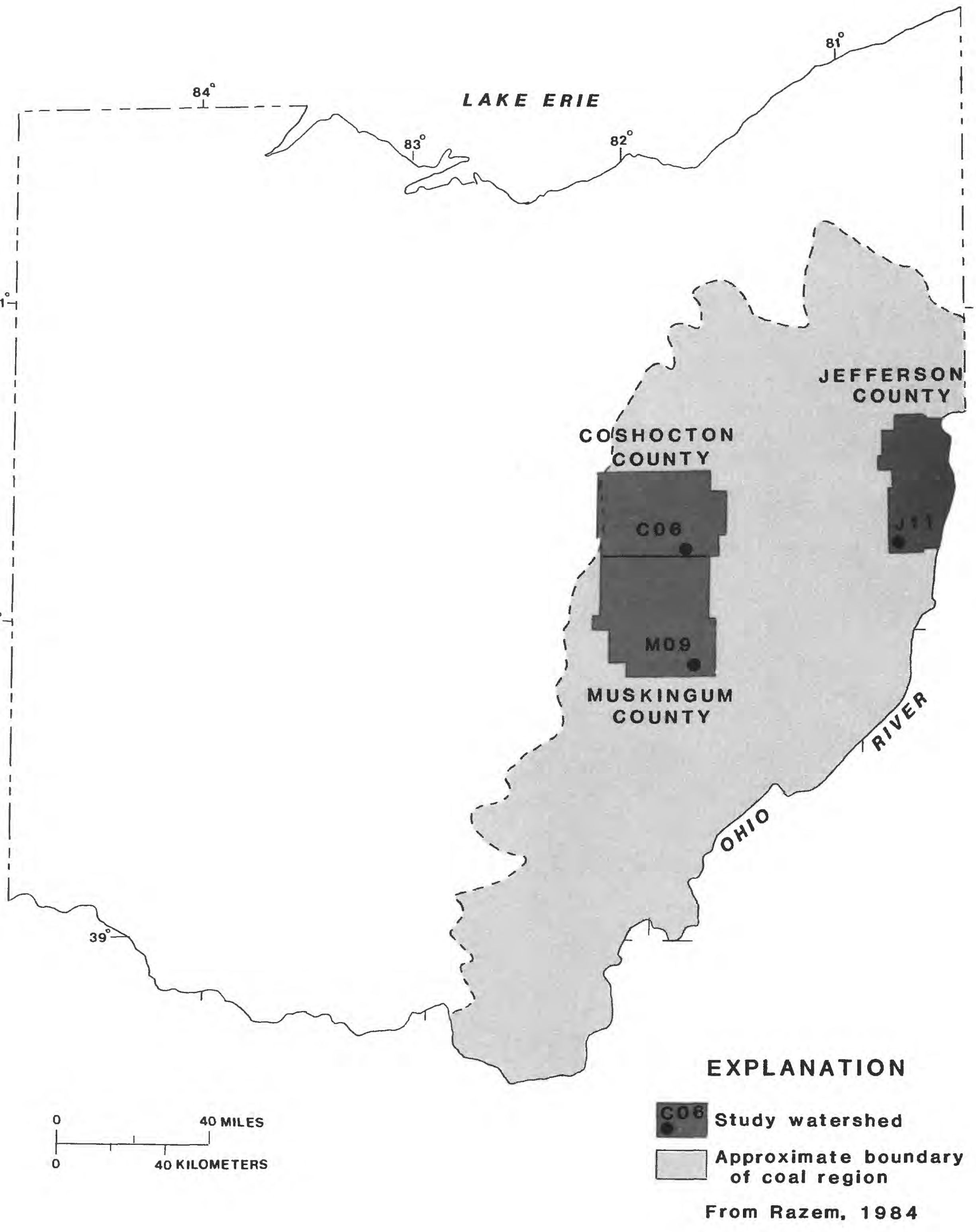


Figure 2.--Location of study watersheds and Ohio's coal region.

Table 1.--Summary of selected physical characteristics and historical data for watersheds M09, C06, and J11

[Data from the U.S. Department of Agriculture, Agricultural Research Service]

	Watersheds		
	M09	C06	J11
Location:			
County	Muskingum	Coshocton	Jefferson
Township	Meigs	Linton	Mt. Pleasant
Section	17	22	34
Quadrangle[1]	Ruraldale	Plainfield	Dillonvale, Harrison-ville
Area (acres):			
Before mining	43	49	29
After reclamation	37	41	32
Relief (feet):			
Before mining	233	265	150
After reclamation	146	191	126
Date mining began	Jan. 1977	Nov. 1976	May 1980
Date reclamation was completed	Sept. 1978	Oct. 1978	June 1982
Period of data collection	June 1976-Jan. 1981	Jan. 1976-Jan. 1981	May 1977-June 1982

[1]U.S. Geological Survey 7.5-minute topographic map.

Data Collection

Ground-water data at the study sites were collected at observation wells that were installed before mining and at wells installed after reclamation to replace those destroyed by mining.[3] Each well was cased, sealed, and screened so that it was open to only one water-bearing zone.

Water levels in the wells were measured monthly. Selected wells were instrumented to record water levels several times a day. Hydraulic conductivities of the aquifers before and after mining were determined by slug tests or by single-well pumping tests.

Samples for water-quality analyses were collected from the observation wells before and after mining and reclamation. Samples were collected with a submersible pump if the well yield permitted, or with a plastic bailer otherwise. The well volumes were discharged several times and allowed to refill before samples were taken.

Data on physical properties and chemical constituents in ground water were obtained; these data have been summarized in terms of water types and in discussions of some of the more common physical properties and chemical constituents. The description of water types in this report is based on the cations (calcium, magnesium, and sodium) and anions (bicarbonate, chloride, and sulfate) that account for most dissolved constituents in the water.

[3]The number of wells at each watershed varied throughout the study, and ranged from 8 (after reclamation at C06) to 16 (after reclamation at M09).

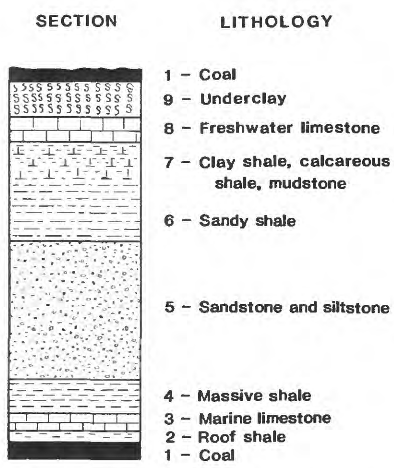


Figure 3.--Generalized stratigraphic column of sedimentary rocks between coal beds (from Brant and DeLong, 1960).

GROUND-WATER CONDITIONS AT THE STUDY WATERSHEDS

Conditions Before Mining and Reclamation

Physical Characteristics and Hydrology

Table 1 presents selected physical characteristics and historical data for the study watersheds. All three watersheds were drained by small streams before mining. In each watershed, relatively impermeable underclay beneath the major coal seams formed bases for local, perched aquifers above deeper, regional ground-water systems (fig. 4).

Before mining, the top aquifers were recharged by precipitation falling within the watershed. Water discharged from the top aquifers by evapotranspiration and by downward leakage through the underclay to deeper aquifers or by lateral movement and discharge to springs or seeps at the coal outcrops.

The middle aquifers were recharged by downward leakage through the overlying clay or by precipitation where the clay was absent; discharge was by downward leakage, evapotranspiration, or by flow into the streams.

In watersheds M09 and C06, the deep regional aquifers are recharged and discharged mainly outside the watershed. The deep regional aquifer under watershed J11 was drained by an underground mine that discharged downgradient from the watershed.

Ground-Water Quality

Ground water in the top and middle aquifers was predominantly calcium bicarbonate in type before mining and reclamation, but calcium sulfate and sodium bicarbonate types also were present. The water in these aquifers ranged from moderately hard to very hard.

Specific conductance--a general indicator of the concentration of dissolved minerals--was greater in the middle and deep regional aquifers than in the top aquifers. The increase in specific conductance with depth is typical of unmined watersheds in the study area. The deeper the ground water circulates, the older it tends to be; thus, the water generally has more contact time with rocks through which it passes than shallower water, and consequently has more time to dissolve minerals from the rocks.

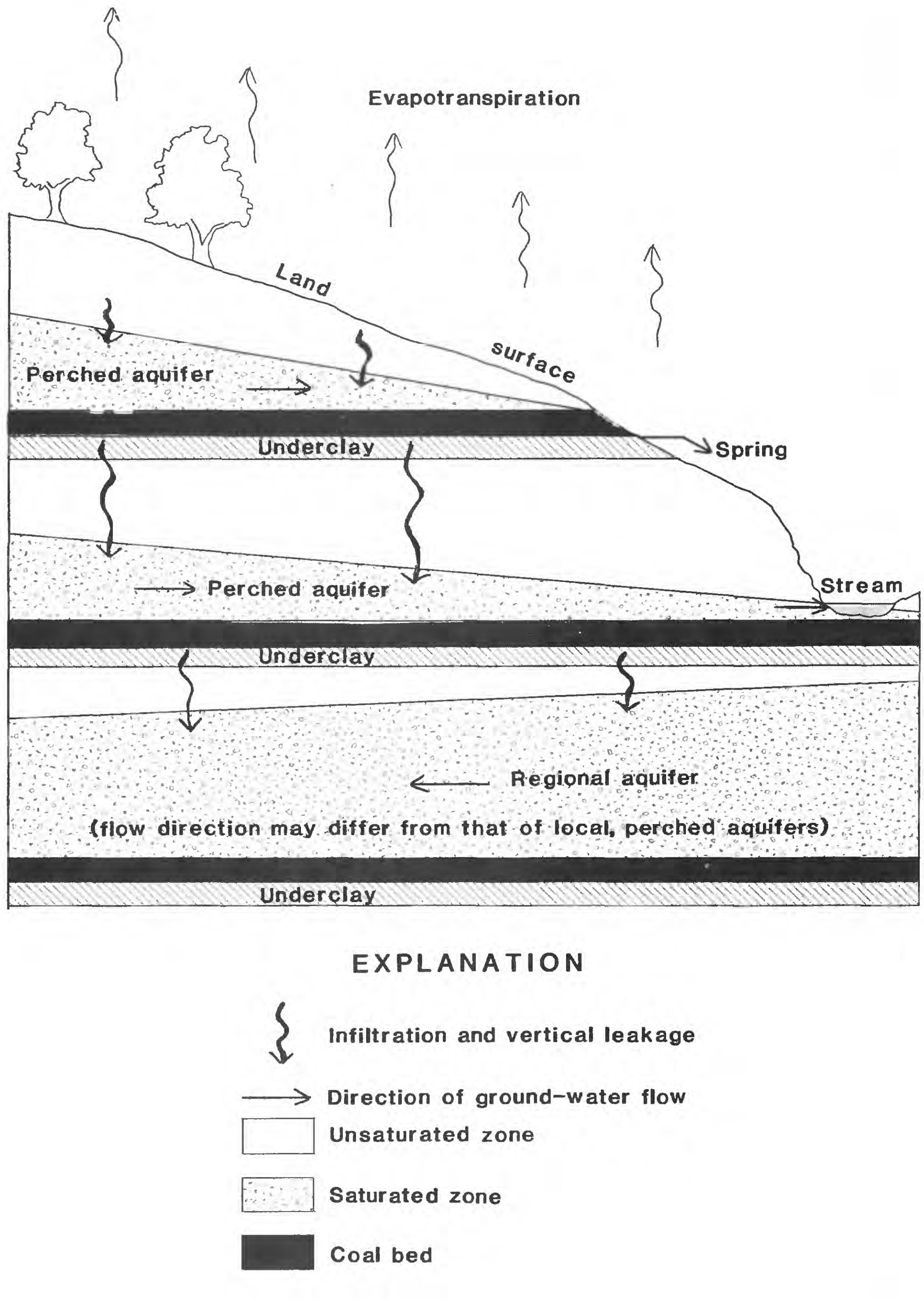


Figure 4.--Conceptual diagram of the ground-water flow system typically found in Ohio's coal region.

Conditions After Mining and Reclamation

Physical Characteristics and Hydrology

Surface mining in the watersheds involved removal of topsoil, blasting (to break up the overburden), removal of the overburden, and removal of coal. Reclamation began immediately after removal of coal, and involved replacement and grading of the spoils, replacement of topsoil, and revegetation.

During surface mining, the top aquifer in each study watershed was destroyed. During reclamation, spoils were returned to the mined-out area and graded to the approximate shape of the original land surface. The relief in all of the watersheds was reduced considerably (table 1). Because most of the underclay was kept intact during mining, perched aquifers are expected to become re-established in the spoils.

Many of the wells reinstalled in the spoils aquifers were dry at first; however, water-level data indicate that the spoils are slowly becoming resaturated. The destruction of the premining top aquifers removed the primary sources of base flow to the small streams draining the watersheds. As a result, stream base flow significantly decreased at watersheds M09 and C06, and ceased altogether at watershed J11.

In contrast, water levels in the middle aquifers remained the same or rose in places where the underclay below the spoils aquifer may have been inadvertently removed or disturbed (fig. 5). The water levels in the deep regional aquifers were not affected by mining activities.

Ground-Water Quality

As mentioned previously, the water in the top aquifers before mining was predominantly a calcium bicarbonate type, although some calcium sulfate-type water was present at watershed J11. Analyses of water from the spoils aquifers, however, indicate that much of the ground water has changed to a calcium sulfate type.

Water quality in the middle aquifers generally did not change, except for one area each in watersheds M09 and J11 where sulfate concentrations increased.

Dissolved minerals in the spoils and middle aquifers increased following mining and reclamation at all three watersheds (table 2, fig. 6). With the exception of the middle aquifer at C06, hardness increased at all three sites and was in the "very hard" range (greater than 180 milligrams per liter) by the end of data collection. The specific conductance of water in the spoils aquifers was about five times greater than that of the premining top aquifers at M09 and C06, and about 1 1/2 times greater at J11. In contrast, changes in specific conductance of water in the middle aquifers were slight at M09 and C06. The postreclamation specific conductance of water in the middle aquifer at J11 was about twice the premining value.

Concentrations of dissolved sulfate, iron, and manganese in the premining top aquifers generally did not exceed U.S. and Ohio Environmental Protection Agency drinking-water limits. After mining and reclamation, however, the limits generally were exceeded. In the middle aquifers, changes in concentration were less pronounced, and concentrations generally did not exceed drinking-water limits (table 2).

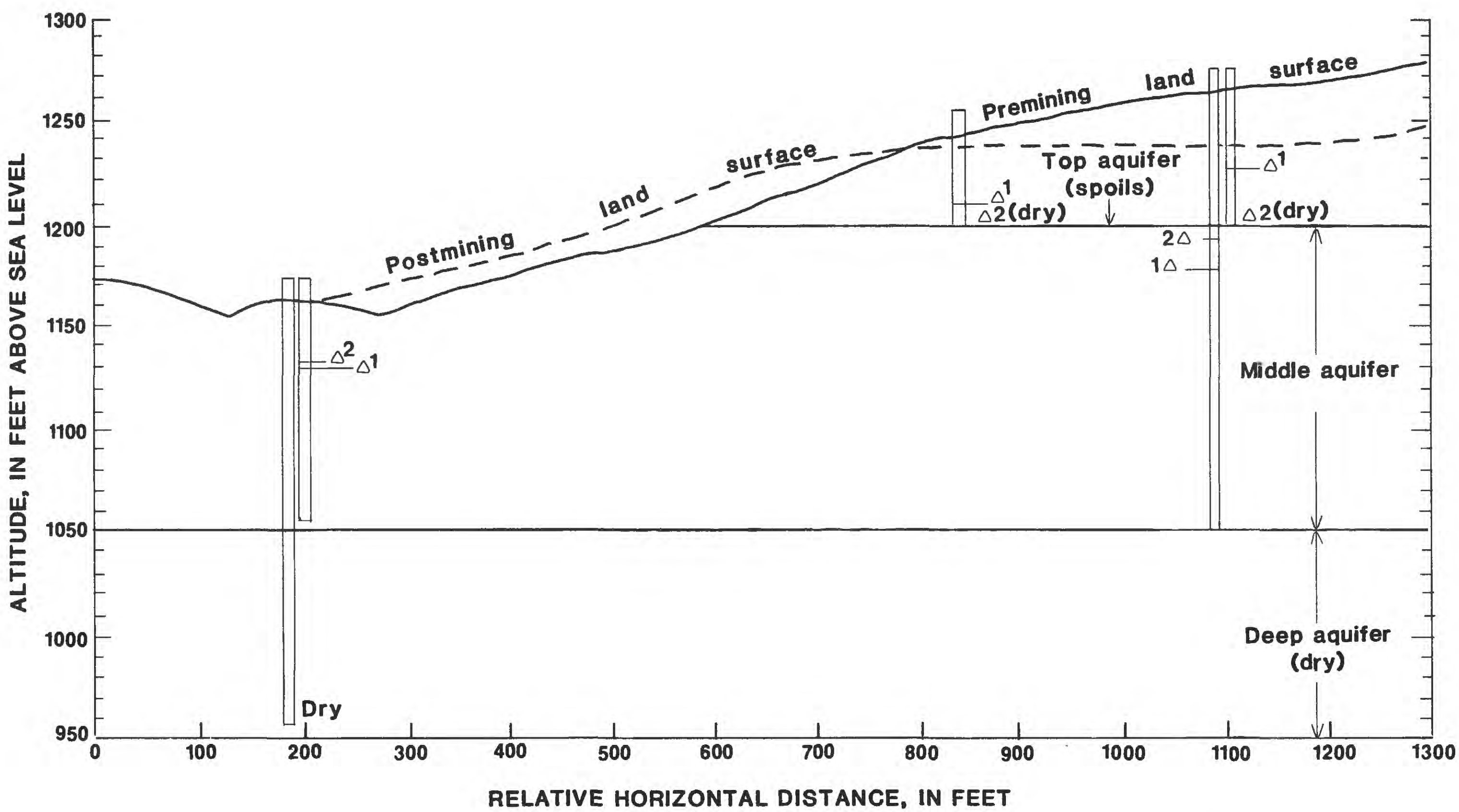
No water-quality changes were noted in the deep regional aquifers at watersheds M09 and C06.

SIGNIFICANCE OF RESULTS

The results of this study are significant primarily because they constitute some of the first data from surface-mined watersheds spanning the entire period from before mining to after reclamation. These data show how the hydrology and water quality of aquifer systems respond to such land-use changes, and provide evidence about subsurface conditions following reclamation.

Much of what has happened to water levels in the aquifers can be explained with reference to the underclay beneath the top aquifers. If the underclay beneath the mined coal bed remains intact, an unsaturated zone should continue to separate the aquifer developing in the spoils from the middle aquifer beneath it. The local rises in water levels in the middle aquifers in watersheds M09 and J11 probably are due to removal or damage of the underclay, which may have opened new conduits for downward leakage of ground water. How much of a hydraulic connecton eventually will develop between the spoils aquifers and the middle aquifers in these places is unknown because the postreclamation ground-water system is not yet in equilibrium.

Some of the changes in ground-water quality in the top aquifers are due to structural changes in top-aquifer materials. Mining and reclamation have converted large chunks of overburden rock to numerous small particles of spoils material. This results in more fresh surface area of rock being exposed to air and water within the new top aquifer. The weathering of these newly exposed surfaces results in higher concentrations of dissolved constituents in the spoils aquifer than in the premining top aquifer. This weathering also allows pyrite in the vicinity of the coal seam to react with the ground water and liberate sulfate ions, hence the trend toward calcium sulfate water type in these places.



EXPLANATION

▯ Well location

$\triangle^1$ Water level, May 20, 1980 (premining)

$\triangle^2$ Water level, October 17, 1980 (postreclamation)

Modified from Razem, 1984

Figure 5.--Hydrogeologic section showing changes resulting from surface mining at watershed J11.

Table 2.--Comparison of ground-water quality before and after mining and reclamation at watersheds M09, C06, and J11

[Drinking-water limits from U.S. Environmental Protection Agency (1976), unless otherwise noted. Data from U.S. Geological Survey (1979-83) and Razem (1983, 1984)]

Property or constituent	Drinking-water limit	M09 Before	M09 After	C06 Before	C06 After	J11 Before	J11 After
		Median[1] concentration or other measurement before mining (top aquifer) and after reclamation (spoils aquifer)					
Specific conductance (µS/cm)	1,200[2]	545	2,950	288	1,600	550	716
pH	5.0-9.0	7.6	6.8	6.8	6.5	7.0	6.8
Hardness (mg/L)	[none]	315	2,000	115	820	270	335
Sulfate, dissolved (mg/L)	250[2]	40	1,500	36	320	84	200
Solids, dissolved[2] (mg/L)	750[2]	--	2,580	--	1,060	335	405
Iron, dissolved (µg/L)	300	40	3,400	130	32,000	30	150
Manganese, dissolved (µg/L)	50	20	2,300	140	1,000	30	400
		Median[3] concentration or other measurement for middle aquifer before mining and after reclamation					
Specific conductance (µS/cm)	1,200[2]	796	946	600	590	680	1,180
pH	5.0-9.0	7.8	7.6	7.2	6.8	7.5	7.0
Hardness (mg/L)	[none]	100	210	190	180	250	640
Sulfate, dissolved (mg/L)	250[2]	36	64	48	31	47	190
Solids, dissolved[2] (mg/L)	750[2]	--	628	--	340	405	770
Iron, dissolved (µg/L)	300	40	140	930	1,100	10	18
Manganese, dissolved (µg/L)	50	20	60	270	665	10	220

[1]Number of samples on which medians are based are as follows. Before mining: M09, 12; C06, 18; J11, 35. After reclamation: M09, 9; C06, 5; J11, 14.

[2]Ohio Environmental Protection Agency (1978) water-quality standards for public water supply.

[3]Number of samples on which medians are based are as follows. Before mining: M09, 14; C06, 9; J11, 30. After reclamation: M09, 43; C06, 28; J11, 10.

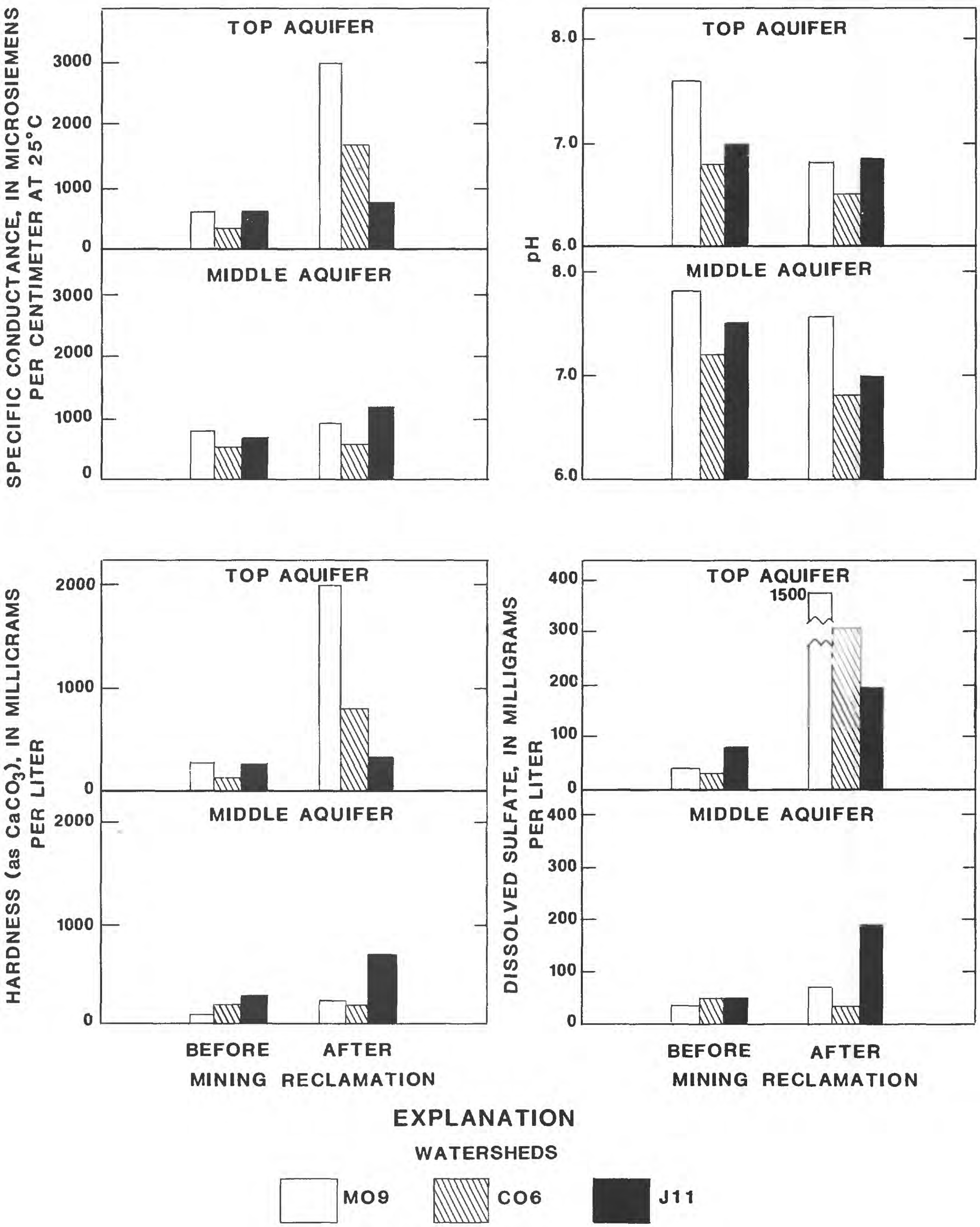


Figure 6.—Median values for selected properties and constituents before mining and after reclamation of the study watersheds (data are presented in table 2)

The underclay layers between the top and middle aquifers appear to have an "insulating" effect on water quality in the middle aquifers. The underclay retards downward leakage of highly mineralized water from the overlying spoils aquifers into the middle aquifers. Thus, water-quality changes in the middle aquifers generally have been less pronounced compared with changes in the top aquifers.

The hydrologic studies at these watersheds do not provide data that would show the effects of mining and reclamation on drinking-water supplies in the vicinity of the sites. All observation wells used were either within or very close to watershed boundaries.

The studies also do not provide sufficient information to predict when water levels and ground-water quality will stabilize. The hydrologic systems at these watersheds took thousands of years to develop; data collected 1 or 2 years after reclamation can only hint at what the final postreclamation water levels and water quality will be. For example, a short-term followup study at watershed J11 was conducted by the U.S. Geological Survey to analyze water samples collected from wells in January and May 1984 (approximately 4 years after mining ended). Results of these analyses indicate that ground water still is becoming more mineralized in the top and middle aquifers. Rates of water-quality change differ considerably throughout the aquifers, however. The places in the middle aquifer where more rapid changes in water quality are taking place may be affected by downward leakage from the top aquifer, but data are insufficient to confirm this possibility (Janet Hren, U.S. Geological Survey, oral commun., 1984).

The documentation of hydrologic changes at watersheds M09, C06, and J11 serves as a basis for comparison with other, similar studies in the Eastern Coal Province and in other areas of the United States. The results of these studies also should be useful to hydrologists and regulatory officials for determining the probable hydrologic consequences of surface mining and reclamation on the ground-water systems of small watersheds.

SELECTED REFERENCES

Brant, R. A., and DeLong, R. M., 1960, Coal resources of Ohio: Ohio Department of Natural Resources, Division of Geological Survey Bulletin 58, 245 p.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Professional Paper 1812, p. 27

Engelke, M. J., Jr., Roth, D. K., and others, 1981, Hydrology of area 7, Eastern Coal Province: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-815, 60 p.

Fenneman, N. M., 1938, Physiography of eastern United States: New York, McGraw-Hill, 714 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water, 2d ed.: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Norris, S. E., 1969, The ground-water situation in Ohio: Ground Water, v. 7, no. 5, p. 25-33.

Ohio Department of Natural Resources, 1978, Southeast Ohio water plan: 517 p.

Ohio Environmental Protection Agency, 1978, Water quality standards: chap. 3745.1 of the Ohio administrative code, 117 p.

Razem, A. C., 1983, Ground-water hydrology before, during, and after coal strip mining of a small watershed in Coshocton County, Ohio: U.S. Geological Survey Water-Resources Investigations Report 83-4155, 36 p.

-----, 1984, Ground-water hydrology and quality before, and after strip mining of a small watershed in Jefferson County, Ohio: U.S. Geological Survey Water-Resources Investigations Report 83-4215, 39 p.

Roth, D. K., Engelke, M. J., Jr., and others, 1981, Hydrology of area 4, Eastern Coal Province: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-343, 62 p.

U.S. Bureau of Mines, 1978, Research on the hydrology and water quality of watersheds subjected to surface mining; phase 1, premining hydrology and water quality conditions: U.S. Bureau of Mines Open-File Report 88-80, 347 p.

----- 1979, Research on the hydrology and water quality of watersheds subjected to surface mining; phase 1, premining hydrology and water quality conditions--Summary report: U.S. Bureau of Mines Open-File Report 31-80, 40 p.

U.S. Bureau of the Census, 1984, Statistical abstract of the United States, 105th ed.: Washington, p. 728.

U.S. Geological Survey, 1979, Water resources data--Ohio, water year 1978: v. 1, p. 347-70.

----- 1980, Water resources data--Ohio, water year 1979: v. 1, p. 433-83.

----- 1981, Water resources data--Ohio, water year 1980: v. 1, p. 509-71.

----- 1982, Water resources data--Ohio, water year 1981: v. 2, p. 179-232.

----- 1983, Water resources data--Ohio, water year 1982: v. 2, p. 149-66.

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

GLOSSARY

Anion is a negatively charged atom or group of atoms.

Aquifer is a part of the subsurface environment containing saturated permeable material that will yield water to wells or springs.

Base flow refers to the sustained or "fair weather" flow of streams, as opposed to the high flows associated with storm runoff; base flow is supplied primarily by ground water in most streams.

Cation is a positively charged atom or group of atoms.

Evapotranspiration is the withdrawal of water from the earth's surface by evaporation from soil and bodies of water, and by transpiration from plants.

Hardness is a property of water that is attributed to the presence of calcium, magnesium, and other alkaline-earth metals. The most noticeable characteristics of hard water are that soap does not lather readily and that scale deposits tend to form in hot-water systems. Durfor and Becker (1964) use the following classifications for hardness:

Hardness range (mg/L as $CaCO_3$)	Description
0-60..........	Soft
61-120.........	Moderately hard
121-180........	Hard
More than 180..	Very hard

Hydraulic conductivity is the movement of a volume of ground water (measured at right angles to the direction of flow) under a unit hydraulic gradient through a unit area. It is often expressed in units of feet per day or meters per day.

Median is the middle value in a series of ranked data; that is, there are an equal number of values greater than and less than the median.

Overburden is soil and rock material above a coal seam.

Perched aquifer is an aquifer separated from an underlying body of ground water by an unsaturated zone; its base is a zone of low permeability that retards downward migration of water.

pH is a scale commonly used to express the degree of acidity or alkalinity of a solution; pH of 7 is the point of neutrality at which there is neither acidity nor alkalinity. As acidity increases, the pH value decreases, and as alkalinity increases the pH value increases. In technical terms, it the negative logarithm (base 10) of the hydrogen-ion activity, in moles per liter.

Recharge is the addition of water to an aquifer.

Single-well pumping test is a test in which a well is pumped and water-level decline in the well is recorded during and after the pumping period in order to determine the hydraulic characteristics of the aquifer in the well's vicinity.

Slug test is a test in which a measured amount of water is poured into a well and water-level changes in the well are subsequently measured in order to determine the hydraulic characteristics of the aquifer in the well's vicinity.

Specific conductance, a measure of the ability of water to conduct an electrical current, is an index of dissolved mineral content. Generally, it is reported in units of microsiemens per centimeter at 25° Celsius.

Spoils are soil and broken-up rock material removed from above a coal seam; drastically disturbed overburden.

Underclay is clay or other fine material forming the base of a coal bed. Underclay often contains the fossilized roots of the plants forming coal.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1986 - 647-320/21715