

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 118

**ABANDONED SUBSURFACE COAL MINES
AS A SOURCE OF WATER FOR
COAL CONVERSION IN EASTERN OHIO**

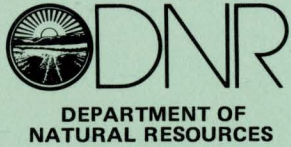
by

Thomas M. Crouch

Horace R. Collins

John O. Helgesen

Columbus
1980



SCIENTIFIC AND TECHNICAL STAFF
OF THE
DIVISION OF GEOLOGICAL SURVEY

ADMINISTRATION

Horace R. Collins, MS, *State Geologist and Division Chief*
Richard A. Struble, PhD, *Geologist and Assistant Chief*

William J. Buschman, Jr., BS, *Administrative Geologist*
Barbara J. Adams, *Office Manager*

REGIONAL GEOLOGY

Robert G. Van Horn, MS, *Geologist and Section Head*
Richard W. Carlton, PhD, *Geologist*
Douglas L. Crowell, MS, *Geologist*
Richard M. DeLong, MS, *Geologist*
Michael C. Hansen, MS, *Geologist*
David A. Hodges, MS, *Geologist*
Dennis N. Hull, MS, *Geologist*
Michele L. Risser, BA, *Geologist*
Clark L. Scheerens, MS, *Geologist*
Joel D. Vormelker, MS, *Geologist*
Beverly A. Leffler, *Public Inquiries Assistant*

SUBSURFACE GEOLOGY

John D. Gray, MS, *Geologist/Acting Section Head*
Allan T. Luczyk, BS, *Environmental Technician*
David A. Nicklaus, BS, *Geology Technician*
James Wooten, *Geology Technician*
Garry E. Yates, *Environmental Technician*
Angelena M. Bailey, *Secretary*
Brenda L. Rinderle, *Office Machine Operator*
Linda F. Tanks, *Technical Typist*

PUBLIC SERVICE

Madge R. Fitak, BS, *Geologist and Supervisor*
Michael S. Temple, BS, *Geologist*
Inalee E. Johnson, *Public Inquiries Assistant*
Rose Lehman, *Technical Typist*
Billie Wilder, *Account Clerk*

GEOCHEMISTRY LABORATORY

David A. Stith, MS, *Geologist and Section Head*
George Botoman, MS, *Geologist*
Norman F. Knapp, PhD, *Chemist*
Cynthia M. Bowman, *Laboratory Technician*
Rodney D. Fritz, *Laboratory Technician*
Richard C. Guimond, BS, *Environmental Technician*
Evelyn M. Jennings, *Laboratory Technician*

LAKE ERIE

Charles H. Carter, PhD, *Geologist and Section Head*
Jonathan A. Fuller, MS, *Geologist*
Donald E. Guy, Jr., BA, *Geologist*
Carl L. Hopfinger, MS, *Geology Technician*
Dale L. Liebenthal, *Research Vessel Operator*
Marlene S. Longer, *Typist*

TECHNICAL PUBLICATIONS

Cartography
Philip J. Celnar, BFA, *Cartography Supervisor*
James A. Brown, *Cartographer*
Leonard M. Guckenheimer, BA, *Cartographer*
Douglas E. Keen, BA, *Cartographer*
James T. Lowery, *Cartographer*
Victor J. Saylor, BA, *Cartographer*
Robert L. Stewart, *Cartographer*
Adam Turk, MS, *Cartographer*
Marie A. Whitenack, BA, *Cartographer*
Photocopy Composition
Jean M. Leshner, *Printing Technician*
Technical Editing
Merriane Hackathorn, MS, *Geologist/Editor*
Karen J. Van Buskirk, BA, *Publication Specialist*

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 118

**ABANDONED SUBSURFACE COAL MINES
AS A SOURCE OF WATER FOR
COAL CONVERSION IN EASTERN OHIO**

by

Thomas M. Crouch
Horace R. Collins
John O. Helgesen

Columbus
1980



Photocopy composer: Jean M. Leshner
Cartographer: Leonard M. Guckenheimer

CONTENTS

	Page		Page
Abstract	1	Location and preparation	12
Introduction	1	Description of test	14
Background	1	Adjustments to drawdown data	15
Purpose and scope	1	Response of system	17
Location and description of area	2	Water-level response	17
Methods of investigation	2	Sources of pumped water	17
Acknowledgments	2	Water-quality variations	21
Geology and mining history	3	Test 2 (Klondyke No. 1 mine)	21
Regional setting	3	Location and description of test	21
Local setting	5	Response of system	22
Mining history	7	Suitability of the mines as a water source	23
Mine hydrology	9	Practical sustained yield	23
Ground-water occurrence	9	Water-quality variability	24
Water-level fluctuations	9	Supplemental surface-water supply	24
Flow system	9	Availability	24
Water quality	12	Water quality	25
Pumping tests	12	Conclusions	25
Test 1 (Buffalo mine)	12	References cited	25

FIGURES

1. Map showing location of study area	3	15. Map showing mine-system drawdowns after 29 days of pumping at 2,000 gal/min (pumping test 1)	16
2. Map showing mines in the study area	4	16. Graph of mine-system drawdown during pumping test 1	17
3. Generalized stratigraphic column of principal units cropping out in Guernsey County, Ohio ..	5	17. Graph of drawdown versus distance from pumping well in test 1	18
4. Map showing contours on the Upper Freeport (No. 7) coal in study area	6	18. Arithmetic graph of drawdown versus time for wells GU-104 and GU-7	18
5. Map showing idealized double-entry room-and-pillar mine layout	7	19. Semilogarithmic graph of drawdown versus time for wells GU-104 and GU-7	19
6. Map showing approximate mine potentiometric elevations, September 12-13, 1978 (prepumping), and locations of observation sites	8	20. Logarithmic graph of drawdown versus time for wells GU-104 and GU-7	19
7. Hydrograph for well GU-1010 (west of study area) and precipitation during 1978	10	21. Graphical relationship between volume of displacement of potentiometric surface and volume of water pumped in test 1	20
8. Hydrographs for wells GU-7 and GU-104	10	22. Graphical comparison between composite time-drawdown curve from pumping test 1 and a hypothetical curve which assumes all pumped water is derived from artesian storage	21
9. Hydrographs for wells GU-4 and GU-6	11	23. Graphs of water-quality variations of pumped water during test 1	22
10. Hydrograph for well GU-1010	11	24. Schematic diagram illustrating probable effects of pumping water from mine system	23
11. Generalized section illustrating relationship between the mine zone, its potentiometric surface, and the water table	12	25. Graph of draft-storage relations for two gaging stations near the study area	24
12. Map showing location, method of collection, water type, and dissolved-solids concentration of mine-water samples	13		
13. Graph of variation of specific conductance with depth in selected observation wells	14		
14. Graphs of seasonal water-level trend and precipitation before, during, and after pumping test 1 ..	15		

TABLES

1. Coal and water requirements for coal-conversion facilities	2	4. Test-well and pump data	15
2. Coal thickness, mine areas, and coal-recovery estimates for mines in the study area	5	5. Ranges and medians of selected parameters in water from two gaging stations near the study area	24
3. Chemical analyses of mine water	14	6. Suspended-sediment concentrations	25

ABANDONED SUBSURFACE COAL MINES AS A SOURCE OF WATER FOR COAL CONVERSION IN EASTERN OHIO

by

Thomas M. Crouch¹
Horace R. Collins²
John O. Helgesen¹

ABSTRACT

Subsurface coal mines are a potential source of water of special importance in a region where ground-water supplies are meager. A study of a 17-square-mile network of mines in Guernsey County, Ohio, was made to determine its water-supply potential for coal conversion, a possible industrial use of water in the area. The mines are in the Upper Freeport (No. 7) coal and contain water under artesian pressure. Most recharge is from local precipitation, and most discharge is to Wills Creek along the western edge of the mined area.

Test pumping at 2,000 gallons of water per minute for 29 days showed that most mines are interconnected. Most pumped water was derived either from intercepted discharge or from increased leakage from overlying rocks. Practical sustained yield is estimated at 1,500 to 2,500 gallons per minute.

Much of the water has dissolved-solids concentration less than 2,000 milligrams per liter and pH near 7.0. Iron and manganese concentrations are generally high, and brackish water is present in some parts of the mine system. During pumping, dissolved-solids concentration of pumped water increased gradually. Substantial long-term changes in the quality of pumped water probably would not occur.

INTRODUCTION

BACKGROUND

Water for cooling and other plant uses is required in large quantities in many coal-conversion processes. Table 1 lists water and coal requirements for commercial-scale coal-conversion facilities using existing or anticipated technology. From 5,100 to 22,000 gal/min³ will be needed to produce 250 x 10⁶ standard cubic feet of high-Btu gas per

day. High-Btu gas is used in home and commercial heating, and production of this magnitude would be roughly equivalent to 10 percent of Ohio's 1977 natural-gas use. Daily water requirements for an operation of this scale are sufficiently large to seriously reduce the number of areas in Ohio suitable for coal-conversion plants. The number of sites is even smaller when considering the proximity of major coal reserves. The cost of obtaining energy through coal conversion dictates that plants be sited where both water and coal are available.

Coal is Ohio's most abundant energy source, and the state is the largest consumer of coal in the nation. Ohio coal tends to be high in sulfur, and air-quality standards mandated over the past several years have seriously jeopardized the conventional use of Ohio's large coal reserves. The conversion of coal into low-sulfur methane or synthetic crude oil seems to offer considerable advantages in that pollutants can be more readily controlled; gas and oil, which are in short supply, would become more plentiful; and Ohio's largest energy resource could be utilized. Because little if any consideration has been given to the possibility of using water from abandoned coal mines for coal-conversion plants, the Ohio Department of Natural Resources, Division of Geological Survey proposed the present study. The project was partially funded by the Ohio Department of Energy under Contract No. 77-11.

PURPOSE AND SCOPE

The purpose of this study was to investigate the water-supply potential of abandoned underground mines in

¹U.S. Geological Survey, Water Resources Division, Columbus, Ohio.

²Ohio Department of Natural Resources, Division of Geological Survey.

³For the convenience of those readers who prefer to use International System (metric) units rather than U.S. customary units, the conversion factors for terms used in this report are listed below:

To convert from	to	multiply by
inches (in)	millimeters (mm)	25.4
feet (ft)	meters (m)	0.3048
miles (mi)	kilometers (km)	1.609
square feet (ft ²)	square meters (m ²)	0.0929
square miles (mi ²)	square kilometers (km ²)	2.590
gallons per minute (gal/min)	liters per second (l/s)	0.06309
cubic feet per second (ft ³ /s)	cubic meters per second (m ³ /s)	0.02832
cubic feet per minute (ft ³ /min)	cubic meters per minute (m ³ /min)	0.02832
cubic feet per second per square mile (ft ³ /s/mi ²)	cubic meters per second per square kilometer (m ³ /s/km ²)	0.01093
tons (short) (t)	metric tons (t)	0.9072
British thermal units per pound (Btu/lb)	joules per kilogram (J/kg)	474.75

TABLE 1.—Coal and water requirements for coal conversion facilities¹

Type of plant	Thermal efficiency (%) ²	Coal ²		Water		
		Tons/day	Tons/10 ⁶ Btu	Gal/min	Tons/day	Tons/10 ⁶ Btu
Electricity 1,000 MW (8.19 x 10 ¹⁰ Btu/day)	35	9,000-14,700	1.11 x 10 ⁻¹ - 1.78 x 10 ⁻¹	41,500 ⁴	24,900	3.08
High-Btu gas ⁵ 250 x 10 ⁶ scfd	65	13,400-21,600	6 x 10 ⁻² - 9.3 x 10 ⁻²	5,100-22,000	30,600-132,000	1.36 x 10 ⁻¹ - 5.85 x 10 ⁻¹
Low-Btu gas ⁶ 525 x 10 ⁶ scfd	72	3,120-5,010	5.31 x 10 ⁻² - 8.6 x 10 ⁻²	2,350	14,100	2.42 x 10 ⁻¹
Low-Btu gas ⁷ 290 x 10 ⁶ scfd	72	4,680-7,700	5.31 x 10 ⁻² - 8.6 x 10 ⁻²	3,150	18,900	2.15 x 10 ⁻¹
Synthetic crude oil ⁸ 26 x 10 ³ bbls/day + Low-Btu gas ⁹ 1.33 x 10 ⁹ scfd	72	23,500-37,550	5.31 x 10 ⁻² - 8.6 x 10 ⁻²	12,650	75,800	1.74 x 10 ⁻¹

¹ From Stout (1974).

² Knowing the product (in terms of Btu/day), coal requirements are calculated based on 8,000-Btu/lb and 13,000-Btu/lb coals.

³ A typical value for thermal efficiency is assigned.

⁴ Based on an increase of 15° F for cooling water discharge.

⁵ Quality of gas = 950 Btu/scf (standard cubic feet).

⁶ Quality of gas = 110 Btu/scf (using air).

⁷ Quality of gas = 303 Btu/scf (using oxygen).

⁸ Based on COED (Char Oil Energy Development) process. Quality of crude = 5.8 x 10⁶ Btu/bbl.

⁹ Quality of gas = 215 Btu/scf (pyrolysis, off-gas of 510 Btu/scf is combined with 120 Btu/scf gas from char gasification).

the Upper Freeport (No. 7) coal in a portion of the Cambridge Coal Field in Guernsey County, Ohio. Specific objectives were to (1) determine quantity and quality of water in the mines, degree of mine interconnection, and natural recharge; (2) determine response of the system to pumping and degree of hydraulic connection between Wills Creek and the mines; (3) estimate practical sustained yield available from the mines; and (4) determine availability and quality of water from Wills Creek below Senecaville Reservoir as a possible source for artificial recharge. Additionally, study procedures and results should be useful in future mine-hydrology investigations.

LOCATION AND DESCRIPTION OF AREA

The study area (figs. 1 and 2) is in Guernsey County and includes portions of Cambridge, Center, Jackson, Richland, and Valley Townships. The area is bounded on the north by I-70 and Ohio Route 265, on the east by Ohio Route 285, on the south by Ohio Route 313, and on the west by I-77. Cambridge, the principal city in Guernsey County, is located approximately 5 miles northwest of the area. There are 14 mines within the area that collectively underlie approximately 16.7 mi² (table 2 and fig. 2).

Several considerations were taken into account in the selection of a study area, and that portion of the Cambridge Coal Field chosen for study met the selection criteria. In order for a mine or group of mines to have a large trapped water supply, the mine or mines must be essentially below regional drainage. Mines that have portions of their void areas not filled with water have a greatly increased potential for poor water quality because of oxidation of pyrite in the rooms exposed to the atmosphere. Sulfur-content level, particularly pyritic sulfur, should be as low as possible. The number of individual mines in Ohio meeting the foregoing requirement is high, but areas having a large number of mines in proximity that meet this requirement are few. Sites should be located reasonably close to coal resources suitable for conversion. Mines meeting this requirement are fewer

still. Regional structure favorable to the formation of a high potential head was another factor considered to be important. Considerations not related to the geology include (1) large labor force in area, (2) good transportation net, (3) building sites, and (4) supporting industries.

METHODS OF INVESTIGATION

The study was made during a 2-year period beginning in January 1977. A 1:24,000-scale map of the mine complex was prepared from larger scale maps of individual mines. Descriptions of stratigraphy and mine history were obtained from available literature and mine maps. Well records provided preliminary information on the hydrogeology.

Forty observation wells were drilled by the air-rotary method and cased to sound bedrock. Although wells were not cased to mine rooms, water levels of wells completed in rooms closely approximate mine-water heads because shallower contributing zones are extremely less transmissive. Water levels were also observed in several privately owned wells and surface ponds. Monitoring of water levels was by periodic measurement, digital recorder, or chart recorder. Elevations of nearly all water-level observation sites were determined by surveying, but, because of inaccurately known reference-point elevations, the determined site elevations could be in error by up to 0.5 foot. Pumping tests were made at two sites.

Ground-water samples for chemical analysis were collected from 13 wells. Variation of specific conductance and temperature with depth was determined in 18 wells. Suspended-sediment concentrations of larger streams in the study area were determined at various discharge rates.

ACKNOWLEDGMENTS

The authors are grateful for the cooperation of many landowners who granted permission for the drilling of wells and continuing access to their property for pumping and water-level measurements. The Ohio Department of Indus-

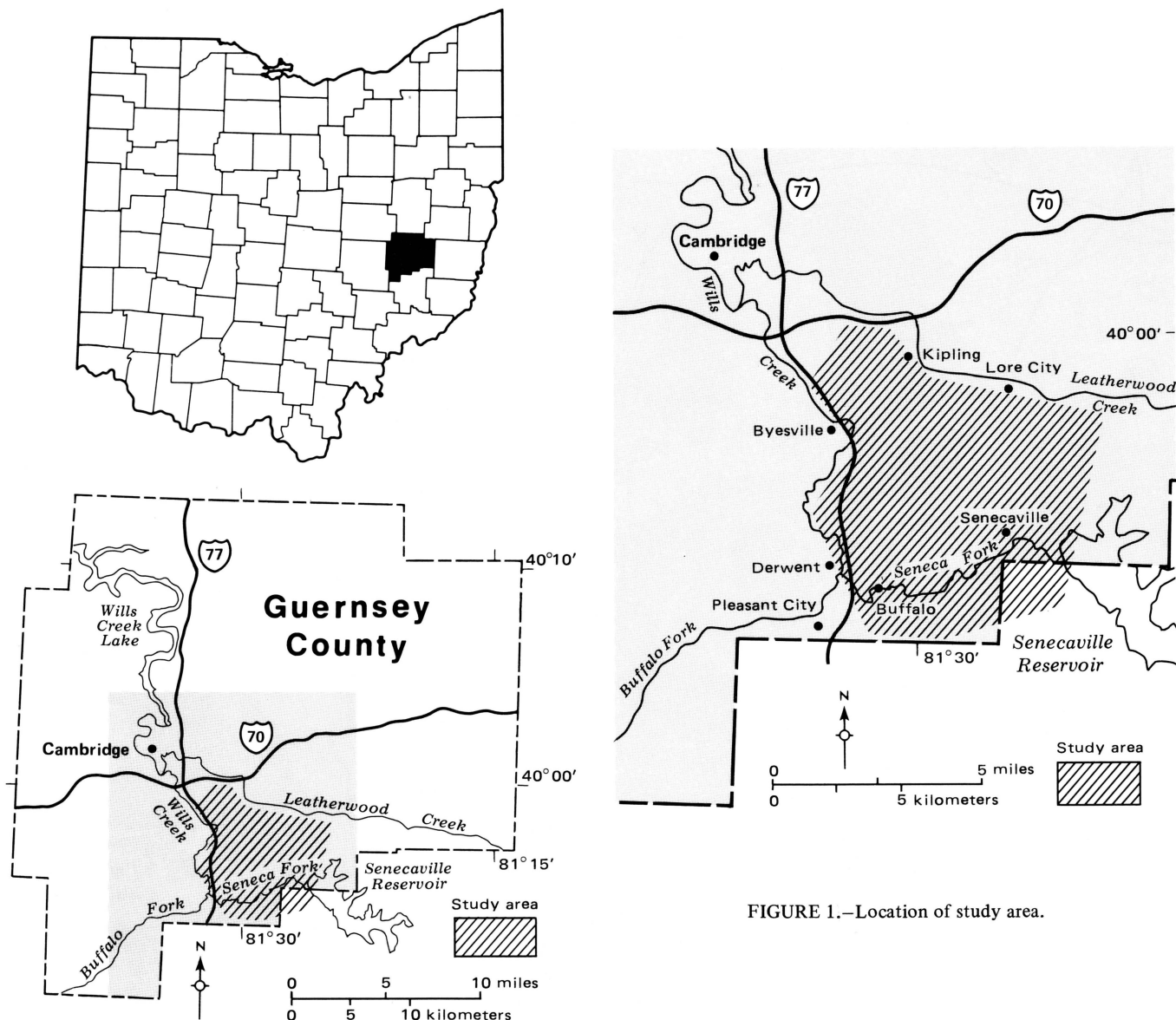


FIGURE 1.—Location of study area.

trial Relations, Division of Mines made mine maps available, and the Ohio Department of Natural Resources, Division of Water supplied well records. Michele L. Risser, Ohio Department of Natural Resources, Division of Geological Survey, determined locations of wells in the formative stage of the project. Community officials provided information on the Byesville and Cambridge water-supply systems. Engineers of the Muskingum Watershed Conservancy District and U.S. Army, Corps of Engineers cooperated by increasing the outflow from Senecaville Reservoir during one of the pumping tests.

GEOLOGY AND MINING HISTORY

REGIONAL SETTING

Guernsey County is in the Unglaciated Allegheny

Plateau. Pennsylvanian rocks about 650 feet thick, ranging stratigraphically from the Lower Kittanning (No. 5) coal in the Allegheny Group to the Meigs Creek (No. 9) coal in the Monongahela Group, crop out in Guernsey County (fig. 3). Allegheny rocks are exposed only in the valleys of Wills Creek and its tributaries in the western half of the county; Monongahela rocks are confined to the higher hills in the easternmost part. Most surface rocks of the county belong to the Conemaugh Group.

Structurally, Guernsey County is on the northwestern flank of the northern Appalachian Basin. Regional dip is southeast at about 30 feet per mile. The Cambridge arch trends northwest-southeast across the western side of the county. This structure has been considered an anticline, as its name implies; however, Clifford and Collins (1974) suggest that the "arch" may in fact be a tear fault on the west side of a block of supra-Salina rocks that has moved on the Salina E salt.

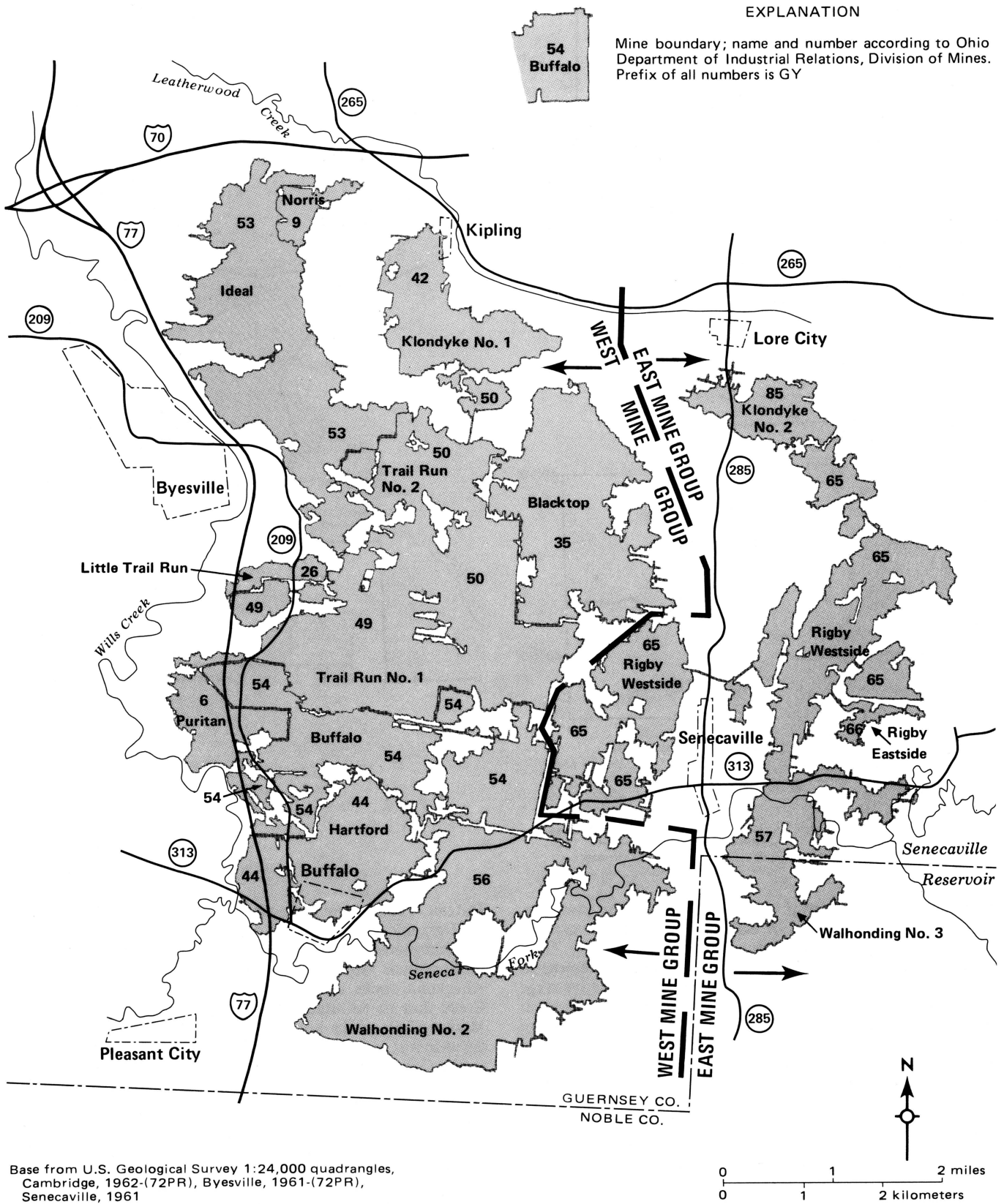


FIGURE 2.—Mines in the study area.

TABLE 2.—Coal thickness, mine areas, and coal-recovery estimates for mines in the study area

Mine name	Mine number ¹	Approximate thickness (ft)	Area (mi ²) ²	Percent mined ³	Reservoir volume (x 10 ⁶ ft ³)
West mines:					
Blacktop	35	4.5	1.54	60	116
Buffalo	54	5.5	1.49	55	95
Hartford	44	5.5	0.98	70	105
Ideal ⁴	53	5.0	1.94	65	172
Klondyke No. 1	42	4.0	0.78	60	99
East mines:					
Norris	9	5.0	0.16	50	14
Puritan	6	5.0	0.41	65	37
Trail Run Nos. 1 and 2 ⁵	49, 50	4.5	3.22	55	222
Walhonding No. 2	56	5.5	2.65	45	183
Klondyke No. 2	85	3.5	0.36	45	16
Rigby Eastside	66	3.5	0.08	50	5
Rigby Westside	65	4.5	2.30	50	119
Walhonding No. 3	57	4.5	0.82	60	60

¹ Assigned by the Ohio Department of Industrial Relations, Division of Mines. Prefix for all numbers is GY.
² Includes rooms and pillars of mined areas.
³ Estimated.
⁴ Includes two small mines—Sugar Point (No. 17) and West Branch (No. 22).
⁵ Trail Run Nos. 1 and 2 could not be separated on the mine map. Also includes Little Trail Run mine (No. 26).

LOCAL SETTING

The surface rocks in the study area are entirely within the Conemaugh Group. The Conemaugh, the thickest of the four groups composing the Pennsylvanian System in Ohio, averages about 425 feet thick in Guernsey County and consists of a repetitive sequence of thick sandstones, mudstones, and sandy shales and thin coals, clays, and marine and nonmarine limestones. Marine units are present only in the lower half of the group (fig. 3). A conspicuous color change in the Pennsylvanian System in Ohio occurs in the lower part of the Conemaugh. Red, purple, and reddish-brown mudstones are quite common above the Mahoning coal, whereas argillaceous units in the underlying Allegheny and Pottsville Groups are shades of gray. The appearance of red beds near the base of the Conemaugh has been used as an approximate boundary between the Conemaugh and Allegheny where the Upper Freeport coal is absent. The more or less subdued topography of the area is largely related to the presence of incompetent mudstone units, which slump readily.

The Upper Freeport coal, the uppermost unit of the Allegheny Group, crops out east of Cambridge for 2 or 3 miles along Leatherwood Creek and southeast along Wills Creek to about Byesville. Upper Freeport coal has been strip mined on a small scale along the northern and northwestern edges of the study area. Coal elevation ranges from over 780 feet above sea level in the northwest part of the area to about 620 feet above sea level in the southeast (fig. 4).

Abrupt changes in thickness of the Upper Freeport coal are common in the Cambridge Field; Condit (1912, p. 176) described such changes as “characteristic.” Condit also noted that where the coal was of uniform thickness the mine top was generally shale, but where the thickness was variable

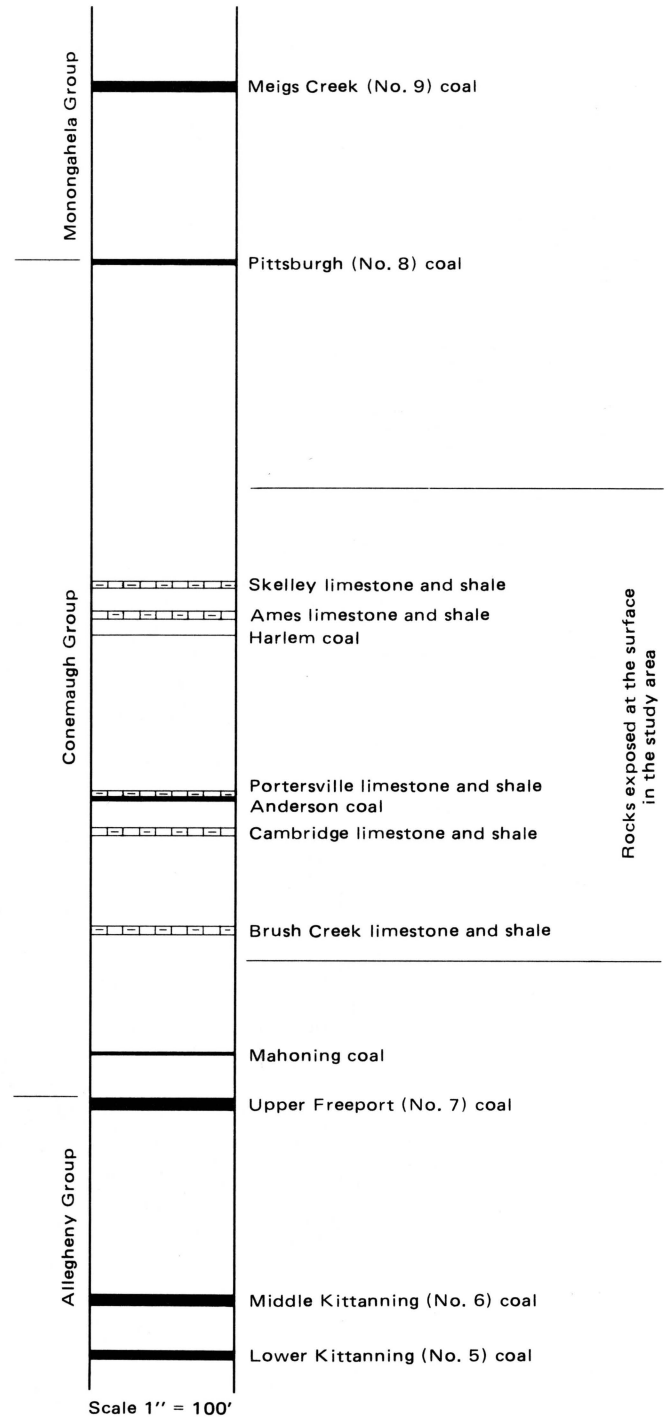


FIGURE 3.—Generalized stratigraphic column of principal units cropping out in Guernsey County, Ohio.

the top was sandstone. The coal is entirely cut out or drastically reduced in thickness in many places by overlying channel sandstone. These interruptions of the coal were variously called by miners “horsebacks,” “wants,” “faults,” or “cut-outs.” These features, which are related to the depositional history of the coal, were detrimental in mining

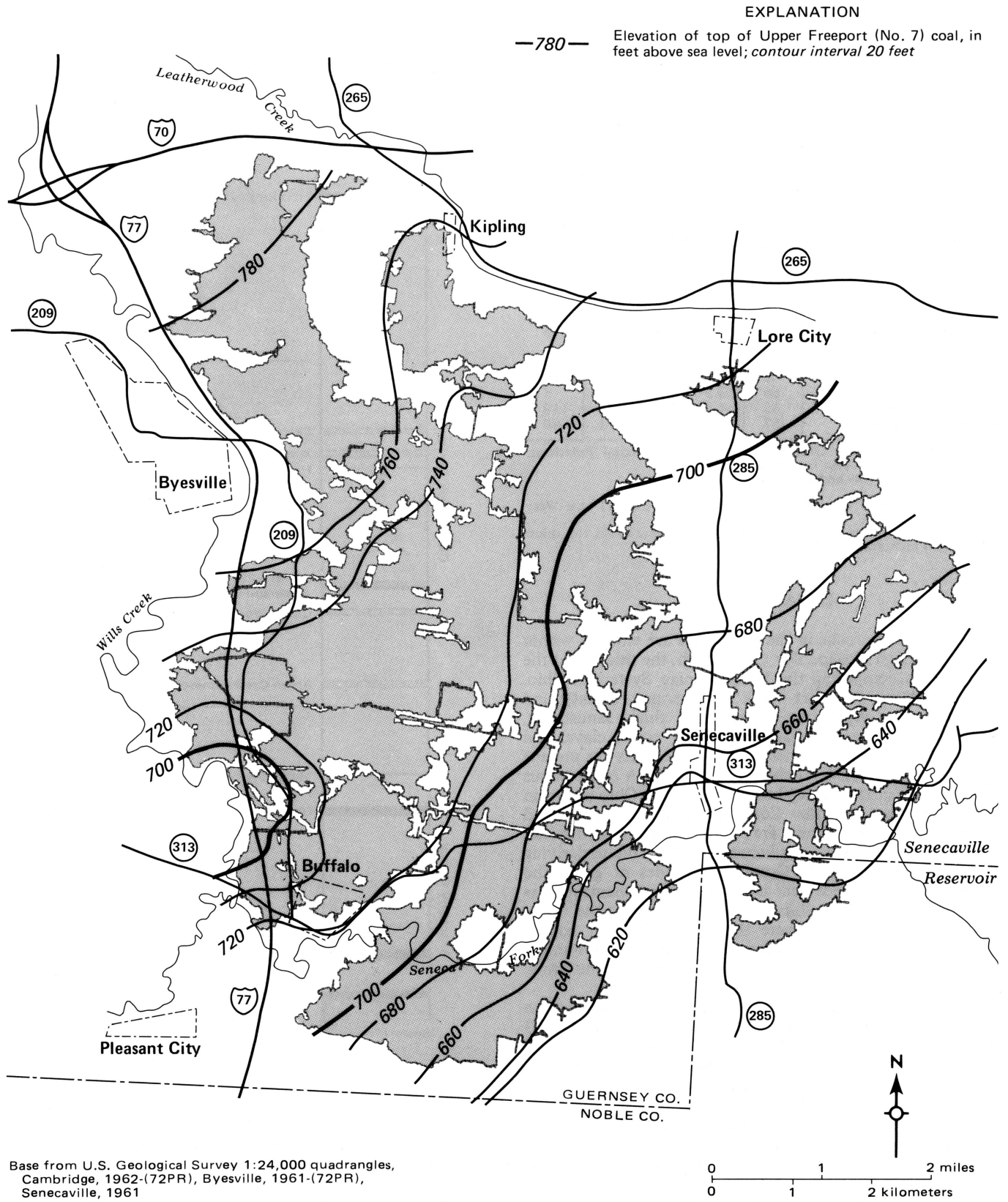


FIGURE 4.—Contours on the Upper Freeport (No. 7) coal in study area.

operations, causing problems in maintaining productivity, in increased mining costs, and in following a uniform mining plan.

In the Cambridge Field the Upper Freeport was for the most part an excellent coal. Analyses of 11 samples (Brant and DeLong, 1960) taken in the general study area averaged 0.83 percent sulfur, 9.28 percent ash, and 12,563 Btu/lb on an as-received basis. The coal is thick by Ohio standards, generally more than 54 inches in the study area.

Relief in the area is moderate; elevations range from about 800 to 1,100 feet above sea level. Mines are about 50 feet deep under major valleys and about 400 feet deep under the highest ridges. In the major valleys bedrock cover is less than 50 feet in some areas and numerous collapse features (sinks) are present. Because of the shallowness of the mine voids in some parts of the area and the presence of collapse features, particular attention was paid to the possibility that subsidence might occur locally when the mines were pumped.

The abundance of sinks in the valleys of Wills Creek and its tributaries is related to the geologic history of the area. The valley now occupied by Wills Creek was part of the preglacial Teays River system. Deep Stage is the name applied to the drainage system created in Ohio by the blocking of the west-flowing Teays system by glacial ice. During Deep Stage drainage many of the ancestral Teays valleys were deeply incised. This is true of Wills Creek valley, which in some places along the western margin of the study area may have been cut below the level of the Upper Freeport coal. The deepened valleys of Wills Creek and its principal tributaries were largely filled with fine-grained alluvial sediments when the glaciers melted.

MINING HISTORY

Pioneer settlers must have known of coal in Guernsey County because it could be seen outcropping in various parts of the county. Wood was extremely plentiful in the early days of settlement, and was used to fire salt boilers in Senecaville in 1816 (Owen, 1895). There was little if any reason, at first, to look for another fuel.

Although it is probable that individual farmers utilized coal that cropped out on their land, it was not until 1850 that the first mine was opened in the county as a commercial venture (Wolfe, 1943, p. 471). This mine, known as the Gaston mine, was about 3 miles east of Cambridge. In 1852, work was started on the Central Ohio Railroad (now Chessie System) which, when completed, provided a means of transporting coal beyond the local market. In 1857, the Scott mine was opened just east of the Gaston mine, and soon after that the Norris mine, which was the first shaft mine in the county, was opened east of the Scott mine (Wolfe, 1943, p. 471). All of these mines were opened in the Upper Freeport coal and were the first in the Cambridge Field, which subsequently became a major mine district of the state.

The Cambridge Field got its greatest development impetus from the expansion of the railroad system in the late 1870's and early 1880's (Sarchet, 1911). The construction of what was later to become the Pennsylvania Railroad (now abandoned) along the valley of Wills Creek south of Cambridge opened the heart of the field to transportation. An east-west branch of the Central Ohio Railroad was also significant in the ultimate development of the field.

Most of the coal in the Cambridge Field was controlled by the Cambridge Collieries, Akron Coal, Morris Coal, and National Coal Companies. The majority of the mines in the study area were opened by these companies in the late 1800's and early 1900's. During this time Guernsey County, on the strength of the Cambridge Field, rose to be the fourth largest producer of coal in the state. Except for 3 years, the 40-year period 1896-1936 saw production levels of over 1,000,000 tons per year. Peak production of 4,497,303 tons was reached in 1918, the last year of World War I. In terms of total historical production, Guernsey County ranks seventh in the state. Because of reserve depletion and the economic conditions in the 1930's, underground mining dwindled rapidly in the area. Most of the mines in the study area were abandoned before World War II.

Mining was by the "room-and-pillar" method (fig. 5), the method used throughout most of Ohio. This method of mining normally recovers 50 percent or more of the coal.

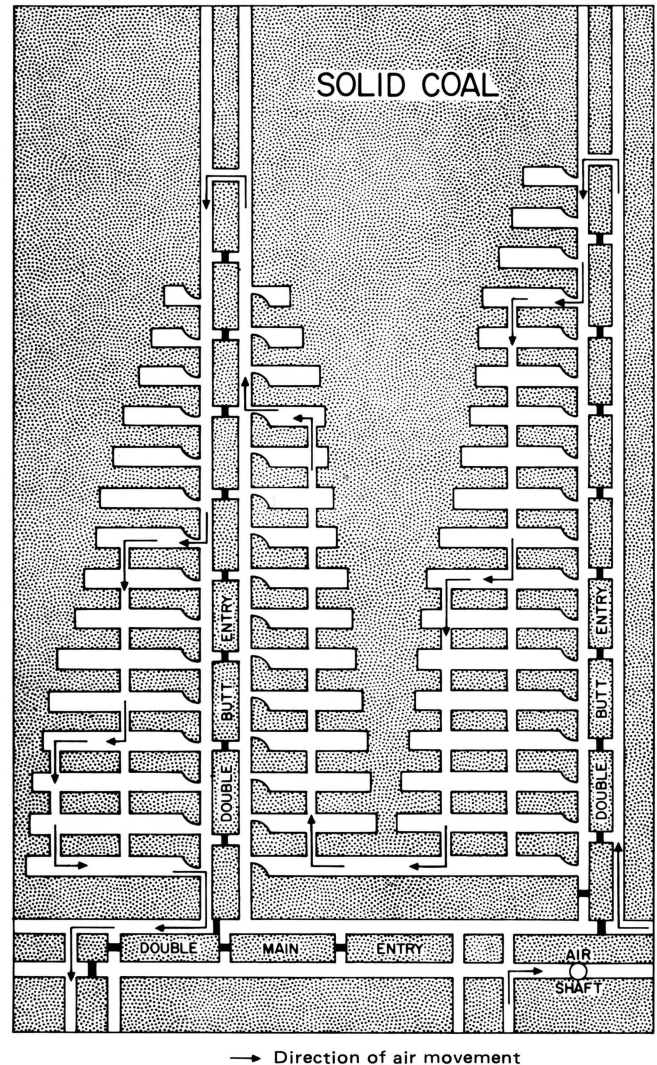


FIGURE 5.—Idealized double-entry room-and-pillar mine layout (from Roy, 1884, p. 333).

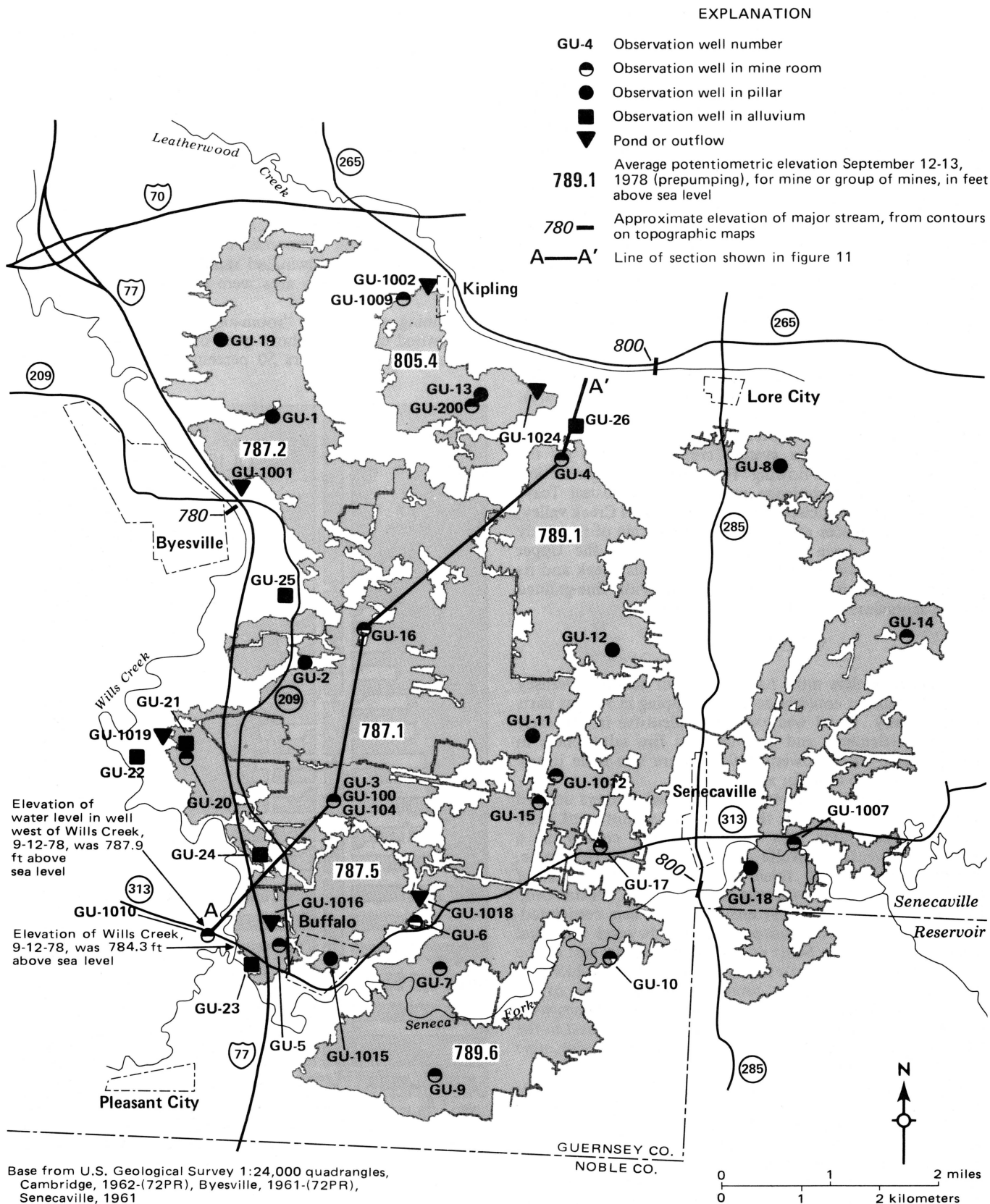


FIGURE 6.—Approximate mine potentiometric elevations, September 12-13, 1978 (prepumping), and locations of observation sites.

Parallel entries are driven into the coal generally at right angles to the principal cleavage plane, or the face cleat, of the coal. These are called the face entries (main entries of figure 5). A pillar of solid coal is left between the two entries. This pillar is cut through at intervals, the distances depending on the individual mining plan, for the circulation of air. As new breakthroughs are made at the face of the entries, the last one is sealed off to force air to the working face. Entries are driven to the left and right of the main entry system. These workings are called butt entries. The butt entries take their name from the fact that they are driven at right angles to the secondary cleavage plane, or the butt cleat, of the coal. The rooms from which the major portion of the coal is removed are driven at right angles to the butt entry. Thus the rooms advance against the face cleat, which, with all things being equal, results in the easiest mining. The rooms generally are started with a narrow neck to provide better roof support at the entry but are then widened to give a larger working face. Rooms may be worked off both sides of the butt entries. Pillars of solid coal, called ribs, are left standing between the rooms to provide support. As on the entries, breakthroughs between rooms are made for air. A mine thus developed is a series of rooms where coal was removed, separated by pillars where coal was left for roof support.

The size of the pillars is proportional to the thickness of the overlying strata. In general, shallow cover requires less roof support, so that pillars can be smaller, resulting in a higher-than-average coal recovery. The mines in the study area were worked under fairly shallow cover and recovery was high. Table 2 lists the estimated percent of recovery for each of the mines in the study area.

Many factors may interfere with carrying out such an idealized (fig. 5) mine layout. Bad top or bottom conditions or areas that cannot be mined for legal or safety reasons are factors that could affect the basic mine layout. As stated earlier, the presence of numerous channel sandstones which entirely cut out or severely reduce seam thickness was a major problem in mining the Cambridge Field.

Leakage into the mines was a problem during mining, as evidenced by the numerous pump holes and masonry dams shown on mine maps. Dams were constructed to control flow within and between mines, and wells (pump holes) were drilled to dewater the mines.

MINE HYDROLOGY

GROUND-WATER OCCURRENCE

All underground mines in the study area are abandoned and flooded. Nearly all mine water is under artesian pressure, that is, the water has a potentiometric surface above the mine roof. The only exception is in the northern part of the Ideal mine (fig. 2), where about 0.2 mi² is under water-table conditions.

The vertical distance between the mine roof and the static water level in a well completed in a mine room ranges from zero in the northwest part of the study area (northern Ideal mine) to about 170 feet in the southeast. This range is primarily due to the southeasterly dip of beds (fig. 4). The potentiometric surface is relatively flat (fig. 6), supporting the concept of a hydraulically interconnected mine system.

WATER-LEVEL FLUCTUATIONS

Water levels in wells that terminate in mine openings of the Upper Freeport coal represent the potentiometric head in the mine. However, water levels in wells completed in coal pillars do not necessarily indicate head in the mine. Water levels in pillar wells are influenced by: (1) head in adjacent mine rooms, (2) width of coal between well and adjacent mine rooms, (3) degree of fracture connection to mine rooms, and (4) rate of flow into the uncased portion of the well from overlying aquifers of higher head than the mine. In observation wells with effective fracture connection to rooms and no appreciable inflow from overlying aquifers, water levels accurately represent mine head. In wells having poor fracture connection to rooms and significant inflow from above, water levels are generally above those of the mine rooms, and approximate the head in the contributing aquifer.

The potentiometric surface fluctuates in response to barometric changes, recharge from precipitation, and natural mine discharge (figs. 7-9). Changes in barometric pressure cause the small (tenths of a foot) day-to-day fluctuations that appear on all the hydrographs. Barometric efficiency of the mine zone is about 70 to 80 percent, as determined from water-level and barometric records.

During the study, water levels (well GU-6, fig. 9) rose in response to recharge from precipitation (bar graph, fig. 7) in December 1977 and March 1978. The rise in December was from high rainfall; that in March resulted from snowmelt. During the growing season (April-October), most precipitation is consumed through evapotranspiration, so that ground-water recharge is small, and water levels decline as the system discharges (figs. 7-9). During periods of low evapotranspiration, mine-water levels respond directly to significant precipitation events, as shown by the hydrograph of well GU-1010 and concurrent precipitation record for December 3-10, 1978 (fig. 10).

Anomalous water-level fluctuations occurred in April and June 1978 in well GU-7 (fig. 8). A possible explanation is that oil wells being drilled through the Walhonding No. 2 mine provided a sudden outlet for trapped air, causing a temporary head decline throughout the mine. Such air releases were observed during the drilling of GU-7 and other wells for this study.

FLOW SYSTEM

Head relationships (fig. 6) indicate that water movement through mines in the study area is generally westward and discharge is primarily to Wills Creek. The head in well GU-1010 in a mine west of Wills Creek also is higher than Wills Creek (fig. 6), suggesting that Wills Creek probably serves as a discharge area for mines on both sides. The water table (above the mines) is probably higher than the potentiometric surface of the water in the mine zone (fig. 11) except along Wills Creek. (The water table shown is postulated mainly upon perennial stream elevations taken from topographic maps.) Therefore, in the vicinity of Wills Creek, some mines discharge water to the surface. A well (GU-1001, fig. 6) used by the community of Byesville since 1958 discharges naturally to the surface at a rate generally exceeding 1,000 gal/min. The well is completed in highly fractured sandstone just above the Ideal mine and discharges water from the mine. Similarly, an old air shaft into the

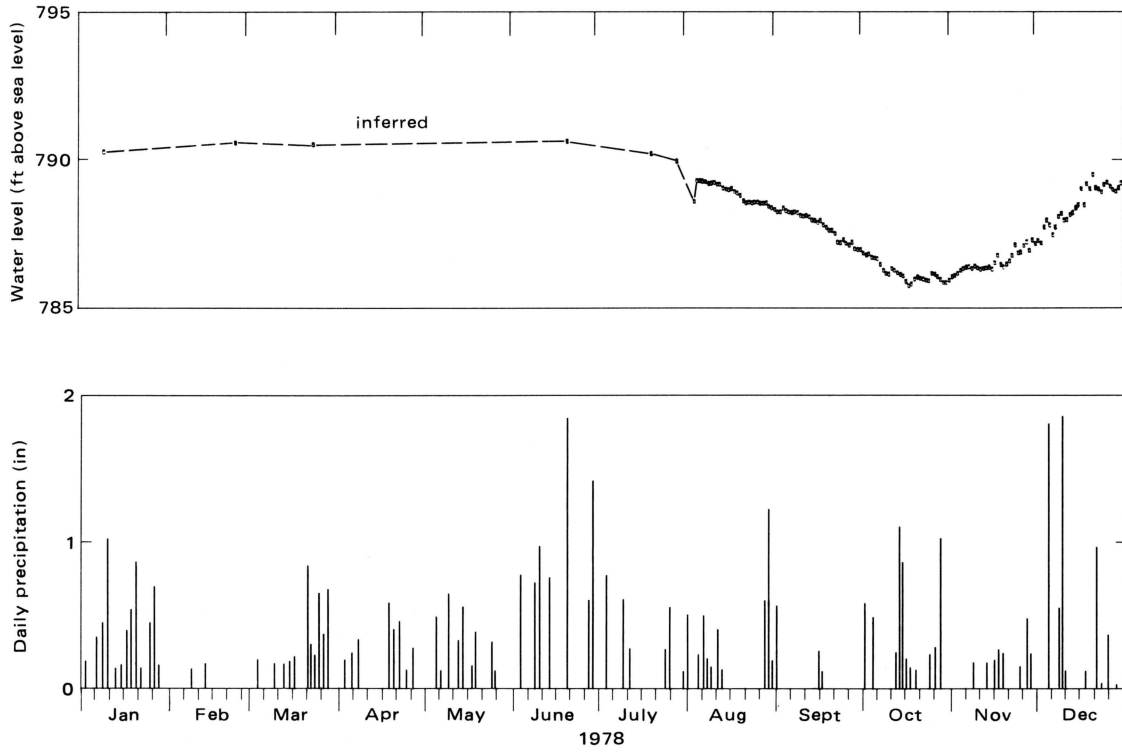


FIGURE 7.—Hydrograph for well GU-1010 (west of study area) and precipitation during 1978.

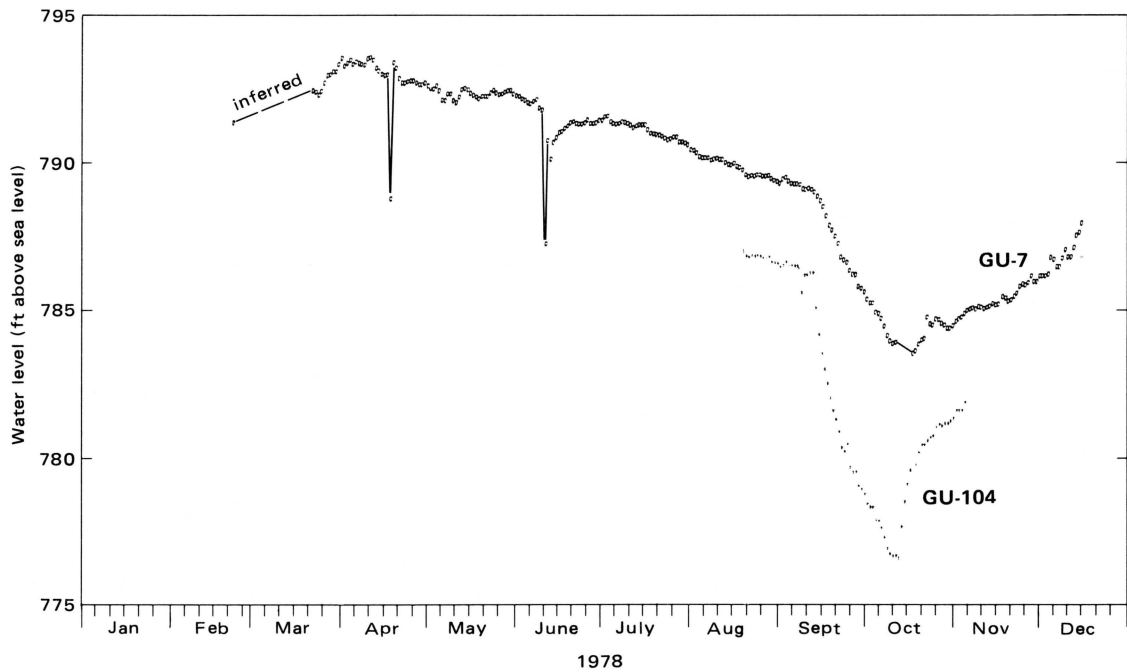


FIGURE 8.—Hydrographs for wells GU-7 and GU-104.

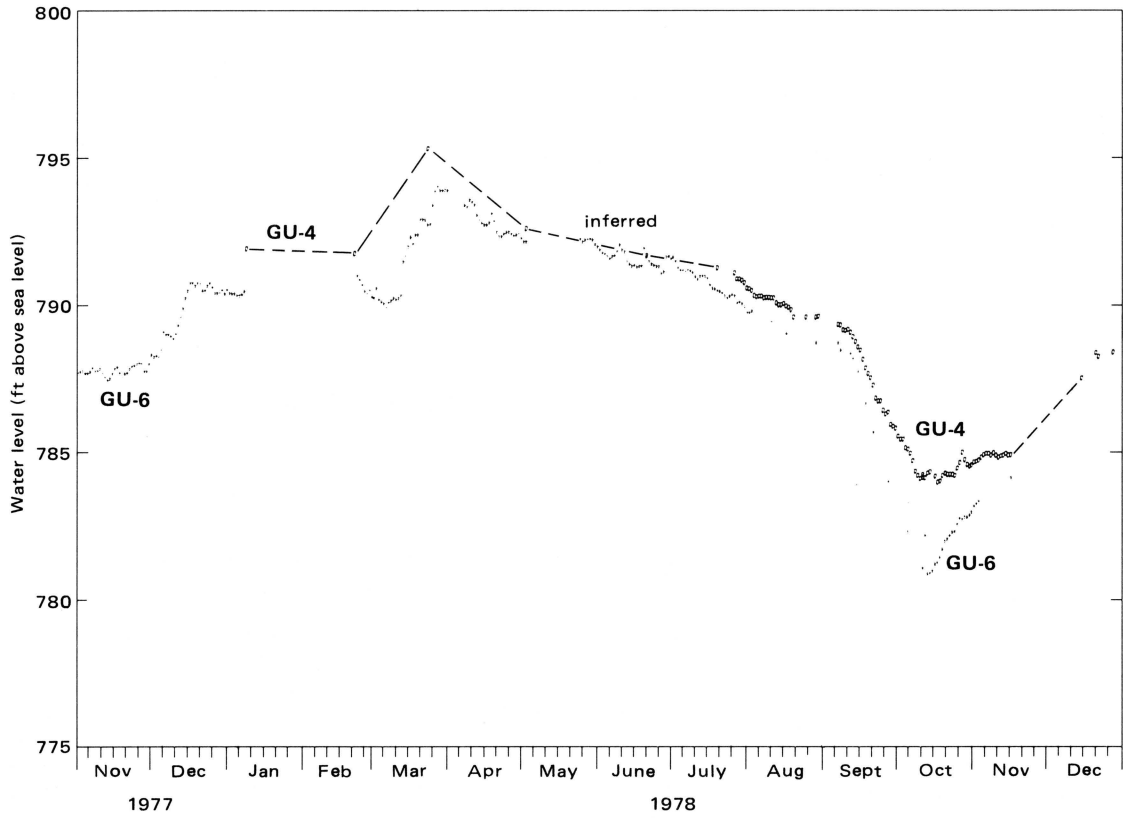


FIGURE 9.—Hydrographs for wells GU-4 and GU-6.

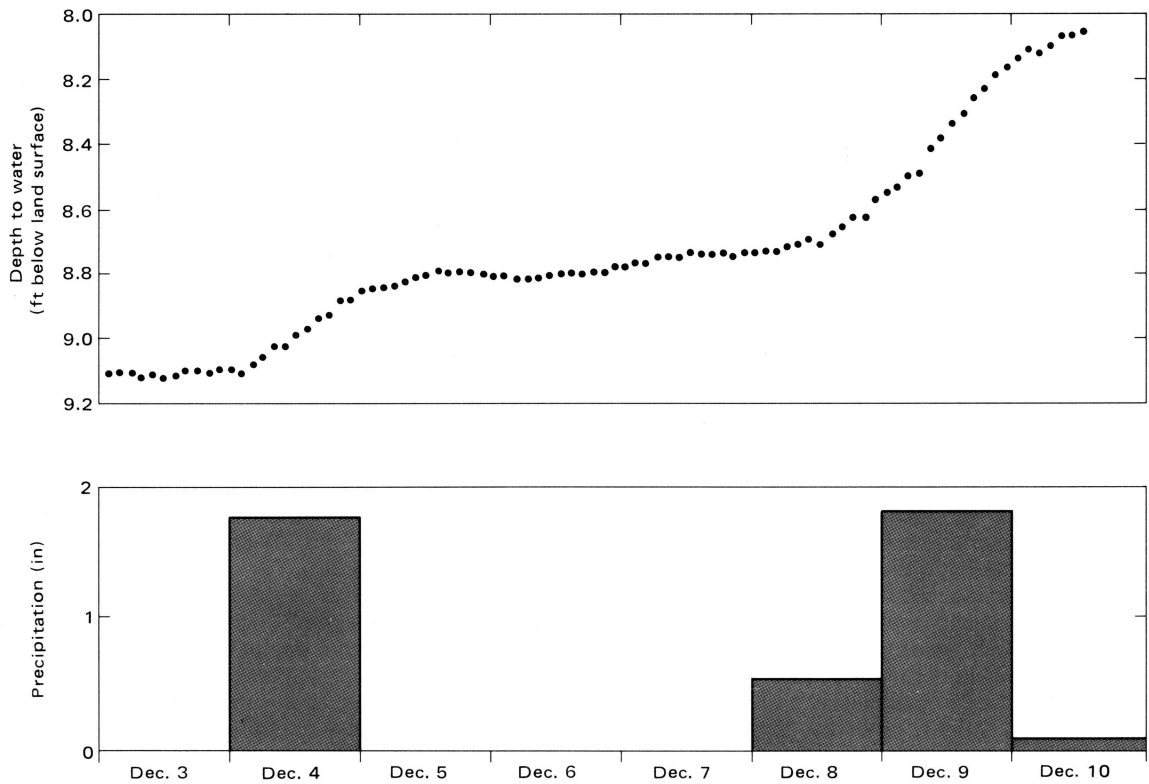


FIGURE 10.—Hydrograph for well GU-1010, adjusted for barometric fluctuations, showing response to precipitation from December 3 to December 10, 1978.

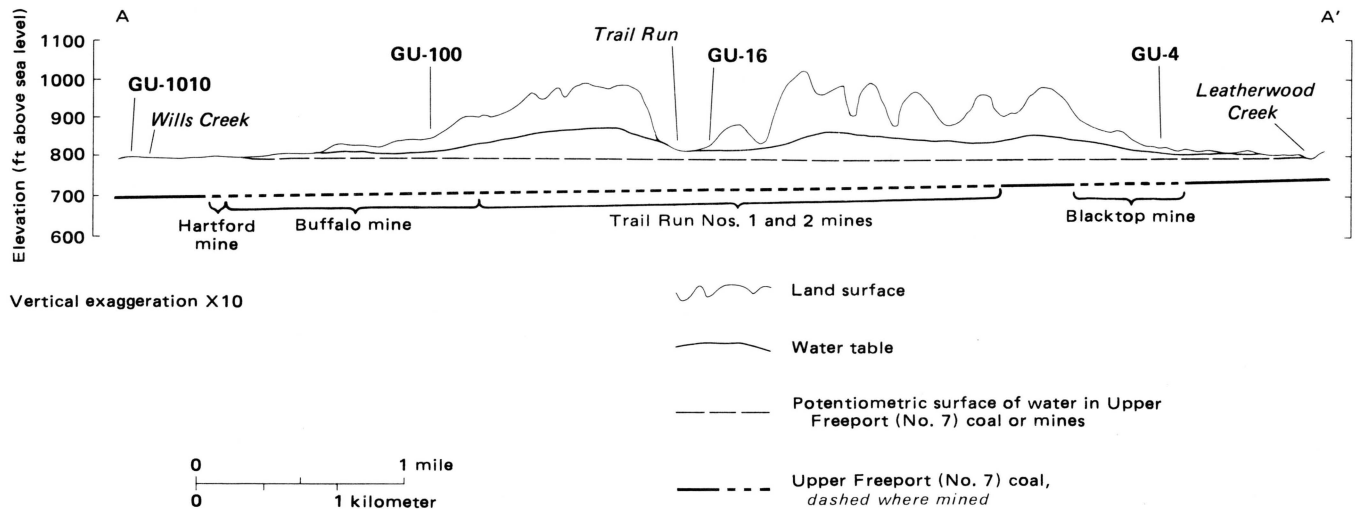


FIGURE 11.—Generalized section illustrating relationship between the mine zone, its potentiometric surface, and the water table. Location of section shown on figure 6.

Klondyke No. 1 mine at Kipling continuously flows at about 20 to 200 gal/min.

Ground-water recharge in the area is mostly from percolation of a part of local precipitation. Some of this recharge water does not reach the mine system, but discharges laterally above the mines because (1) stratification of the rocks tends to impede vertical flow more than horizontal flow, and (2) the mine system can only accept recharge at a rate commensurate with its discharge rate. Ground water not discharged laterally above the mines becomes the main recharge to the mine system; lateral flow in the coal zone into and out of the study area is estimated to be small. The mine-water system can basically be described as follows: water enters the mines after leaking vertically through overlying rocks, moves through the mines, and discharges upward through overlying rocks and alluvium to Wills Creek.

WATER QUALITY

Mine water collected from 12 sites differs considerably in chemical composition (table 3 and fig. 12). Water in much of the mine system is of the calcium or sodium bicarbonate type and has dissolved-solids concentration less than 2,000 mg/l. Water in the Walhonding No. 2 mine (wells GU-7 and GU-9) is of the sodium sulfate type, and water in the Rigby Westside mine (well GU-14) and Walhonding No. 3 mine (well GU-1007) is of the sodium chloride type. These mines contain more highly mineralized water than do the other mines.

Bicarbonate water of relatively low dissolved-solids concentration predominates in shallow (northwestern and western) parts of the mine system; in this area, ground-water circulation is relatively fast because Wills Creek serves as a nearby discharge area and well GU-1001 is a surface discharge point. Brackish water prevails in deeper parts of the mine system, where circulation is probably much slower. High concentrations of hydrogen sulfide and phenols in the eastern and southern mines probably also reflect slow circulation.

Barium, lead, strontium, and zinc are commonly present

in the mine water, although at concentrations generally much lower than 1 mg/l. Trace elements which are absent or of very low concentrations include antimony, arsenic, cadmium, chromium, copper, cyanide, mercury, nickel, selenium, and silver. Samples taken from observation wells were collected as near to the bottoms of wells as possible. Samples obtained from shallower depths might not be representative of the mine water, as illustrated by vertical profiles of specific conductance (fig. 13). In several observation wells (GU-7, GU-9, GU-10, GU-15, GU-16, GU-17, and GU-104), specific conductance of mine water is markedly higher than that of water above the mine. The less-mineralized water in the well bore is thought to be from shallower zones, slowly moving down into the top of the mine void. Because samples taken from wells GU-10 and GU-3 (near well GU-104) had specific-conductance values (based on vertical profiles) much lower than mine water in those wells, results of those analyses are not given in this report. Results of all other analyses are assumed to be representative of mine water.

PUMPING TESTS

TEST 1 (BUFFALO MINE)

Location and preparation

Test well 1 (GU-100, fig. 6) was completed in a mine room of the Buffalo mine near the main entry on lot 18, tract 3, T. 1 N., R. 2 W., Valley Township. Table 4 presents test well and pump data.

Frequency of water-level observations was increased during the month preceding the pumping test to obtain adequate background fluctuation and trend data. A short trial test to check equipment was made on September 7, 1978. A variable-rate test (up to 2,800 gal/min) was made on September 8 to note hydrologic response and identify any water-quality problems associated with discharging the mine water.

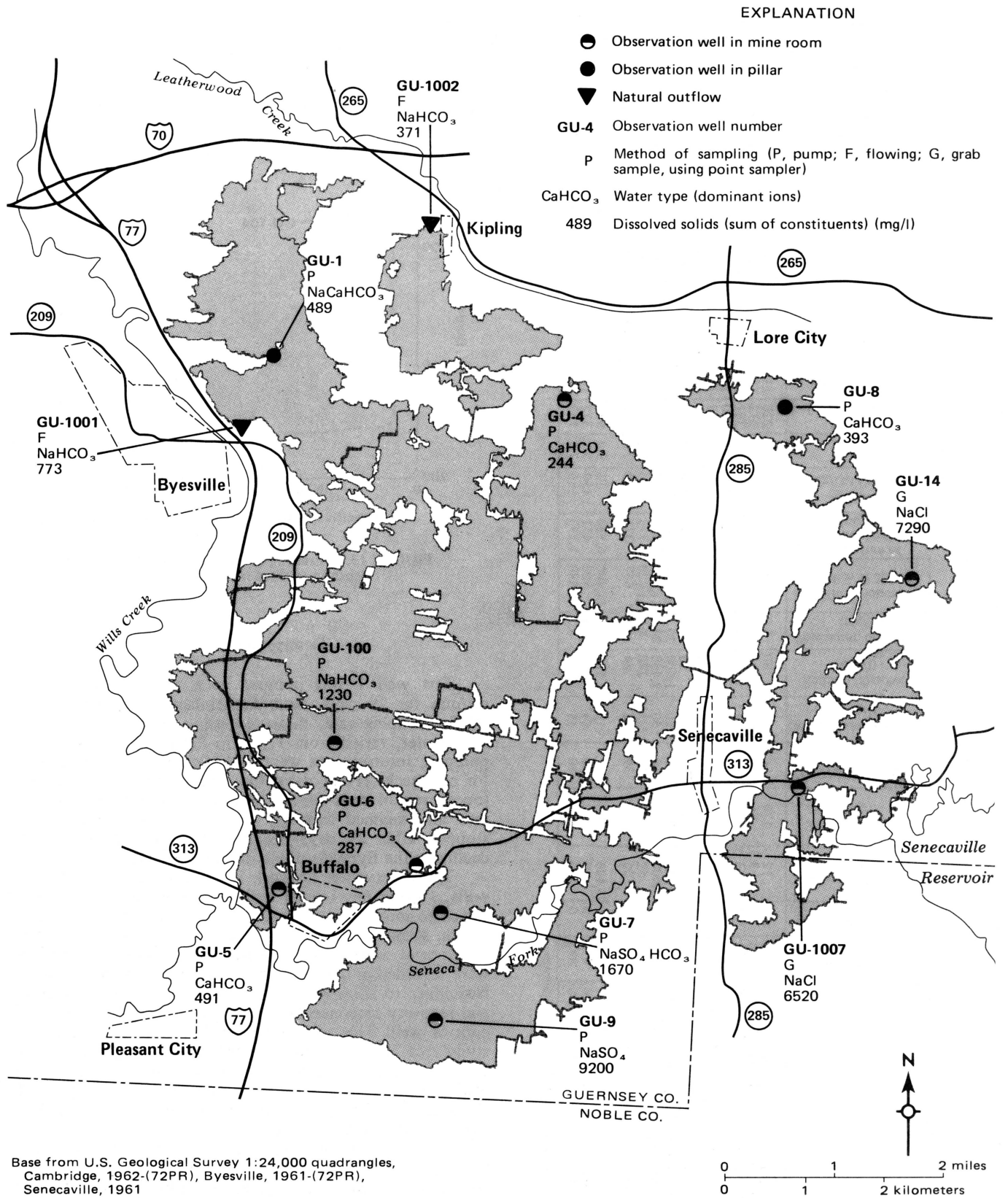


FIGURE 12.—Location, method of collection, water type, and dissolved-solids concentration of mine-water samples.

TABLE 3.-Chemical analyses of mine water¹

Well number	Mine	Date of sample	Temperature (°C)	Bicarbonate (mg/l)	Carbonate (mg/l)	Chloride, dissolved (mg/l)	Sulfate, dissolved (mg/l)	Calcium, dissolved (mg/l)	Magnesium, dissolved (mg/l)	Sodium, dissolved (mg/l)	Potassium, dissolved (mg/l)	Specific conductance (μmhos at 25°C)	Solids, sum of constituents, dissolved (mg/l)	Hardness (mg/l as CaCO ₃)	pH	Alkalinity (mg/l as CaCO ₃)	Silica, dissolved (mg/l)	Iron, total recoverable (μg/l)	Iron, dissolved (μg/l)	Manganese, total recoverable (μg/l)	Manganese, dissolved (μg/l)	NO ₂ + NO ₃ dissolved (mg/l as N)	Carbon, organic total (mg/l)	Phenols (μg/l)	Hydrogen sulfide (mg/l)
GU-1	Ideal	10-26-77	12.5	276	0	12	170	54	18	80	4.0	750	489	210	7.0	226	11	7,900	3,500	240	190	-	12	5	0
GU-4	Blacktop	11-02-77	12.0	136	0	3.3	86	40	14	17	2.0	320	244	210	6.5	112	13	1,000	660	380	380	-	9.5	0	0.2
GU-5	Hartford	10-26-77	14.0	464	0	33	44	100	33	30	2.8	845	491	390	7.1	381	18	1,800	920	220	220	-	8.2	2	0.3
GU-6	Hartford	10-27-77	12.5	280	0	25	59	21	22	22	1.4	550	287	230	7.3	230	12	9,800	6,300	290	250	-	12	3	0.3
GU-7	Walhonding No. 2	10-27-77	13.5	567	0	170	640	78	27	410	8.4	2,700	1,670	310	6.7	465	15	38,000	38,000	610	610	-	13	3	0.5
GU-8	Klondyke No. 2	11-02-77	13.0	381	0	4.5	52	76	21	36	2.6	535	393	280	7.4	312	12	8,900	760	380	280	-	12	0	0.3
GU-9	Walhonding No. 2	5-02-78	15.0	73	0	640	6,400	72	250	1,600	30	10,000	9,200	1,200	5.4	60	41	-	110,000	-	13,000	13,000	-	15	0.3
GU-14	Rigby Westside	11-03-77	14.0	1,190	0	3,000	900	310	30	2,400	24	11,500	7,290	900	7.4	976	9.4	78,000	29,000	2,000	410	-	23	54	0.8
GU-1001	Ideal	9-19-77	13.5	496	0	52	170	36	13	240	4.2	1,120	773	140	6.7	407	9.5	3,400	3,400	260	260	-	8.0	0	0.2
GU-1002	Klondyke No. 1	12-02-76	11.5	312	0	26	43	39	12	84	3.1	657	371	150	7.4	256	9.4	1,200	1,200	200	200	-	2.7	3	0
GU-1007	Walhonding No. 3	11-03-77	14.0	468	316	3,400	43	1.7	2.1	2,500	23	11,400	6,520	13	9.4	910	0.2	3,200	430	30	20	-	10	76	1.2
GU-100	Buffalo	9-08-78	14.0	456	0	17	22	40	11	120	4.1	800	451	150	7.2	372	10	1,230	190	160	160	-	10	2	2.4
GU-100	Buffalo	10-11-78	13.0	892	0	120	190	40	15	400	5.2	1,880	1,230	160	7.4	732	11	1,500	1,400	260	260	-	-	0	0

¹ Analyses performed by U.S. Geological Survey.

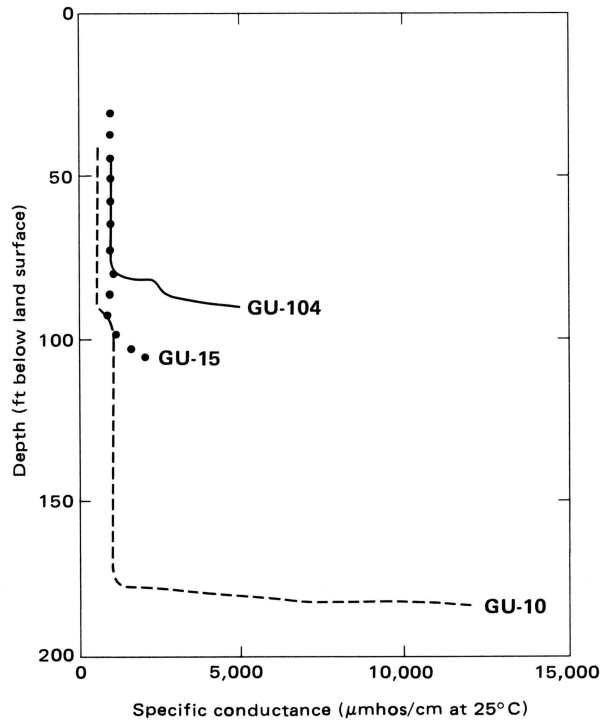


FIGURE 13.-Variation of specific conductance with depth in selected observation wells.

Description of test

Test well 1 was pumped at a rate of about 2,000 gal/min for 29 days, from September 13 to October 12, 1978. Pumping rate, measured using an orifice weir and manometer, varied from 1,950 to 2,020 gal/min. The only pumping interruptions were at times of engine shutdowns for oil checks (twice daily for 2 minutes) and oil changes (once every 4 days for 30 minutes). Water was discharged into an unnamed tributary to Wills Creek. Pumping was stopped after 29 days because of significant water-level decline in the Byesville public-supply well (GU-1001).

The observation network for test 1 comprised 32 test wells, 10 privately owned wells, and 4 ponds. The network served to monitor potentiometric head in mine rooms, coal pillars, strata above the Upper Freeport coal, and alluvium above or at some distance from the coal mines. Water levels were recorded or observed periodically from August through November to show prepumping trends, pumping response, and recovery response. Well GU-1010 (fig. 6) was used as a control well. This well is across Wills Creek opposite the study area, in a mine not affected by pumping in the study area. Comparison of prepumping hydrographs of the control well and observation wells in mines later affected by test 1 shows nearly identical response to barometric-pressure fluctuation and seasonal conditions.

The weather just prior to and during pumping was unusually dry. About 0.3 inch of rain fell during September (fig. 14). The only other significant rainfall before the end of pumping was 0.5 inch on October 1 and 0.4 inch on October 4. During the pumping period, the control well (GU-1010) showed a steady decline in head, and recharge from precipitation was not significant. On the day the test

TABLE 4.—Test well and pump data

	Test well 1 (Buffalo mine)	Test well 2 (Klondyke No. 1 mine)
Casing diameter (in)	16	12
Total depth below land surface (ft)	86	72
Mine interval below land surface (ft)	78-82	65-70
Depth of slotted interval (ft)	76-85	63-72
Slot schedule	4 courses of 2-ft x 2-in slots	3 courses of 2-ft x ¼-in slots
Pump and power	turbine; 150-horsepower diesel	6-horsepower electric submersible (commercial power)
Pump intake depth (ft)	74	64
Discharge-line diameter (in)	8	4

ended and during the next 4 days, a total of 2.3 inches of rain fell. The end of significant head decline in GU-1010 on October 12 was probably in response to renewed precipitation and not to the end of pumping.

Adjustments to drawdown data

Determination of drawdown attributable to the test pumping required adjustments for fluctuations caused by barometric-pressure changes and the natural seasonal head decline.

Drawdown was adjusted for barometric effect by

converting the mercury barograph to an inverse water barograph, multiplying by the approximate barometric efficiency of the mine system, 0.75, and applying the adjustment.

The seasonal water-level trend was determined using the barometrically adjusted hydrograph for well GU-1010 (fig. 14). Adjusted prepumping hydrographs constructed for three observation wells in mines of the study area show essentially the same seasonal water-level trends as well GU-1010. Pumping-test drawdowns were therefore adjusted by taking into account the seasonal decline observed in well GU-1010 during the corresponding pumping interval.

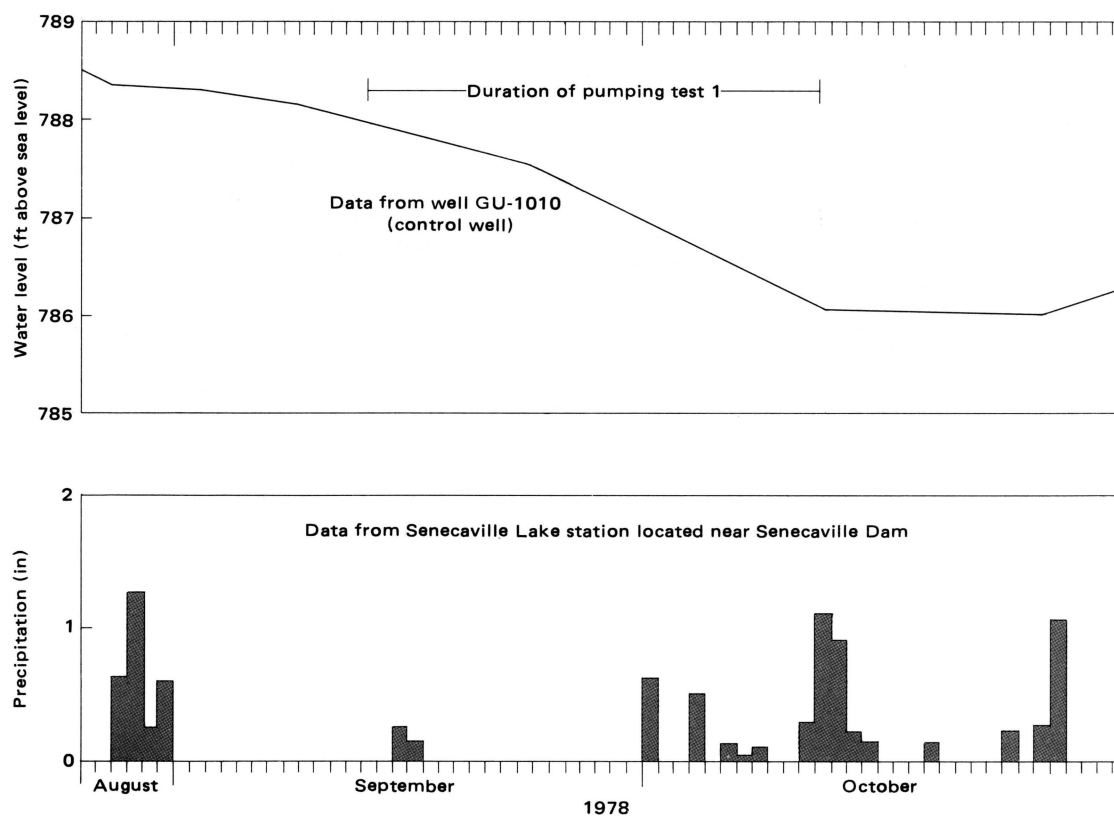





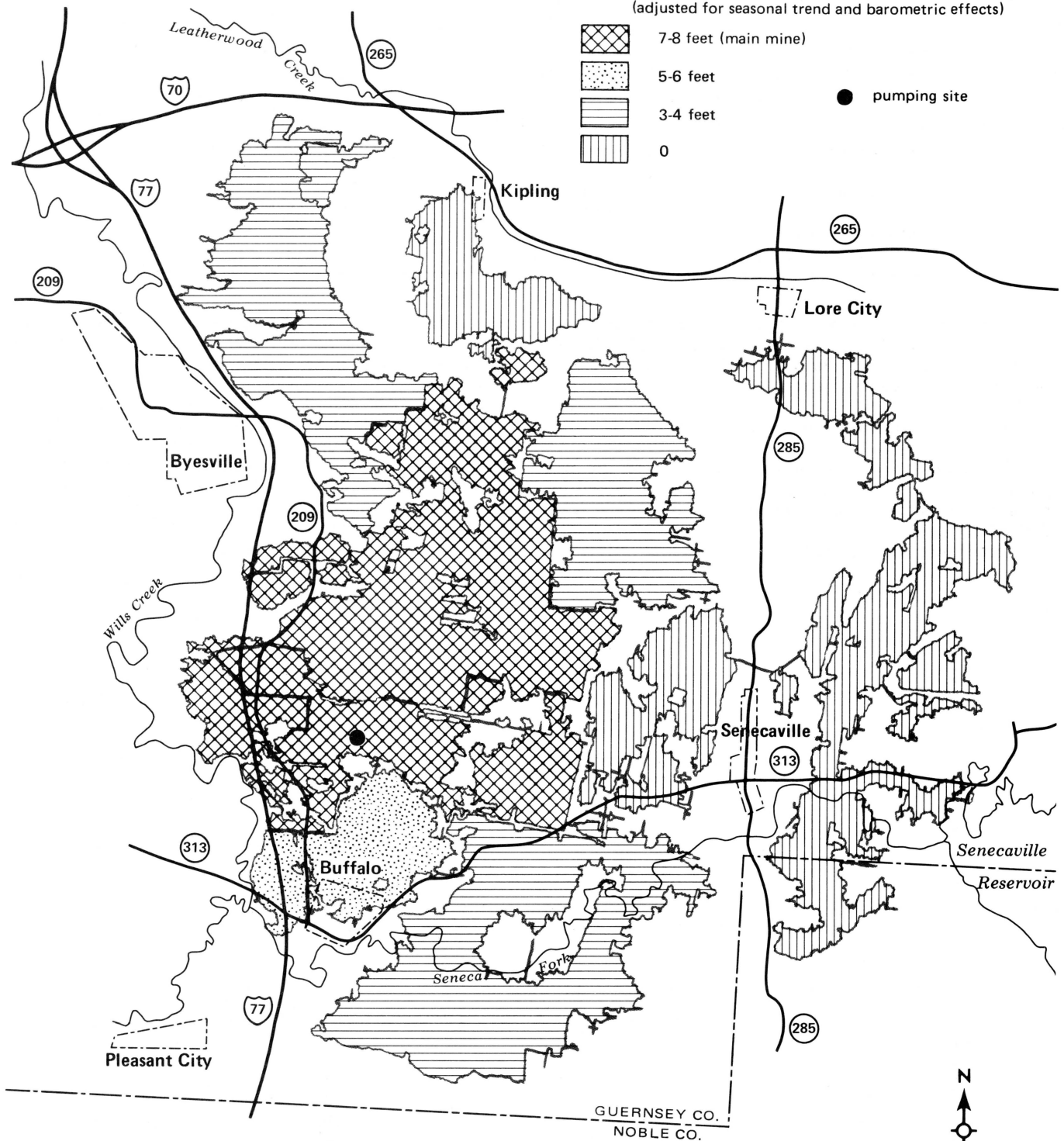


FIGURE 14.—Seasonal water-level trend (adjusted for barometric fluctuations) and precipitation before, during, and after pumping test 1.

EXPLANATION

Drawdown caused by pumping 2,000 gal/min for 29 days
(adjusted for seasonal trend and barometric effects)

-  7-8 feet (main mine)
-  5-6 feet
-  3-4 feet
-  0
-  pumping site



Base from U.S. Geological Survey 1:24,000 quadrangles,
Cambridge, 1962-(72PR), Byesville, 1961-(72PR),
Senecaville, 1961

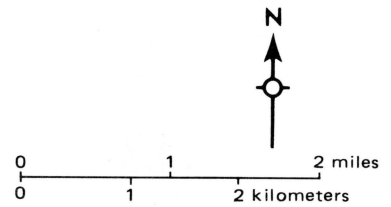


FIGURE 15.—Mine-system drawdowns after 29 days of pumping at 2,000 gal/min (pumping test 1).

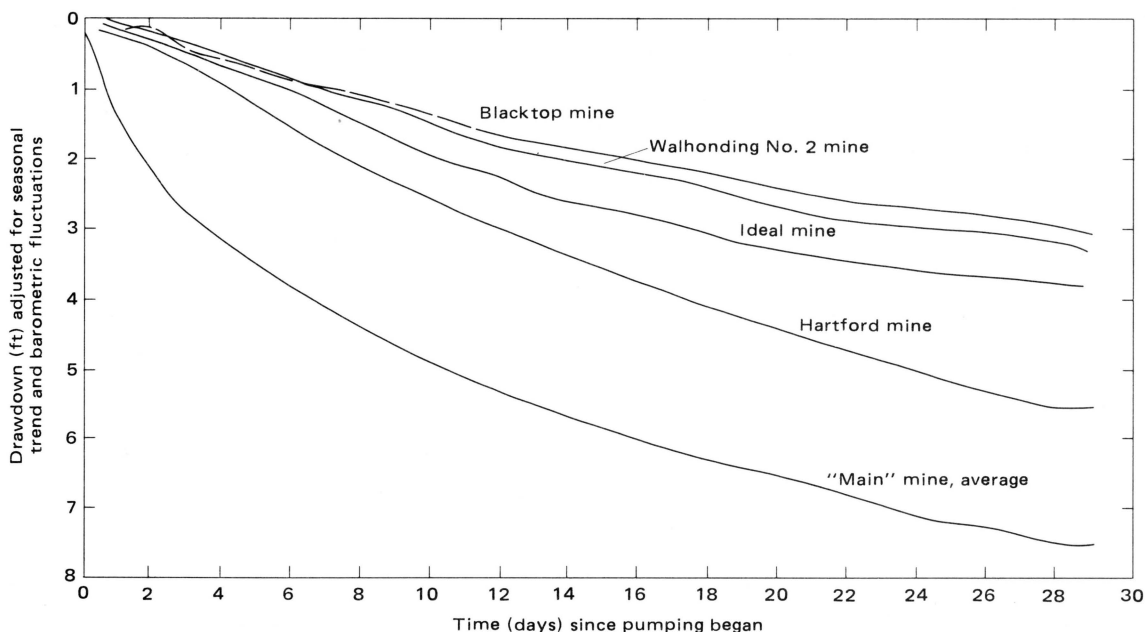


FIGURE 16.—Mine-system drawdown during pumping test 1.

Response of system

Water-level response.—During the 29 days of pumping, potentiometric levels declined by as much as 10 feet in the west mine group (fig. 2). Approximate adjusted drawdowns at the end of pumping are shown in figure 15. Nearly equal drawdowns in several mines (referred to collectively as “main” mine in figure 15) indicate virtually unrestricted hydraulic interconnection. Smaller, delayed drawdowns in the Hartford, Ideal, Walhonding No. 2, and Blacktop mines show less effective connection with the main mine. Neither the east mine group nor the Klondyke No. 1 mine responded to pumping. Water-level response in alluvium along Wills Creek was insignificant, probably reflecting low hydraulic conductivity. Drilling also indicated that the alluvium is fine grained, clay and silt being predominant.

Figure 16 shows drawdowns throughout the 29 days of pumping and the relative response of the affected mines. The main mine group responded within minutes of the start of pumping. In fact, water levels near the pumped well began declining instantaneously, and response at well GU-20, 6,600 feet away, was within 5 seconds. Heads in all affected mines began declining within 1 day. Drawdown continued throughout the pumping period, though at decreasing rates (fig. 16). Distance-drawdown plots (fig. 17) of observation wells completed in a given mine unit show similar drawdowns in most cases. Differences in drawdown within a mine unit are probably caused by local restrictions of hydraulic connection, such as collapsed areas or dams built in mine passageways.

Time-drawdown graphs for wells GU-104 and GU-7 are shown in figures 18-20. The graphs for well GU-104 are representative of time-drawdown relationships throughout the main mine group (fig. 15). The graphs for well GU-7 are representative of the response of the Walhonding No. 2 mine and of the other affected mines in the west group.

When pumping was stopped on October 12, water levels in the main mine began rising immediately. Water levels in other mines continued to decline, although at a slower rate, before rising; the delay was about 2 days in the Ideal and Hartford mines and about 4 days in the Walhonding No. 2 and Blacktop mines. Rate of recovery was highest in the main mine and lowest in the Walhonding No. 2 and Blacktop mines. Rates of recovery likely included some effect of recharge from rain that fell during October-December. Heads in all mines recovered to natural levels within 1 to 2 months following the end of pumping.

Sources of pumped water.—The mine-water system consists of a network of large voids. Models used in analyzing typical (porous- or fracture-media) ground-water systems are, therefore, not applicable. Because of the uniform drawdown within each affected mine and the lack of response in closely adjacent mines (Klondyke No. 1 and the east mines), the mine system is considered approximately analogous to a laterally extensive tank of finite dimensions under artesian pressure. The mines would respond as such a tank if the following assumptions were true: (1) drawdown is equal throughout the mines, including pillars, at any time during pumping, and (2) no leakage occurs into or out of the mines and all pumped water is derived from artesian storage. In such a system, drawdown would be related to pumping by

$$s = \frac{Qt}{SA}$$

where

- s = drawdown (ft)
- Q = pumping rate (ft³/min)
- t = time (min)
- S = storage coefficient
- A = gross area of affected mines (ft²).

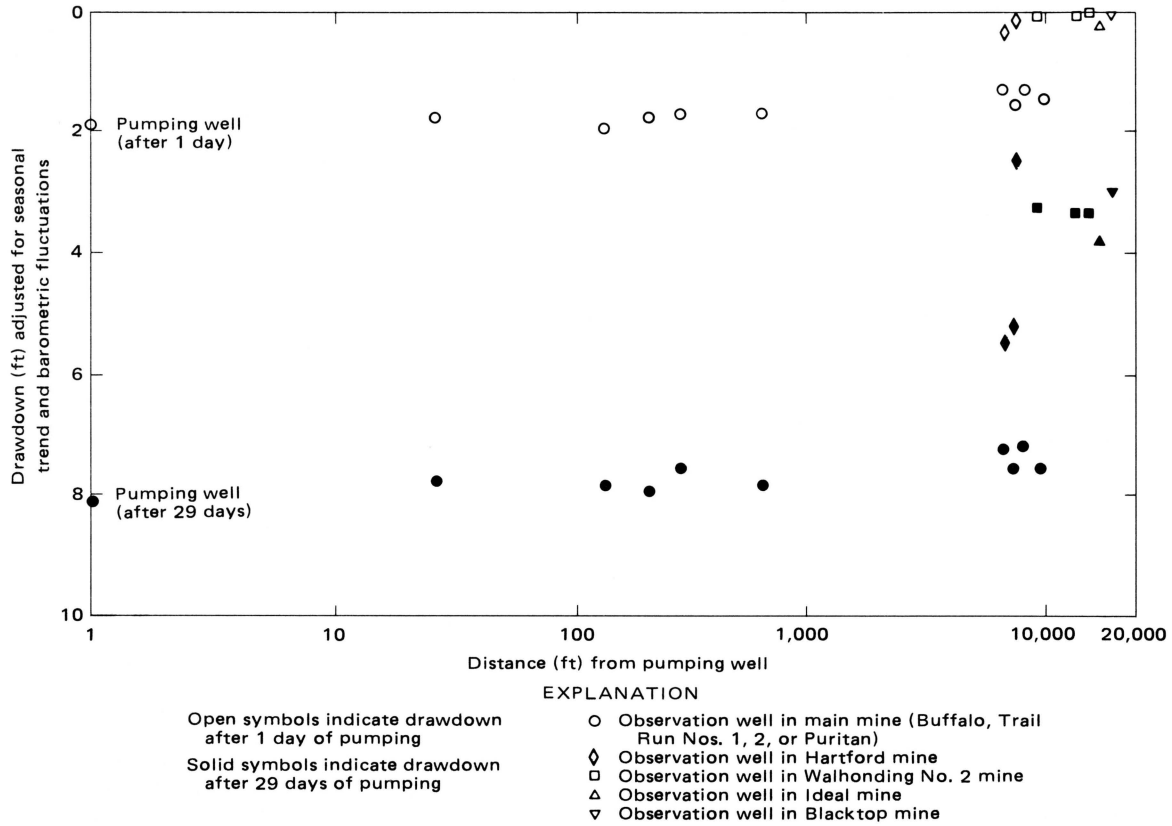


FIGURE 17.—Drawdown versus distance from pumping well in test 1.

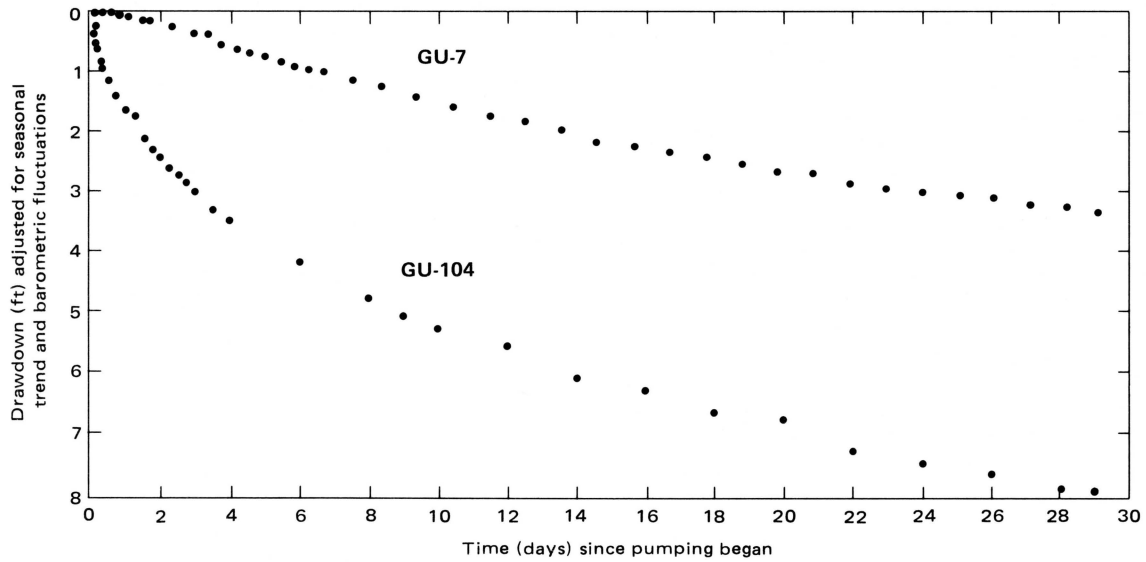


FIGURE 18.—Arithmetic graph of drawdown versus time for wells GU-104 and GU-7.

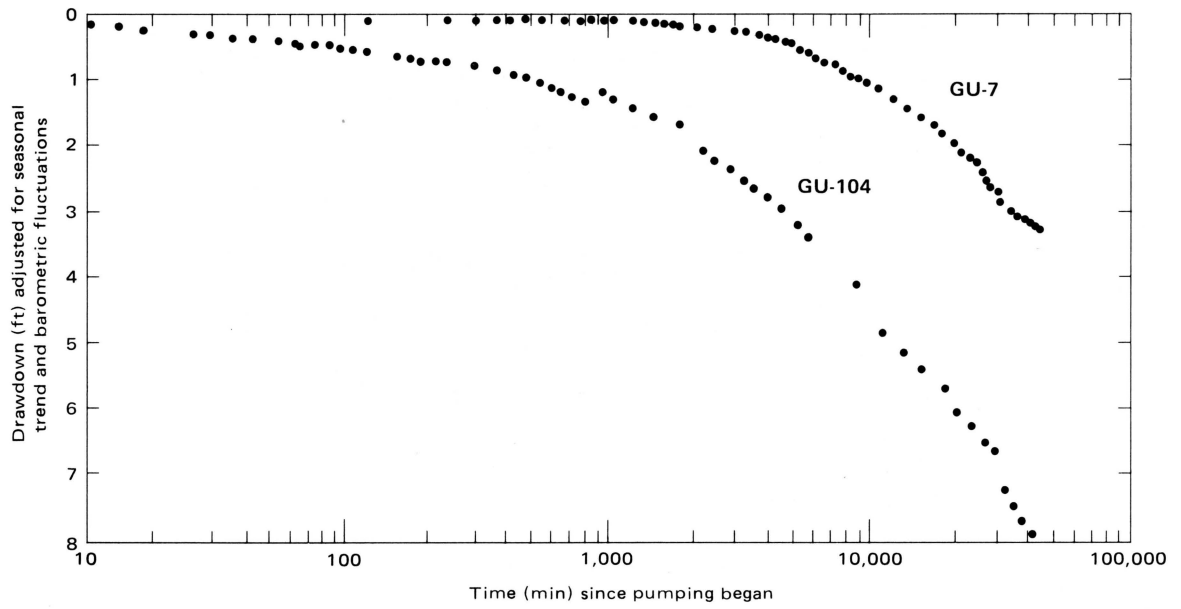


FIGURE 19.—Semilogarithmic graph of drawdown versus time for wells GU-104 and GU-7.

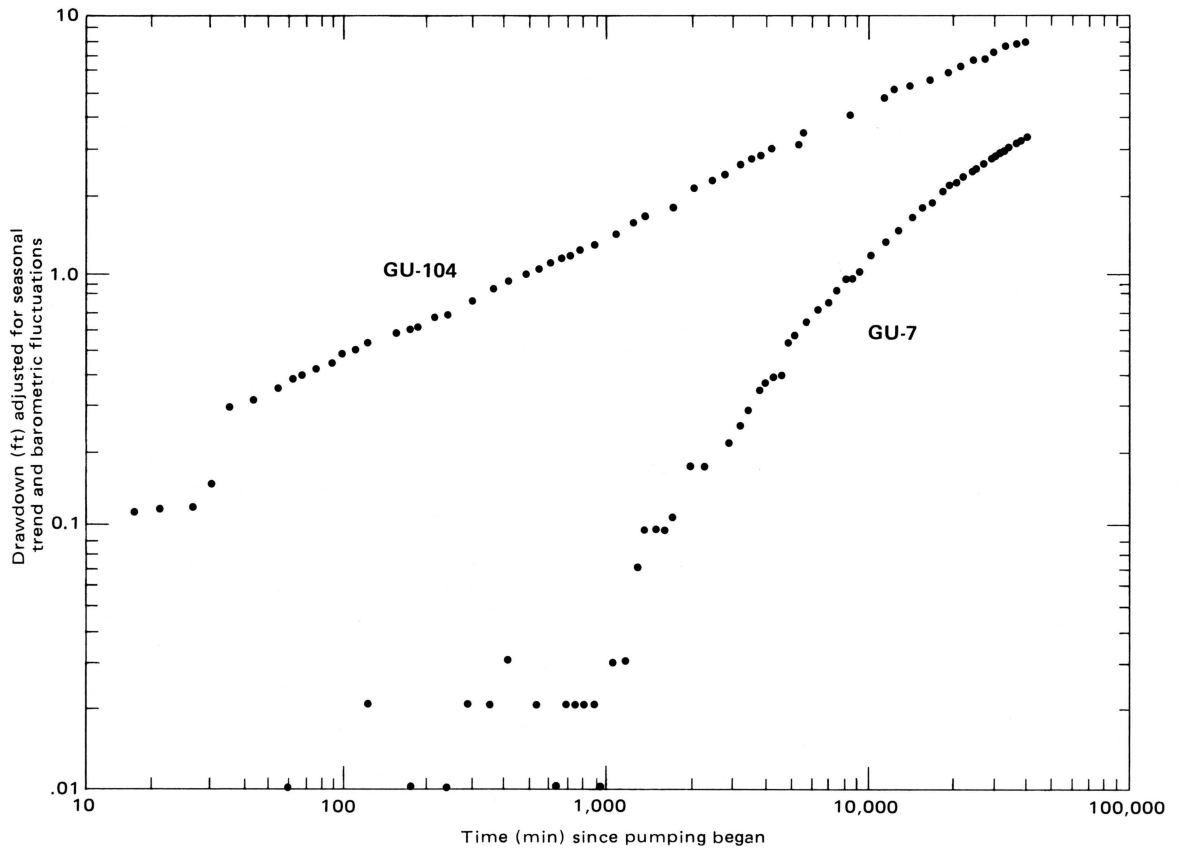


FIGURE 20.—Logarithmic graph of drawdown versus time for wells GU-104 and GU-7.

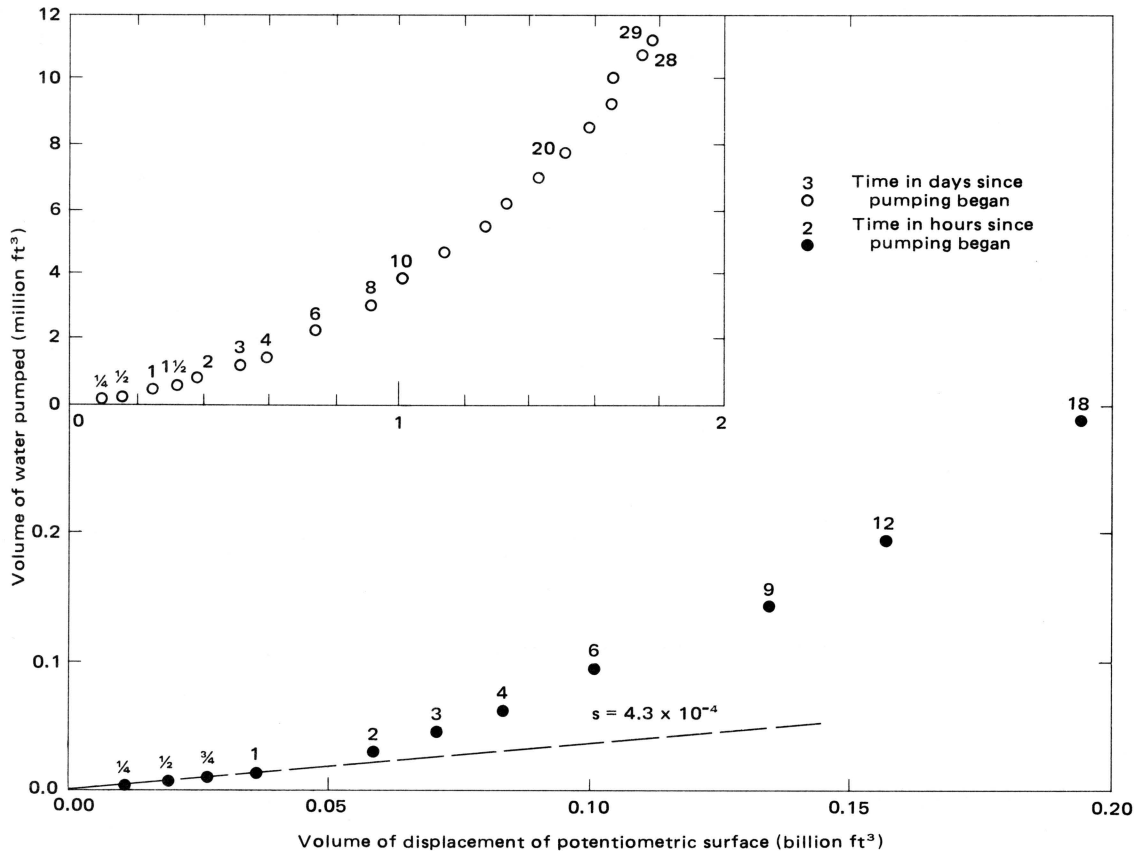


FIGURE 21.—Relationship between volume of displacement of potentiometric surface and volume of water pumped in test 1.

The ratio of volume pumped to volume of displacement of the potentiometric surface over the mines is the storage coefficient of the mine system (Bennett and others, 1967), as shown by rearranging the preceding equation as

$$S = \frac{Qt}{sA}$$

The numerator is volume pumped and the denominator is volume of displacement (the sum of the displacement volumes, based on average drawdowns, of individual mines). This ratio would be constant with time (linear trend in fig. 21) if there were no leakage into or out of the mines.

In the actual mine system this ratio is not constant (fig. 21), but increases during pumping. This is probably due to a decrease of natural discharge from the mine system and an increase in leakage into the system. Both of these effects are a result of decreased head in the mine system. During early pumping, when drawdowns are smallest, the ratio, S , approximates the storage coefficient of the mine system. This ratio, based on the first hour of pumping, is 4.3×10^{-4} , and is used to compute a hypothetical time-drawdown curve (curve 1, fig. 22) for a nonleaky system. Also shown is the composite (area-weighted) time-drawdown curve (curve 2, fig. 22) for the affected mines. The difference between these curves is presumed to be the effect of intercepted discharge and induced recharge. The ratio of the hypothetical time to

reach a given drawdown on curve 1 to the actual pumping time to reach the same drawdown on curve 2 approximates the fraction of pumped water derived from artesian storage. This ratio is 0.27 after 1 day and only 0.07 after 29 days, indicating that most pumped water is derived from intercepted discharge and induced recharge. Although the pumped water was withdrawn from the mines, the mines were not dewatered.

Intercepted discharge consists of water diverted from discharge to Wills Creek, and from natural outflow through well GU-1001 (which ceased flowing within 1 day of the start of pumping). The source of most induced recharge is believed to be vertical leakage from overlying rocks, which increases along with the head difference between the mines and overlying strata. Some of the water in overlying rocks would have discharged laterally above the mine zone had it not been for the increased vertical gradient caused by pumping. Lateral leakage through adjacent coal (surrounding the mines) is thought to be small, considering the lack of discernible response in mines near but not directly connected to the affected mines. Leakage from underlying rocks is probably insignificant because of the presence of a relatively impermeable clay directly under the coal.

To confirm the storage coefficient determined from early drawdown data, early recovery data were used to construct a volume-ratio graph similar to figure 21. The calculated storage coefficient was 3.6×10^{-4} , based on the

first hour of recovery. In addition to this method, the following incident corroborated the calculated storage coefficient.

On September 1, 1978, an anomalous rise in water level (0.32 foot between 0800 and 1100 hours) was recorded at observation well GU-7 in the Walthonding No. 2 mine. On September 14, 1978, debris in the main shaft (5,500 feet from well GU-7) of this mine, which has been used as a dump for many years, was observed to have recently dropped about 20 feet. It is believed that this drop caused displacement of water which in turn caused the water-level rise on September 1. If so, storage coefficient (ratio of estimated volume of displacement in the shaft to volume of the displacement of the potentiometric surface, assuming an equal head rise over the entire mine) was calculated to be 3.0×10^{-4} , a value in agreement with the values calculated from the pumping test.

Water-quality variations.—Variations in chemical quality of the pumped water were documented by (1) a continuous record of specific conductance (fig. 23); (2) several field determinations of temperature, pH, and total iron (fig. 23); and (3) two laboratory analyses (table 3). Water was obtained from a tap in the discharge line about 15 feet from the pump.

The specific-conductance record indicates a gradual increase in dissolved-solids concentration throughout the

pumping period. The more highly mineralized water probably came from nearby rooms in the mine network; these rooms have slow circulation under natural (nonpumping) conditions. The dashed line in figure 23 is thought to approximate actual specific conductance; short-term variations in the record are caused by periodic accumulation of air bubbles on the instrument probe.

Samples for laboratory analysis were collected after about 4 hours of pumping during the preliminary (variable-rate) test on September 8, 1978, and about 1 day before the end of sustained pumping on October 11, 1978. Results (well GU-100 in table 3) show substantial increases in the concentrations of several constituents during pumping, most notably dissolved solids, bicarbonate, sulfate, chloride, sodium, iron, manganese, and strontium (90 to 1,200 mg/l, not shown in table). Among concentrations that decreased were those of aluminum (40 to 20 mg/l), barium (1,000 to 400 mg/l), and lead (63 to 25 mg/l).

TEST 2 (KLONDYKE NO. 1 MINE)

Location and description of test

Test well 2 (GU-200, fig. 6) was drilled into the Klondyke No. 1 mine in the NW¼ sec. 8, T. 1 N., R. 2 W., Richland Township. This mine was the only one in the west

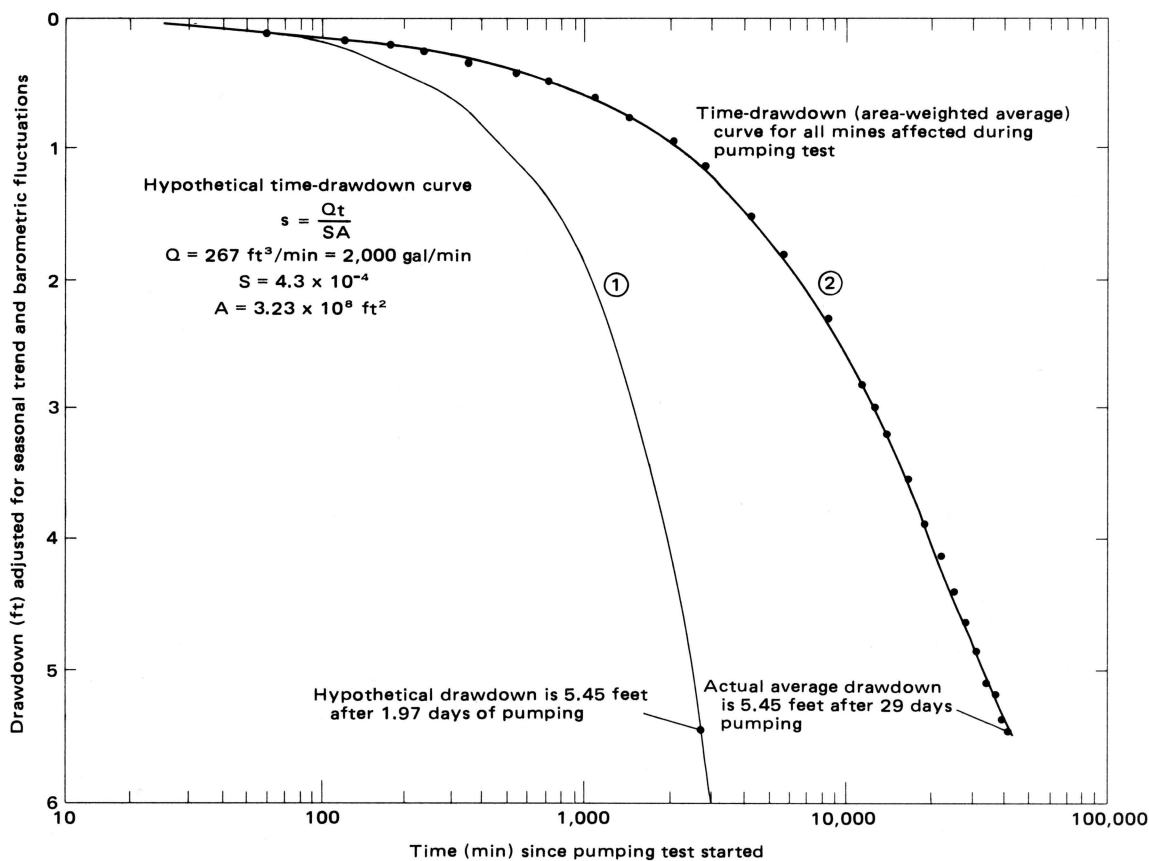


FIGURE 22.—Comparison between composite time-drawdown curve from pumping test 1 and a hypothetical curve which assumes all pumped water is derived from artesian storage.

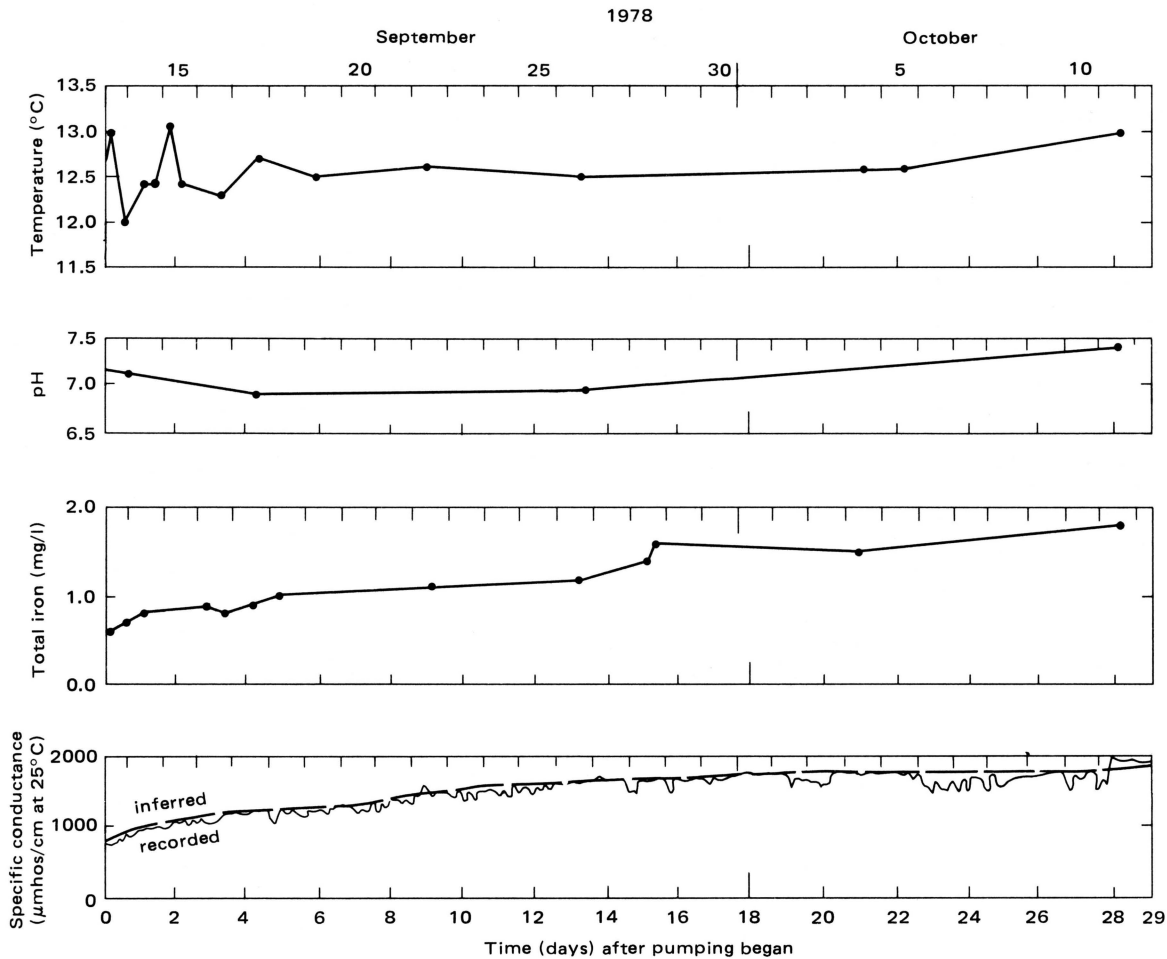


FIGURE 23.—Water-quality variations of pumped water during test 1.

mine group that did not respond to test 1. Table 4 presents test well and pump data.

The well was pumped without interruption at 230 ± 10 gal/min for 14 days, from December 14 to December 28, 1978. Discharge was measured by the time-volume method. Water was discharged into an unnamed tributary to Leatherwood Creek. Pumping was stopped after 14 days because of increasing drawdowns in nearby domestic supply wells.

The observation-site network for test 2 comprised 11 test wells, 7 privately owned wells, the air shaft near Kipling, and a pond in a mine "sink."

About 4 inches of rain fell in December prior to the test; during the test, about 0.9 inch fell December 21 and about 0.4 inch fell December 25.

Response of system

Drawdowns in observation wells completed in the Klondyke No. 1 mine were about 4 feet at the end of pumping. Shallower wells at the test site showed nearly equal drawdowns, indicating effective vertical hydraulic connection in that area. Water levels were affected by recharge from rain during the test, rising about 0.5 foot on

the sixth day of pumping before resuming the downward trend. Outflow from the air shaft, which was more than 100 gal/min before pumping, ceased within the first day of pumping.

Analysis of data from test 2 was based on the same methods and assumptions used for test 1. The nature of time-drawdown relationships were similar to those of test 1. Water levels did not stabilize during pumping, although recharge from precipitation (discussed above) exceeded the rate of discharge for about 1 day. Water levels in the nearby Blacktop, Trail Run, and Ideal mines did not respond to the pumping. As with test 1, the source of nearly all pumped water was intercepted discharge from the system and increased leakage from above. The storage coefficient of the mine zone, as determined by the graphical method described for test 1, is about 5.5×10^{-4} , similar to that determined for test 1.

The chemical quality of the pumped water did not change significantly during the test, based on field determinations of specific conductance, temperature, pH, and total iron. Temperature and pH were essentially constant at 11°C and 6.6, respectively. Specific conductance ranged from 505 to 570 micromhos, first increasing and then decreasing. Total iron decreased from 3.5 to 2.4 mg/l.

SUITABILITY OF THE MINES AS A WATER SOURCE

PRACTICAL SUSTAINED YIELD

Our estimate of practical sustained yield available from the mine system is based on the results of test pumping, hydrologic conditions during the tests, and analysis of the natural water budget.

It was concluded that the source of pumped water was largely intercepted discharge from the mine system and increased leakage from overlying rocks. No significant induced flow occurred from rocks laterally adjacent to the interconnected mines or from Wills Creek and associated alluvial deposits. Response to pumping is therefore limited chiefly to the immediate area of interconnected mines. A safe withdrawal rate depends primarily on the extent to which water levels decline and thereby affect domestic, municipal, or other water supplies.

Response of the system to pumping was affected by concurrent hydrologic conditions. Test 1 (most useful because it was longer and affected a greater mine area) was made during an unusually dry period and therefore caused greater water-level declines than might occur during periods of significant ground-water recharge. Replenishment from precipitation may, in fact, be sufficient to cause water-level rises during pumping. Such rises were observed during test 2 and during test pumping of a mine complex in southern Ohio (Klaer, 1966).

Because Wills Creek or other sources of water beyond the limits of the study area do not contribute significant recharge during pumping, a safe average withdrawal rate is limited to long-term natural ground-water recharge (or discharge) in the study area. This rate has been estimated from the following. (1) Estimated average outflow from the Byesville municipal well (GU-1001) is 1,200 gal/min. Assuming that this is essentially all the discharge from a 4-mi² area (Ideal and Norris mines plus part of Trail Run mine), it represents about 9 inches of water per year. (2) Estimated average flow from the air shaft at Kipling (GU-1002) is 100 gal/min. Assuming that this is essentially all the discharge from a 0.78-mi² area (Klondyke No. 1 mine), it represents about 4 inches of water per year. (3) Base flow in this part of Ohio is estimated to constitute about 50 percent of total streamflow (W. A. Pettyjohn, oral commun., 1979), or about 7 inches of water per year.

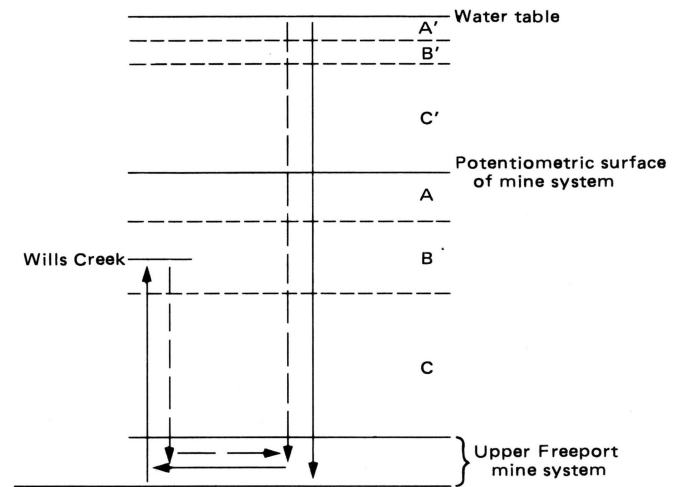
A long-term average ground-water recharge and discharge of 7 inches per year would be equivalent to about 2,900 gal/min in the area underlain by the interconnected mine system, or about 0.5 ft³/s/mi². Similar ground-water discharge rates have been determined for mined areas in West Virginia (Carpenter and Herndon, 1963, p. 6-7) and Maryland (Hollyday and McKenzie, 1973, p. 11).

Practical sustained yield through pumping is less than the natural yield of the ground-water system because not all natural discharge can be intercepted. However, because the entire interconnected mine system acts as a sink during pumping, most natural ground-water discharge can be diverted to pumping wells. In fact, a single well in the main mine would be adequate to pump the entire interconnected system.

Expected response of the system to various pumping rates is described schematically (fig. 24) in terms of relative water levels. Practical sustained yield, a long-term average that could be supported without adverse effects, is estimated

to be 1,500 to 2,500 gal/min. At any given time, however, the safe withdrawal rate depends on concurrent hydrologic conditions. Under unusually dry conditions a withdrawal rate significantly less than this long-term average might be necessary if well interference and reduction of Wills Creek base flow is to be minimized. In figure 24, the upper value of pumping-rate range C is an approximate rate which might cause dewatering in a significant part of the mine system.

No land subsidence effects were observed during test pumping. It is unlikely that subsidence would result from pumping to water levels similar to those that occurred during testing. The possibility of subsidence, particularly in areas of thin bedrock cover, may increase, however, if water levels are lowered excessively and repeatedly.



Water-level range ¹	Pumping rate (gal/min)	Probable effects of pumping
A	<1,500	Part of natural discharge intercepted and leakage from above increased. General direction (solid arrows) of natural flow through system not changed. Water-level declines probably small.
B	1,500-2,500	Most natural discharge intercepted and leakage from above increased further. Gradient direction (dashed arrows) may be reversed in discharge part of system, but induced infiltration from Wills Creek probably small because of low hydraulic conductivity of alluvium. Water-level declines in some shallow wells probably significant. Reduction of base flow to Wills Creek significant during dry periods.
C	2,500-5,000	Essentially all natural discharge diverted to the mines, which have become main sink of system. Water-level declines in some wells may be excessive. Reduction of base flow to Wills Creek significant during dry periods. Eventual depletion of ground water possible.

¹Each range of potentiometric surface (A, B, or C) and corresponding range of water table (A', B', or C') results from the indicated pumping.

FIGURE 24.—Schematic diagram illustrating probable effects of pumping water from mine system.

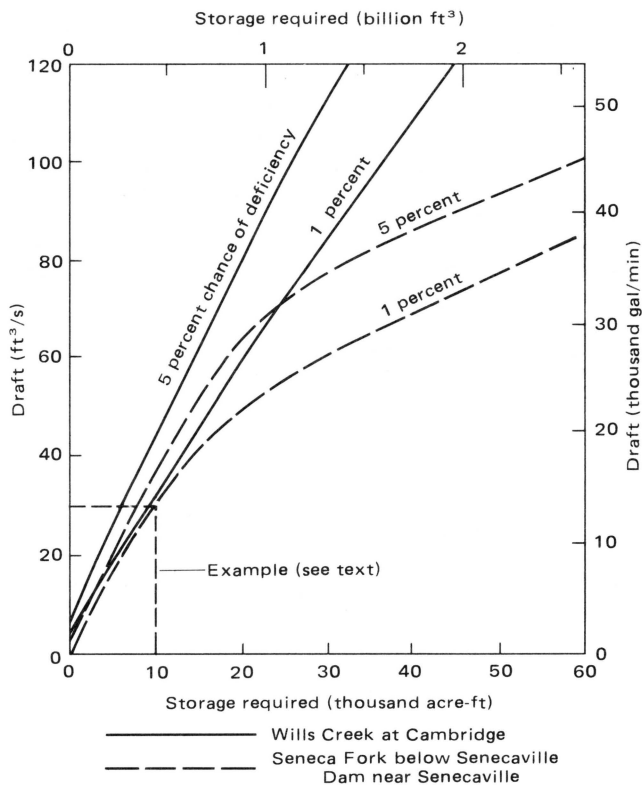


FIGURE 25.—Draft-storage relations for two gaging stations near the study area.

In addition to its water-supply potential, the mine-water system also constitutes a large heat reservoir. This reservoir could provide a means of heating and cooling through the use of a heat-exchange system such as a ground-water heat pump. In such a system, the water could be pumped from the mines, used as a heat source or sink, and returned to the mines at a separate location. Such use would not deplete the water supply and would result in minimal drawdown.

WATER-QUALITY VARIABILITY

Results of chemical analyses (table 3) probably describe a nearly complete range of chemical quality of the mine water in the study area. Areas of relatively good- or poor-quality water can be identified (see section on Water quality under Mine hydrology), depending on the properties important to a given water use.

At a given withdrawal point in the mine system, changing water quality could result from movement of water from different parts of the mine, rocks overlying the mine, and(or) adjacent mines. Water moving from different parts of a mine, as probably occurred during pumping test 1, could either improve or degrade the quality of water being pumped. The contribution of shallower water would probably improve water quality; this would likely become increasingly effective through time, as increased downward leakage is a major response to pumping. Any influence from adjacent mines, particularly if hydraulic interconnection is poor, would be expected to be significant only under relatively long-term large-scale ground-water development.

SUPPLEMENTAL SURFACE-WATER SUPPLY

AVAILABILITY

Water-supply potentials of Seneca Fork and Wills Creek were evaluated using storage analyses (Riggs and Hardison, 1973) of 1939-77 data from gaging stations on those streams. Discharge of Seneca Fork below Senecaville Dam near Senecaville is regulated by the releases from Senecaville Reservoir. Discharge of Wills Creek at Cambridge, downstream in the basin, also is affected by the reservoir operation.

Results (fig. 25) indicate the volume of storage that would be required to maintain a given sustained draft rate at given chances of deficiency. For example (fig. 25), a draft rate of 30 ft³/s from Seneca Fork below Senecaville Dam would require about 10,000 acre-feet of storage (not accounting for evaporation or seepage loss), assuming a 1 percent chance of deficiency. Draft rates up to about 4 ft³/s

TABLE 5.—Ranges and medians of selected parameters in water from two gaging stations near the study area¹

Parameter	Seneca Fork below Senecaville Dam near Senecaville			Wills Creek at Cambridge		
	Range	Median	Number of determinations	Range	Median	Number of determinations
Temperature (°C)	2.5-26	13	35	0.5-28	13	33
Bicarbonate (mg/l)	70-184	143	17	100-216	138	16
Chloride (mg/l)	3.6-22	6	38	7.5-48	18	35
Sulfate (mg/l)	41-120	62	26	66-580	242	27
Calcium (mg/l)	45-60	50	9	49-100	76	8
Sodium (mg/l)	4.9-6.9	5.5	7	8.5-59	14	5
Specific conductance (µmho)	308-465	358	44	351-1,300	817	40
Solids, sum of constituents (mg/l)	200-231	213	7	258-663	290	5
Hardness (mg/l as CaCO ₃)	120-220	170	26	160-680	331	24
pH	7.2-8.5	7.8	28	6.9-8.6	7.8	27
Iron, dissolved (µg/l)	10-30	15	6	10-70	20	5
Manganese, dissolved (µg/l)	0-380	60	7	60-870	400	5
NO ₂ + NO ₃ (mg/l)	0.01-0.71	0.23	11	0.14-2.5	0.42	10
Dissolved oxygen (mg/l)	5.3-11.3	8.2	7	4.3-10.9	7.6	7

¹ Based on samples collected and analyzed by U.S. Geological Survey between 1964 and 1977.

TABLE 6.—Suspended-sediment concentrations¹

Station	Date	Discharge (ft ³ /s)	Suspended sediment concentration (mg/l)
Seneca Fork at Buffalo	3-29-78	91.4	36
	3-30-78	576	62
Wills Creek at Byesville	3-28-78	1,300	39
	3-29-78	559	60
Leatherwood Creek at Kipling	3-28-78	242	90
	3-30-78	117	61
	6-28-78	852	315

¹ Analyses performed by U.S. Geological Survey.

at the Wills Creek station may require no storage. However, availability of surface water during dry periods is doubtful without storage facilities if pumping from the mines is concurrent, because of reduced base flow caused by the ground-water pumping.

Surface water is therefore available for supplemental supply, the amount depending on storage capacity. Surface storage may not be feasible because of the volume that probably would be required. The interconnected mines constitute a reservoir which would readily accept water at a single recharge point, with none of the well-clogging problems usually associated with recharge wells in porous-medium aquifers. However, if a potentiometric level above the mines (artesian condition) is to be maintained, storage capacity is limited by the small artesian storage coefficient of the mines. Under this condition storage capacity of the interconnected mines is only about 3.2 acre-feet (140,000 ft³) per foot of head change. Artificial recharge of any significant volume is therefore possible only if a sizeable mine area is dewatered. Before water-table conditions are reached, however, adverse effects of pumping are probable, as discussed previously.

WATER QUALITY

Evaluation of stream water for supply includes consideration of water quality. A summary of results of chemical analyses (table 5) gives values for selected parameters based on samples collected at the two gaging stations. None of the parameters show any significant seasonal fluctuation or

long-term trends.

Sediment concentration of streams is of importance in assessing potential sediment problems in using and storing the water. Although no historical data are available, samples collected and analyzed during this study (table 6) provide some examples of suspended-sediment concentration within the study area.

CONCLUSIONS

(1) About 12.4 mi² of the Cambridge Coal Field in eastern Ohio consists of abandoned and flooded mines with effective hydraulic interconnection. The mines are recharged primarily by local precipitation and discharge mainly to Wills Creek.

(2) Water pumped from the mine system is derived principally from intercepted discharge to Wills Creek and increased leakage from overlying rocks; little water is induced from laterally adjacent rocks or from Wills Creek and associated alluvium.

(3) Practical sustained yield available from the mine system is estimated to be 1,500 to 2,500 gal/min. This yield is limited by the natural ground-water recharge (or discharge) rate of the area and would vary with concurrent hydrologic conditions and allowable water levels. The estimated yield is less than expected water demands of typical commercial-scale coal-conversion facilities. Nevertheless, the mines are a potentially important source of water for smaller industrial, commercial, or municipal uses in a region where ground-water supplies are meager.

(4) Ground-water quality differs considerably among the mines. In much of the area, total dissolved-solids concentration is less than 2,000 mg/l, pH is near 7.0, and elemental concentrations are not notably high except for iron and manganese. Water in some areas, particularly in southern and eastern mines, is brackish and contains high concentrations of chloride, sulfate, and sodium.

(5) Analysis of streamflow records indicates that surface water in the study area constitutes a possible additional source of water for coal conversion or other uses. Seneca Fork or Wills Creek could supply larger quantities of water than the mines, although large storage facilities would be needed. Use of the mines for storage (by artificial recharge) would be impractical because of their small storage capacity under artesian conditions.

REFERENCES CITED

- Bennett, G. D., Ata-Ur-Rehman, Ijaz Ahmed Sheikh, and Sabir, Ali, 1967, Analysis of aquifer tests in the Punjab region of West Pakistan: U.S. Geological Survey Water-Supply Paper 1608-G, 56 p.
- Brant, R. A., and DeLong, R. M., 1960, Coal resources of Ohio: Ohio Geological Survey Bulletin 58, 254 p.
- Carpenter, L. V., and Herndon, L. K., 1963, Acid mine drainage from bituminous coal mines: West Virginia University Engineering Experiment Station Research Bulletin 10.
- Clifford, M. J., and Collins, H. R., 1974, Structures in southeastern Ohio (abs.): American Association of Petroleum Geologists Bulletin, v. 58, p. 1891.
- Condit, D. D., 1912, Conemaugh formation in Ohio: Ohio Geological Survey Bulletin 17, 363 p.
- Hollyday, E. F., and McKenzie, S. W., 1973, Hydrogeology of the formation and neutralization of acid waters draining from underground coal mines of western Maryland: Maryland Geological Survey Report of Investigations 20, 50 p.
- Klaer, F. H., Jr., 1966, Available mine water supply for Ralston Purina Company, Wellston, Ohio: Columbus, Ohio, Fred H. Klaer, Jr. and Associates, 8 p.
- Owen, C. O., & Co., 1895, Portrait and biographical record of Guernsey County, Ohio: Chicago, C. O. Owen & Co., Publishers, 545 p.
- Riggs, H. C., and Hardison, C. H., 1973, Storage analysis for water supply: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chapter B2, 20 p.
- Roy, Andrew, 1884, Coal mining in Ohio: Ohio Geological Survey, v. 5, p. 301-370.
- Sarchet, C. P. B., Col., 1911, History of Guernsey County, Ohio: Indianapolis, Ind., B. F. Bowen & Co., v. 1, 425 p.
- Stout, G. E., 1974, Proceedings of the workshop on research needs related to water for energy: Water Resources Center, University of Illinois at Urbana-Champaign, Research Report 93, 297 p.
- Wolfe, W. G., 1943, Stories of Guernsey County, Ohio: Kingsport, Tennessee, Kingsport Press, Inc., 1,093 p.