GROUND-WATER STUDY 4

by

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1.0 ABSTRACT

Geology and Occurrence of Coal

Greene County lies within the Appalachian Plateau physiographic province. As part of the Appalachian coal basin (Eastern Coal Province), the area contains much of the Nation's high-volatile, high BTU and metallurgical grade, bituminous coal reserves. The coal-bearing rocks of the basin are nearly flat-lying and consist of interbedded coal, sandstone, siltstone, shale, and limestone of Pennsylvania and Permian age. The oldest exposed rocks include the upper 60 feet of the Conemaugh Group.

The principal seams that have been developed for coal mining are the Pittsburgh, Sewickley, and Waynesburg coals of the Monongahela and lower Dunkard Groups. A large thickness of overburden has made it impractical to mine coal seams of the Allegheny Group. The upper Dunkard Group contains a few coal seams less than 3 feet thick, which have been mined locally by surface-mining methods.

Hydrology

Greene County has a temperate climate and its average annual precipitation that ranges from 38 to 41 inches. Large topographic relief (200 to 600 feet) and the interlayering of permeable and relatively impermeable rocks enhances horizontal ground-water movement and the occurrence of hillside springs. Bedrock permeability is small and attributed mostly to fracture openings along joints and bedding planes.

Unconsolidated valley-fill deposits of probable Recent age commonly are less than 25 feet thick and consist mostly of clay and silt but also contain some fine gravel. Pleistocene deposits, which are generally less than 40 feet thick and are difficult to distinguish from locally derived valley fill, have been mapped in benches along the major valleys of the study area. The saturated zone of these deposits is usually thin, but contributes significant quantities of water locally. Natural water quality of shallow aquifers is generally suitable for most uses. Mineralization of the water tends to increase with depth.

Mining Method

The Pittsburgh coal seam has a consistent average thickness exceeding 6 feet, and constitutes the major coal to be developed by subsurface methods in the area. Depth to this coal ranges from 0 feet at its outcrop to about 1,400 feet in the west-central part of the county. The eastern one-third of the Pittsburgh coal reserve has been largely removed by underground mining. In contrast, the Sewickley and Waynesburg coal seams are less persistent and thinner and have been mined mostly by small-scale surface mines.

Probable Hydrologic Consequences

Water-level declines in wells overlying underground mining operations depend on the thickness of bedrock between the mine and the well bottom and the amount of secondary permeability induced by coal excavation. Drawdown gradients are steep near the mine opening and decrease rapidly with distance away from the mine according to cross-sectional flow model results. Observation wells located in shallow aquifers above the mines and downgradient from waste refuse piles can be used to detect changes in ground-water storage and chemistry attributed to mining.

2.0 GEOLOGIC SETTING

2.1 ROCK TYPES AND CONTINUITY OF STRATA

BEDROCK IS COMPOSED OF SANDSTONE, SILTSTONE, SHALE, LIMESTONE, AND COAL INTERBEDDED IN COMPLEX SEQUENCES

Sedimentary strata vary in thickness, shape, and lateral extent. Bedrock in Greene County consists of interbedded sandstone, siltstone, shale (or mudstone), limestone, and coal. Sandstone and limestone are the thickest lithologic units, exceeding 90 feet in some areas (fig. 2.1-1). However, sandstones and limestones where they are interbedded with thin shales and siltstones are commonly less than 20 and 3 feet thick, respectively. Coal beds are typically less than 10 feet thick and contain one or more claystone partings.

The lower and upper limits of each bedrock formation are either marked by persistent limestones or by easily correlatable coal beds (fig. 2.1-1). In most areas, contacts with overlying formations are conformable. The predominant rock type of the Glenshaw and Casselman Formations is mudstone, interbedded with some sandstone and limestone. The Pittsburgh Formation is composed mostly of limestone and contains persistent coal seams. The basal unit of the Lower Member is the Pittsburgh coal, which is the most valuable coal unit in the county. The Uniontown Formation consists of a dominantly shale member overlying a limestone member. Both members contain siltstone, sandstone and coal. The Waynesburg Formation usually contains one or more massive channel sandstones, and the Washington and Greene Formations have numerous lenses of siltstone or calcareous mudstone and some sandstone.

The unconsolidated Carmichaels Formation, which unconformably overlies many of the bedrock formations exposed in Greene County, is composed of mostly clay and iron-stained sand. The Carmichaels is usually less than 40 feet thick and is difficult to distinguish from locally derived valley fill. Unconsolidated valley-fill deposits, which consist mostly of clay and silt and also some fine gravel, commonly are less than 25 feet thick.

With the exception of certain coal seams, the geometry of individual lithologic units is variable and complex. The cycle of deposition (cyclothem) (fig. 2.1-2) is representative of the geology just north of the study area (1) and, although idealized, is believed to be representative of the lithologic associations found in Greene County. A relatively persistent coal seam, at the base of the cycle, is overlain directly by a sandstone or mudstone. The next overlying lithologic units may be any one of the four general associations: (1) channel deposits of cross-bedded sandstone; (2) sheet-like deposits of interbedded sandstone, siltstone, and mudstone; (3) lenticular or sheetlike deposits of mudstone, limestone, and siltstone; and (4) lenticular or tabular deposits of limestone and mudstone. The sequence, whichever is present, is topped with a claystone or underclay to a coal, which may begin the next cycle of deposition. Hence, individual units are discontinuous, with lithologic variation greatest in the direction perpendicular to bedding.

Sandstones are mostly fine grained, contain 60-75 percent quartz, and have a siliceous cement. The texture in channel-type deposits is coarse grained. Siltstones commonly are mixed with mudstone. Shales (mudstones) are fissile to plastic and consist of the clays illite, chlorite, and kaolinite (1). Limestones (marlstones) are microcrystalline with a calcite matrix, less than 8 percent dolomite, and contain more than 10 percent clay minerals. Coal beds are bituminous and contain claystone partings and pyrite locally.

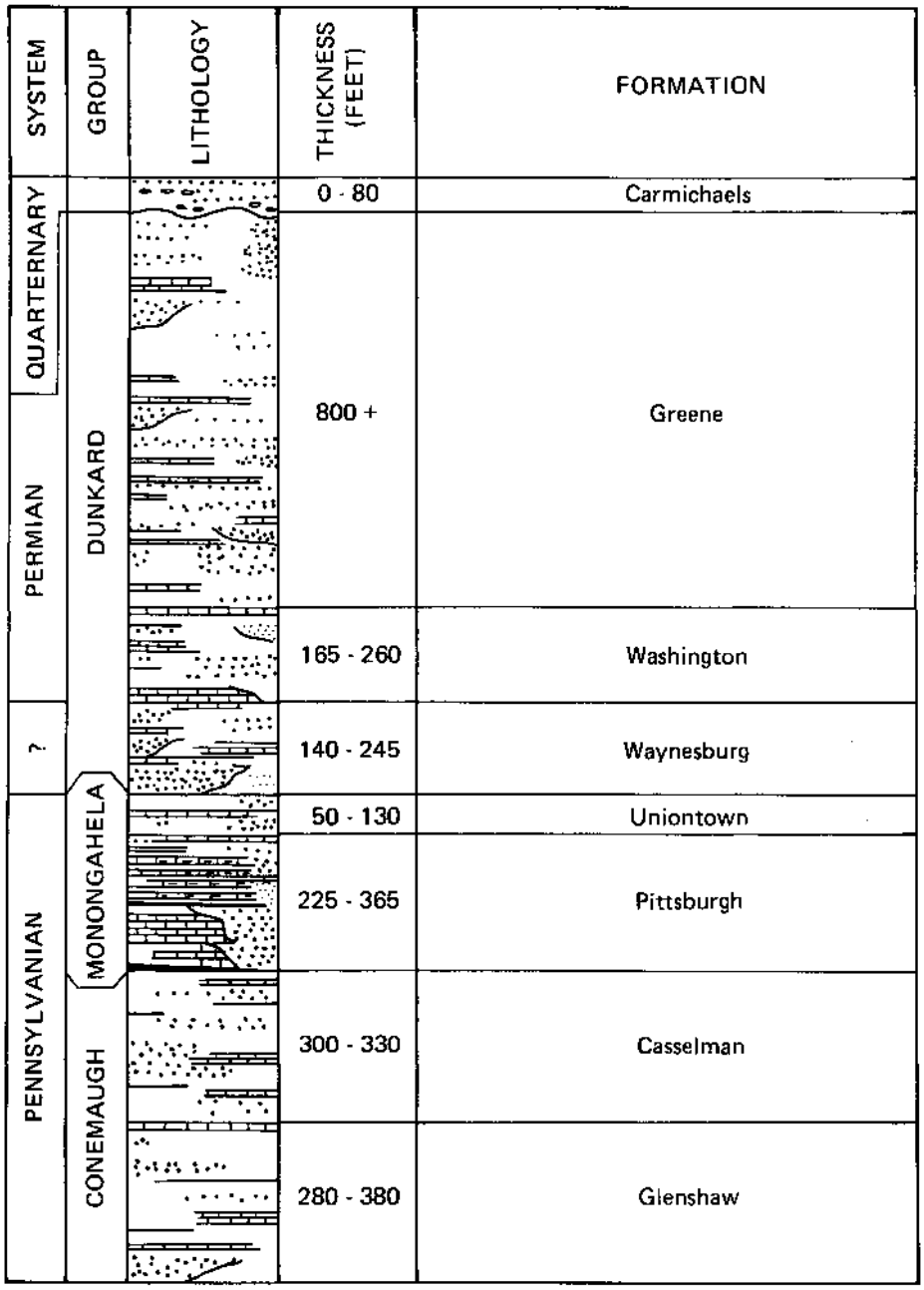


Figure 2.1-1.—Generalized geologic column for Green County.

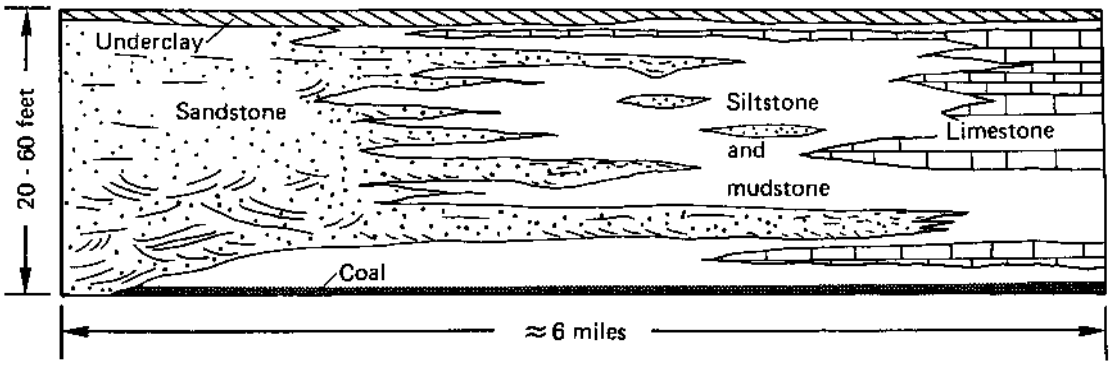


Figure 2.1-2.— Idealized section of lithologic associations.
(Modified from Berryhill and others, 1971)

2.0 GEOLOGIC SETTING

2.2 STRUCTURAL GEOLOGY

BEDROCK HAS BEEN GENTLY FOLDED TO FORM SUBPARALLEL ANTICLINES AND SYNCLINES

The bedrock dips at angles of less than 3˚; orientation of the folds generally correlates with local joint directions.

The dip of strata, jointing, and faulting can affect ground-water flow patterns in the county area. The effect is especially true for natural flow of the shallow ground-water system and flow to and from surface mines. Vertical fracture zones might interconnect deep subsurface mines and shallow aquifers. Therefore, a brief discussion of structural geology of the study area is important.

Bedrock has been gently folded to form a series of subparallel anticlines and synclines trending north to northeast (fig. 2.2-1). Dips of the rocks generally are less than 3˚. The bases of coal seams, such as the Pittsburgh seam, probably were nearly horizontal prior to folding, are easily identifiable in test holes, and are relatively continuous between test borings. For these reasons, the bases of coal seams are useful in identifying local and regional attitudes of strata in the Pennsylvanian and Lower Permian rocks of the region. The altitude of the base of the Pittsburgh coal seam as determined from drill-hole data was used to prepare the structure-contour map (fig. 2.2-1).

Fractures and joints occur in most of the rocks. Systematic joint sets in coal, termed cleat, tend to follow the regional structure. Face cleat, the predominant joint set, trends N. 70˚ W. in the Pittsburgh seam or perpendicular to regional folding in Greene County. Butt cleat, or secondary jointing, is generally parallel to folding (fig. 2.2-1).

Joints in surface outcrops of sandstone and limestone also tend to follow the regional structure (fig. 2.2-2). The Roman numerals indicate the relative order of dominance, with 'I' being the greatest. Photolinear features such as straight river courses, stream valleys, and abrupt right-angle bends of streams as determined from infrared aerial photographs (fig. 2.2-3) may be useful in identifying regional jointing trends. The most dominant photo-lineaments (Roman numeral I) correlate closely to the Pittsburgh coal cleat. Photolineaments may also be indicative of major fracture zones. The reader is referred to the Reports of Investigation series by the U.S. Bureau of Mines for further information on methods of data analysis for jointing in this coal region.

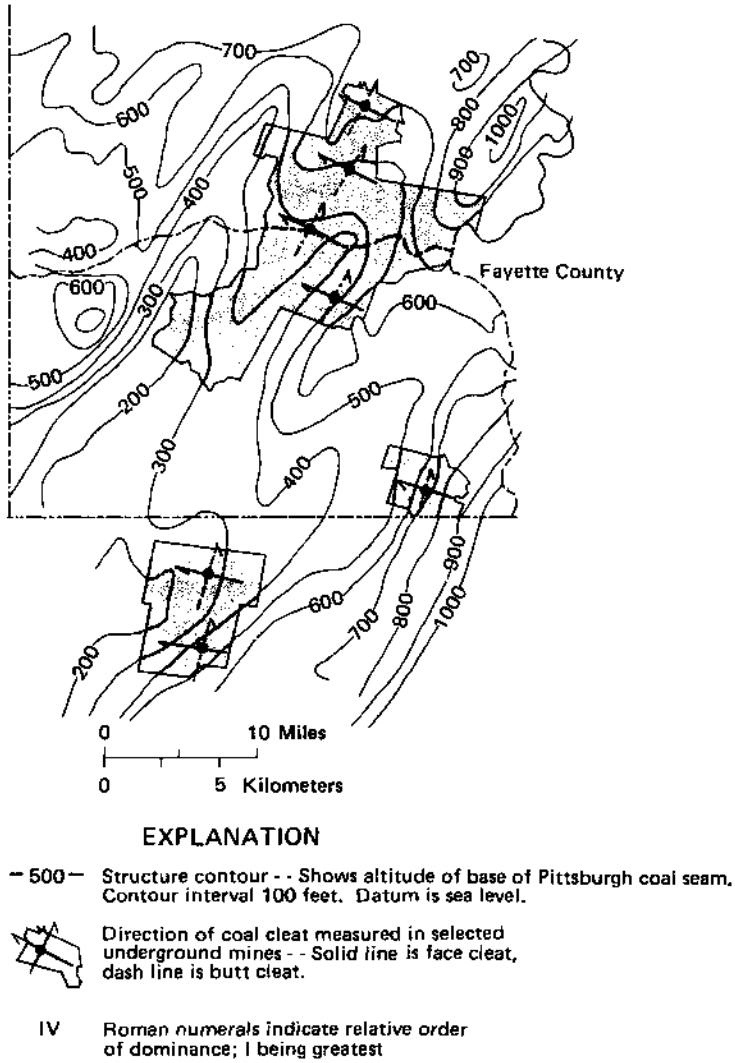


Figure 2.2-1.— General structure and cleat direction of Pittsburgh coal seam in and near Greene County.
(Modified from McCulloch and others, 1976)

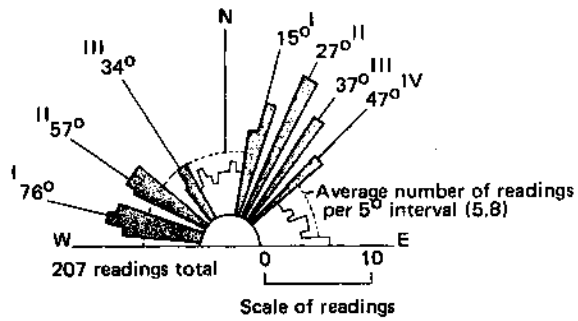


Figure 2.2-2.— Composite rose diagram of principal surface joint trends.
(From Diamond and others, 1967)

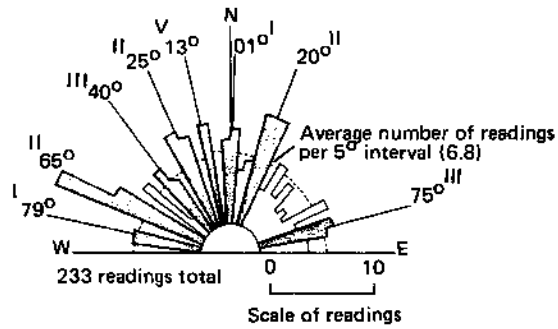


Figure 2.2-3.— Composite rose diagram of principal infrared photograph photolinears.
(From Diamond and others, 1967)

3.0 GROUND-WATER HYDROLOGY

3.1 RECHARGE, OCCURRENCE, AND MOVEMENT

AN ACTIVE, SHALLOW FLOW SYSTEM OVERLIES A DEEPER, STAGNANT FLOW SYSTEM

Ground water is stored in all rock types but moves most readily through joints and fracture openings at shallow depths.

The source of ground water is precipitation. The mean annual precipitation ranges from 38 to 41 inches across Greene County. Part of the precipitation returns to the atmosphere via evaporation and transpiration, part flows overland into streams, and part seeps downward through soils and rock to the saturated zone. Within the saturated zone, movement continues downward and laterally toward discharge locations such as springs and streams and upward toward major stream valleys (fig. 3.1-1). Analysis of streamflow hydrograph separation (into base-flow and direct-runoff components) indicates that, on the average, 22 to 25 percent of annual precipitation circulates through the aquifer system of Greene County. Shallow local aquifers, exposed in the area, receive direct recharge from rain or snowmelt. The deeper, regional aquifer system is recharged by leakage from the overlying aquifers or from streams in upland valleys.

Water occurs in fracture openings and intergranular pore spaces in all rock types below the water table. The size and interconnection of the fracture openings and pores control the permeability of the bedrock, which constitutes the larger part of the bedrock permeability. Fracture openings tend to diminish in width and number as overburden thickness increases; thus, bedrock permeability is reduced with depth.

Most ground-water circulation is within the shallow, more permeable bedrock aquifers. Downward movement beneath hills is retarded by relatively impermeable confining layers such as shales, mudstones, and unfractured limestones. At shallow depths below the water table, such confining layers can cause perching of ground water and lateral flow to hillsides where the water discharges at springs or seeps. At greater depths, the hydraulic head is commonly great enough to force vertical leakage through confining layers into the underlying confined aquifer units (fig. 3.1-1). Vertical head loss is reflected by decreasing water levels as well depths increase in such recharge areas. The water level indicated by each well (fig. 3.1-2) represents average annual head of the interval open to the well. Water levels at well sites A, and B show a vertical head loss with depth.

Movement in the deeper regional aquifer system is predominantly lateral toward major valleys and relatively stagnant in comparison to the more permeable shallow flow system. Vertical leakage through confining layers beneath major valleys is usually upward. Wells drilled in such discharge areas flow or their water levels become higher as well depth increases, as shown by well site C of figure 3.1-2. The deeper bedrock aquifers contain brackish to salty (saline) water that has not been flushed by fresher shallow water circulation (fig. 3.1-1). The salty (saline) brine, which is about 1,700 feet below average land surface in Greene County, marks the base of the regional fresh water aquifer system.

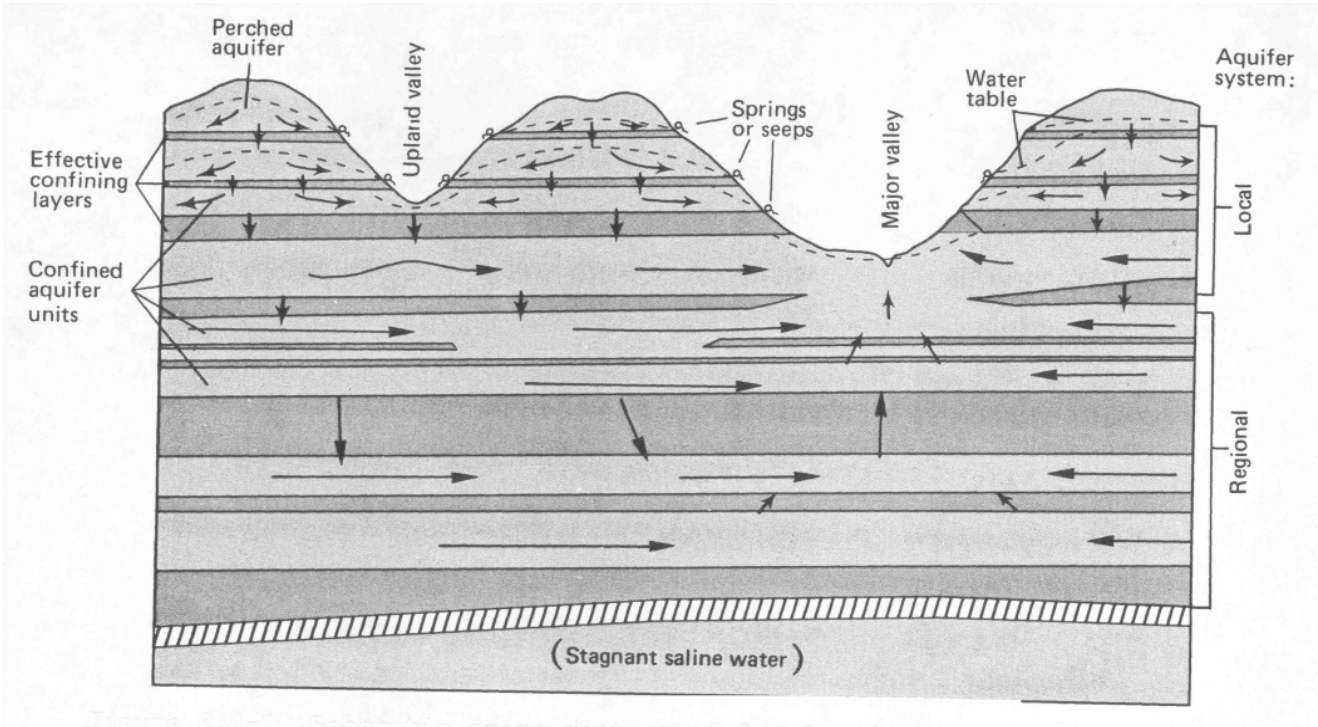


Figure 3.1-1.— Schematic cross section of local and regional ground-water movement. (Length and number of arrows are generally proportional to relative flow rate.

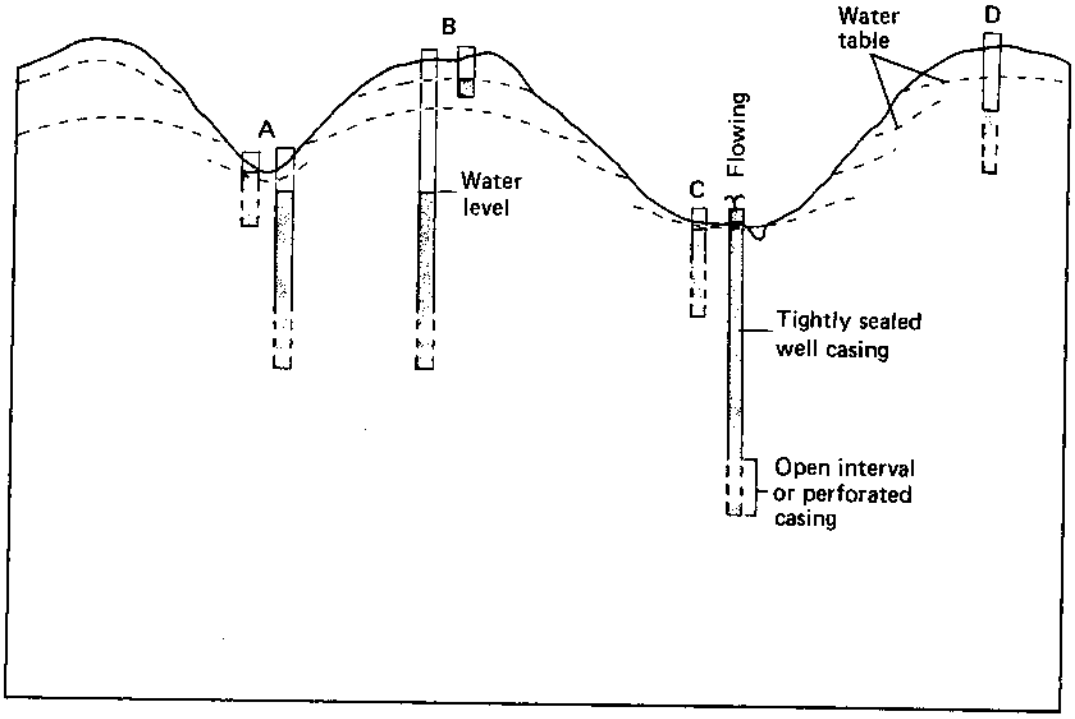


Figure 3.1-2.— Relationship of water levels in wells to well depth and topographic position.

3.0 GROUND-WATER HYDROLOGY

3.2 WATER-LEVEL FLUCTUATIONS

WATER-LEVEL CHANGES IN DIFFERENT WELLS REFLECT VARIABLE RECHARGE

Aquifer storage capacity, permeability, and potential recharge are principal hydrologic conditions that affect water-level fluctuations in wells.

Water-level hydrographs from four different wells in Greene County show the relationship between water-level changes and rainfall (fig. 3.2-1). The relative depths and topographic positions of the wells are indicated in figure 3.2-2. Daily water-level changes range from about 0.2 foot in deep confined aquifers to about 5 feet in shallow bedrock aquifers. Of the bedrock wells (numbers 602, 118, and 803), the hilltop well (602) shows the greatest water-level fluctuations and the valley well (803) shows the least change. Well 804, which is completed in unconsolidated alluvium, also responds readily to rainfall.

The observed results are related primarily to differences in potential for recharge, aquifer-storage capacity, permeability, and location with respect to the ground-water flow system. Wells 602, 118, and 804 are essentially completed in water-table aquifers that receive recharge directly from percolation. Potential recharge to the water table is affected by precipitation intensity and duration, land slope, vegetation, and soil-moisture conditions. Recharge potential is probably smallest at the forested hillside site (well 118) and largest at the flat, grassed, valley site (well 804) where surface runoff tends to collect.

Recharge potential at the sparsely forested hilltop site (well 602) is probably in between that of the hillside and valley sites. Recharge is also proportional to soil-moisture content. Water-table levels respond more readily to rain during moist soil conditions, such as in June (fig. 3.2-1), than during dry soil conditions, such as in mid-July.

Specific yields of the bedrock water table aquifers penetrated by wells 602 and 118 probably are similar, and the differences in water-level response to recharge may be due to differences in infiltration. However, alluvial aquifers generally have larger apparent specific yield than shallow bedrock aquifers in Greene County. This could explain why water-level rises are larger in bedrock well 602 than in alluvial well 804, even though recharge from the same rainfall event may be larger at well 804.

Well 803 is completed in a confined aquifer about 100 feet below the water table. Daily water-level fluctuations are small in comparison to the other three hydrographs and correlation to rainfall is not readily apparent. Confined aquifers have storage coefficients that are usually several orders of magnitude smaller than the specific yield of water-table aquifers. Given the same recharge, water-level rises are expected to be much greater in a confined aquifer. However, recharge to confined aquifers is generally much slower and smaller than that received by the overlying water-table aquifer. Water-level rises observed in well 803 represent small pressure changes and slow leakage applied through the confined layers.

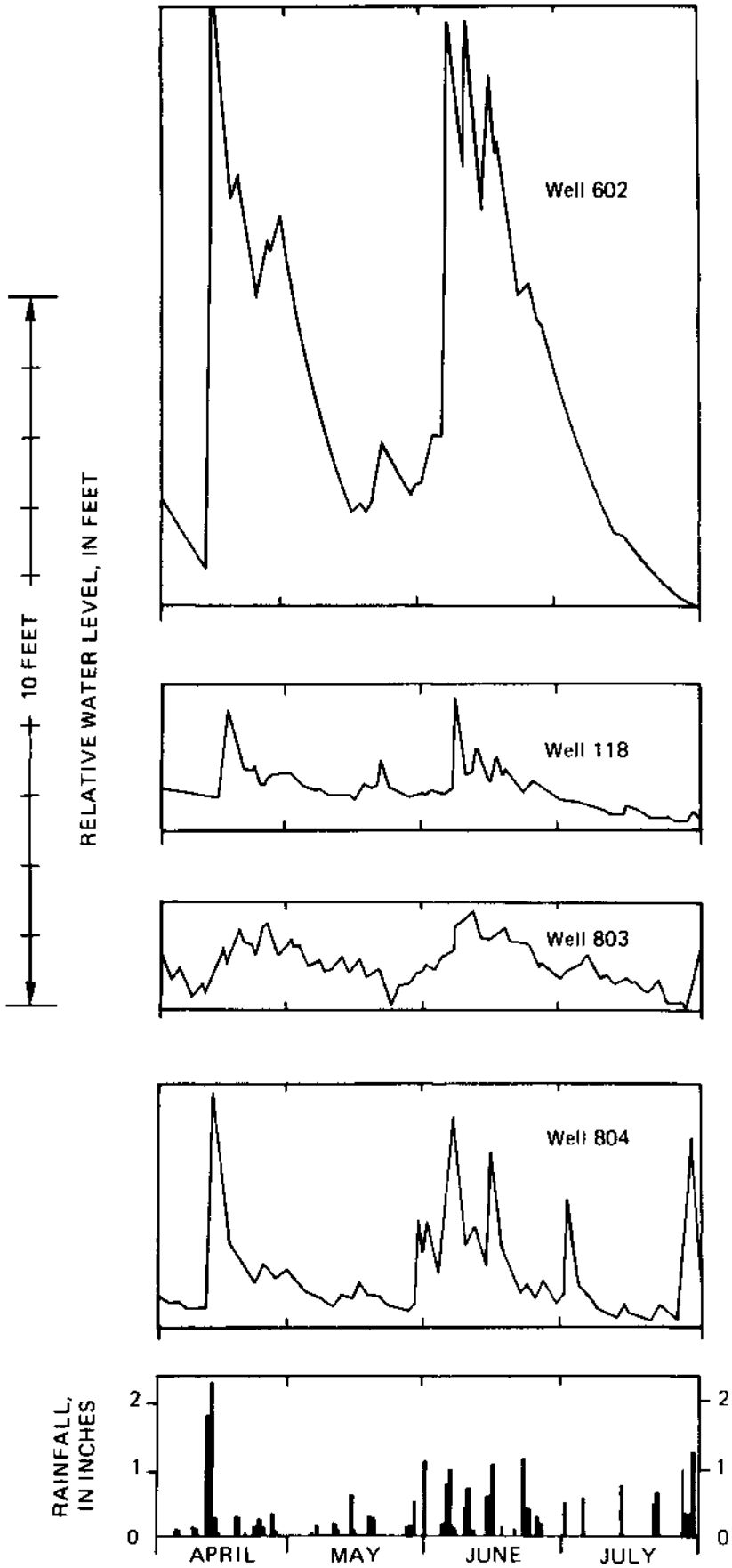


Figure 3.2-1.— Comparison between water-levels in wells and daily rainfall.

The number and type of aquifers tapped by a well must be defined before aquifer-storage changes due to natural or mining-related conditions can be accurately evaluated. Bedrock wells, with large open-hole intervals, effectively tap and interconnect a number of aquifer units. Such an open-hole well, located along a hilltop, functions like a leaky cistern, in which the well bore receives recharge water rapidly from the shallow aquifers and loses the water more slowly to deeper, less permeable aquifer zones. The hydrograph of well 602 may show this cistern effect to a certain extent. The water level in another hilltop well (not shown), which is 165-feet deep and has only 21 feet of casing, rises as much as 45 feet in less than a day and takes more than a month to return to the original level. Such a well may poorly represent storage changes within all aquifer units open to well. Many existing domestic and stock wells in Greene County are constructed by the open-hole method to provide greater yield and well storage.

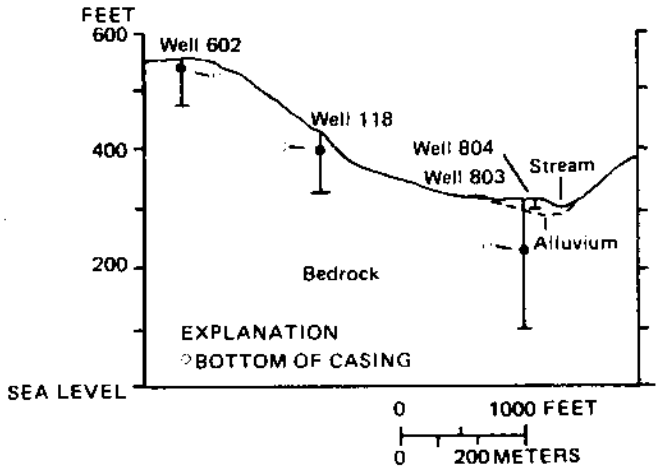


Figure 3.2-2.— Representative topographic setting of observation wells.

3.0 GROUND-WATER HYDROLOGY

3.3 AQUIFER IDENTIFICATION

FRACTURE PERMEABILITY COMMONLY ASSOCIATED WITH SANDSTONES AND COALS

Well and spring inventory, test wells and borehole geophysical logs are used to locate water-bearing zones in bedrock.

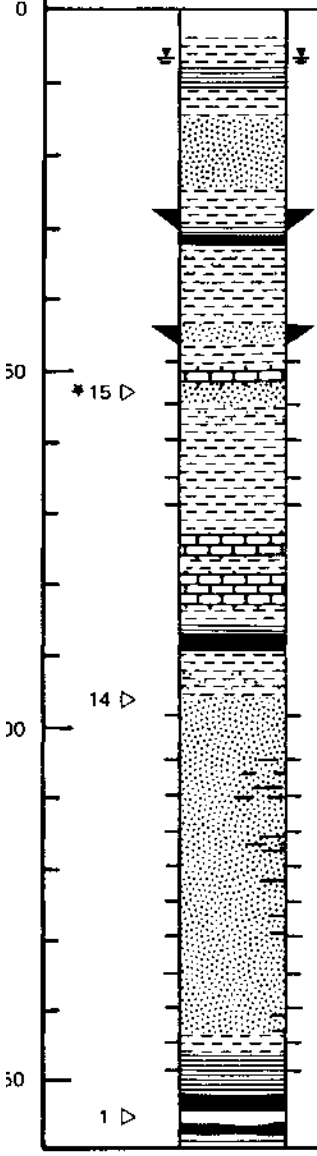
Bedrock in the study area normally yields water to wells and springs through discrete fractures such as joints and bedding-plane openings. Waterbearing zones are most common in fractured sandstone and coal but also occur at changes in lithology. Shale, mudstone, and dense limestone are usually confining layers. Therefore, lithology can be used to correlate aquifer units across an area.

Well and spring inventory is a relatively inexpensive and rapid method of identifying aquifers. The types of data obtained and presented in the U.S. Geological Survey water-resources reports is shown in table 3.3-1. Other sources of such data include water-well completion reports, U.S. Department of Agriculture Soil Conservation Service spring records, and field inventory. The types of data provided by each of these sources are indicated in table 3.3-1. Complete inventory coverage is rarely achieved from any single source. Current information on water levels, discharge rates, use status, and ownership are best obtained by field checking. Locations are plotted on 7½-minute topographic quadrangle maps and latitude, longitude, and altitude of land-surface elevation are determined.

Springs and shallow wells can be used to locate water-table or perched water-table aquifers. Springs and seeps that occur at the same altitudes along a hillside are usually the result of local perched aquifers. Generally, the water table ranges from 25 to 70 feet below the surface along hilltops and is less than 10 feet below the surface in valleys. Most aquifers below the water-table aquifer are confined by underlying and overlying less permeable beds.

Test wells provide a more reliable method of identifying aquifers, particularly in areas where wells are few or nonexistent. An example of the pertinent hydrogeologic and well-construction information for confined sandstone aquifer units is indicated in figure 3.3-1. The descriptions of drill cuttings and geophysical logs were used to construct the detailed columnar section. The most useful geophysical logs for ground-water study in Greene County included gamma, density, electric, temperature, and caliper. Application of these and other logs to ground-water work is described in (7). Columnar sections from several wells may be used to draw a cross section, which helps to describe the location of a particular aquifer unit and its relative continuity with respect to a minable coal seam.

WELL NUMBER: GR 813 | LAND OWNER: WAYNESBURG COLLEGE
LATITUDE: 39° 54' 03" | LONGITUDE: 08° 01' 00"
LAND SURFACE ELEVATION= 947 FT. | DATE DRILLED: 11 - 21 - 80
STATIC WATER ELEVATION = 940 FT. | DATE MEASURED: 3 - 24 - 82
WELL DEPTH: 159 FT. | FORMATION: WAYNESBURG
PRINCIPAL AQUIFER UNIT(S): Thin sandstone 20 feet below Waynesburg 'B' coal and Waynesburg sandstone.



STRIP COLUMN	DEPTH INTERVAL (Feet)	WELL CUTTING DESCRIPTION
	0 - 4	Loam
	4 - 15	Shale, gray, dark - gray, black; trace of coal, (Little Washington Coal) at 9 ft
	15 - 24	Sandstone, gray, fine - grained, micaceous
	24 - 31.5	Shale, gray, dark - gray
	31.5 - 32.5	Coal, impure, (Waynesburg 'B')
	32.5 - 44	Shale, gray, dark - gray; silty shale; brown, hard, siltstone
	44 - 46	Sandstone, light - gray, gray, fine - grained
	46 - 50	Shale, gray
	50 - 52	Limestone, tan
	52 - 55	Sandstone, gray; Crevice at 53 - 54.5 ft
	55 - 73	Shale, gray; gray, silty shale
	73 - 76	Limestone, tan
	76 - 79	Shale, gray
	79 - 83	Limestone, tan
	83 - 87	Shale, dark - gray, black
	87 - 89	Coal, impure, (Waynesburg 'A')
	89 - 96	Shale, gray, sandy
	96 - 144	Sandstone, light - gray, fine - medium - grained (Waynesburg sandstone)
	144 - 153	Shale, dark - gray, black
	153 - 158.5	Coal, (Waynesburg) with a 1 ft shale parting at 155 ft
	158.5 - 159	Shale, black

WELL CONSTRUCTION

Diameter and depth of hole: 6¼ in. x 159 ft
Casing diameter and type: 4 in. - PVC
Casing length: 160 ft
Casing perforations: 49 - 69, 99 - 149 ft
Formation packers: 28, 44 ft
Seal type and location: bentonite and neat cement from land surface to 28 ft

15 ▷ Water Bearing Zones at 53, 96, 155 ft; Numbers are yield estimates from each zone in gallons per minute

* Crevice from 53 to 54.5 ft

Figure 3.3-1.— Lithology and well-construction information for test well GR 813 in Franklin Township.

Table 3.3-1. – Record of selected wells and springs from the Greene County study.

[gal/min, gallons per minute; gal/min/ft, gallons per minute per foot of drawdown;
Data source: D, driller's water-well completion report; F, field visit and property owner interview; S, Soil Conservation Service spring records]

Data Source	F			D,F	D,F	D,F	F	F	F	F		
Well location												
Well number	Latitude	Longitude	7½ minute quadrangle map name	Owner	Driller	Year completed	Use	Altitude of land surface above sea level (feet)	Topographic setting	Aquifer lithology	
116	395257	802700	Wind Ridge	Ryerson State Park	Pa. Drilling Co.	1962	P	999	V	Wbrg	sandstone
322	395543	802352	Wind Ridge	Ross, David	E. Byron Braddock	1977	H	1,154	S	Wsng	sandstone
365	395617	802258	Wind Ridge	Minton, Robert	E. Byron Braddock	1977	U	1,136	V	Gren	sandstone and shale
402	395132	801158	Oak Forest	Orndoff, Charles	—	—	S	973	V	Pbrg	limestone, sandstone and shale
510	395243	802313	Wind Ridge	Robinson, Barbara	Allen Burns	1976	H	1,210	S	Gren	limestone
516	395456	802916	Wind Ridge	Parley, Frank	E. Byron Braddock	1977	H	912	V	Wbrg	sandstone
519	395439	802614	Wind Ridge	Staggers, Anna	E. Byron Braddock	1969	H	1,380	S	Gren	shale
533	395309	802933	Wind Ridge	Weekly, Roger	E. Byron Braddock	1978	H	1,340	H	Gren	shale
654	395538	802226	Rodgersville	Miller, D.	Steve Harman	1978	U	1,070	V	Gren	shale
727	395510	802928	Wind Ridge	Barnhart, Harold	E. Byron Braddock	1977	H	920	S	Unnn	limestone, sandstone and shale
801	395259	802706	Wind Ridge	USGS	Stockert Drilling Co.	1980	O	1,011	H	Wbrg	sandstone and shale
802	395812	802649	Wind Ridge	USGS	Stockert Drilling Co.	1980	O	946	V	Wbrg	sandstone and shale
804	395807	802652	Wind Ridge	USGS	Stockert Drilling Co.	1980	O	939	V	Alvm	sand, gravel and clay

Data Source D,F	D			D	F		D,F	D	F	F
Well number	Well depth below land surface (feet)	Casing		Depth to water-bearing zones (feet)	Static Water Level		Yield (gal/min)	Specific Capacity (gal/min/ft)	Specific Conductance (micromhos at 25˚ C)	PH (units)
		Depth (feet)	Diameter (inches)		Depth below land surface (feet)	Date measured				
116	138	19	12	95; 115	36	10/69	6	0.40	2,190	8.6
322	80	17	8	40	30	9/79	1	—	435	—
365	76	23	8	30; 50	30	9/77	4	—		—
402	600	7	3.5	—	F	9/81	1	—	780	7.5
510	74	25	8	35; 51	—	—	2	—	580	—
516	53	18	10	32	18	10/79	6	—	360	6.4
519	40	—	8	26	10	3/69	20	.80	1,680	—
533	184	22	8	85	54	2/80	2	.08	425	7.5
654	60	1	4	—	0.3	5/80	6	1.2	690	9.1
727	79	—	5	—	63	7/80	1	—	330	7.2
801	163	10	6.5	—	47	10/80	1	.02	1,750	8.6
802	218	18	6.5	98; 118	10	12/81	45	2.2	11,000	7.6
804	19	4	6.5	—	5	12/81	4	1.6	725	7.4

Remarks:
Owner: USGS, U.S. Geological Survey
Use: H, domestic; P public; S, stock; O, observation; U, unused
Topographic setting:
H, hilltop or ridge;
S, hillside; V, valley.
Aquifer: Formation names:
Pbrg, Pittsburgh;
Unnn, Uniontown;
Wbrg, Waynesburg;
Wsng, Washington;
Gren, Greene;
Alvm, alluvium.
Static water level: F, flowing.

Data Source:	S,F			S,F	S,F	F	F	F	F	S,F	F	F	F	F
Spring location														
Spring number	Latitude	Longitude	7½ minute quadrangle map name	Owner	Use	Altitude of land surface (feet)	Aquifer	Permanence	Improvements	Date yield measured (M) or estimated (E)	Yield (gal/min)	Date quality parameters measured	Specific conductance (micromhos at 25 ˚C)	PH (units)
1303	395112	801520	Holbrook	Greenlee, Dr. P.	S	1,360	Gren	Perennial	Trough	E 10/25/79	1.5	10/25/79	750	7.6
1304	395105	801645	Hol brook	Shriver, Ephriam	H	1,100	Gren	Intermittent	Trough	M 10/25/79	.1	10/25/79	520	7.2
1701	395619	802430	Wind Ridge	Whipkey, Reed	H	1,180	Wsng	Perennial	Other	M 11/21/80	2.0	11/21/80	390	7.7
1702	395624	802425	Wind Ridge	Whipkey, Reed	U	1,200	Wsng	Intermittent	None	M 11/21/80	.0	11/21/80	220	7.0
1798	395239	802303	Wind Ridge	Richardson, Lester	U	1,160	Gren	Perenial	Spring House	E 8/28/81	.1	8/28/81	450	7.3
2000	394527	801931	Holbrook	George, Norman	H	1,080	Gren	Perenial	Spring House	M 9/ 1/81	1.0	9/ 1/81	235	7.5
2305	394659	802925	New Freeport	Yoss , Elmer	H	1,440	Gren	Perenial	Trough	M 8/27/81	.1	8/27/81	325	8.2

3.4 ESTIMATION OF AQUIFER PROPERTIES

AQUIFER TEST METHODS USED TO ESTIMATE TRANSMISSIVITY AND STORAGE COEFFICIENTS

Time-drawdown, specific capacity, recovery, and slug tests provide estimates of aquifer characteristics. Borehole storage, well development, and impermeable boundaries are common test considerations.

Quantitative evaluation of ground-water flow requires a knowledge of hydraulic coefficients, such as transmissivity (T), storage (S), and apparent specific yield (S_{ya}). Several controlled well tests were used to estimate these characteristics in Greene County. The following examples illustrate methods and analysis found to be most useful in the bedrock aquifers.

A two-well aquifer test was designed to determine the continuity and to estimate hydraulic coefficients of the Waynesburg Sandstone Member of the Washington Formation near Ryerson Station State Park, western Greene County. The pumped well was an existing Park water-supply well (116) that is open to the lower Waynesburg Formation containing 45 feet of Waynesburg Sandstone. An observation well (801) was drilled 435 feet distant (fig. 3.4-1) to a depth of 159 feet and completed in the same stratigraphic unit. Before drilling the observation well, a procedure outlined in (10), was used to estimate the time rate of expansion of the cone of depression to help determine an appropriate distance between the pumping well and the observation well for the aquifer test. Values of transmissivity between 0.1 and 20 ft^2/d and storage coefficient between 10^{-5} and 10^{-4} (for confined aquifers), and a pumping rate of 7 gal/min were used in the analysis.

The Waynesburg Sandstone Member is mostly silty to sandy shale at well 801, which differs markedly from the medium- to coarse-grained sandstone tapped by well 116. Well development of well 801 indicated a yield of less than 1 gal/min or 10 times less than the reported yield of well 116. At such a small low yield potential, well 801 obviously could not be used as the pumping well for the aquifer test. Well 801, nevertheless, was suitable as an observation well for pumping well 116, as the drawdown rate in well 801 was expected to be small.

Tests were first conducted on well 801 for later comparison to the two-well test. In addition to surging with air by the driller, the well was overpumped a number of times to ensure full development. A slug-test method, adapted from (3) and outlined in (8), was conducted by quickly injecting a weighted pipe capped at both ends that had a volume of 0.200 ft. The timed water-level response and sample calculation of transmissivity and storage are shown in figure 3.4-2. This test method explicitly considers well-bore storage and was found to work well in small-yielding aquifers where the water-level response occurred entirely within tightly sealed casing. However, slug tests in which the water level fluctuated in the open hole (below the bottom of casing) or in poorly sealed casing generally did not plot on any of the theoretical type curves. Under such conditions, the measured response may not represent the intent of the method.

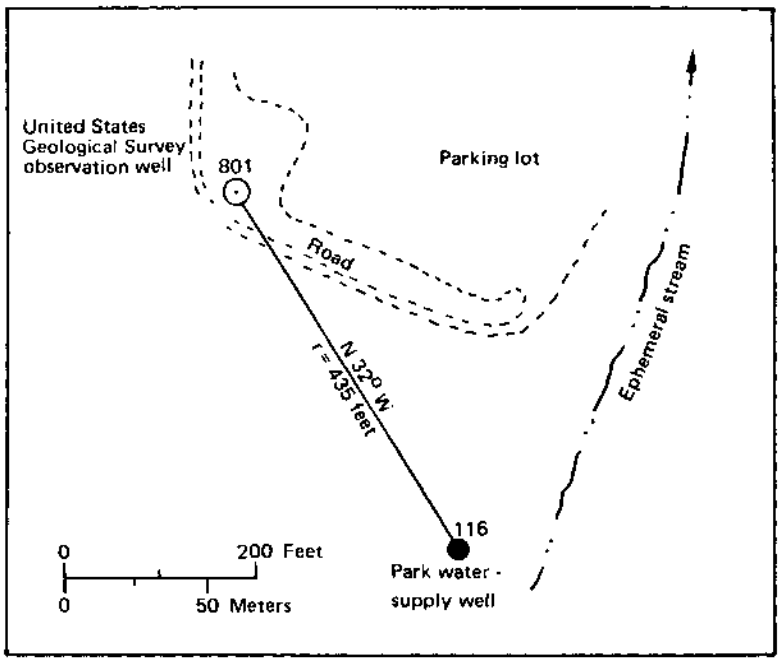


Figure 3.4-1.— Location of aquifer test site at Ryerson Station State Park.

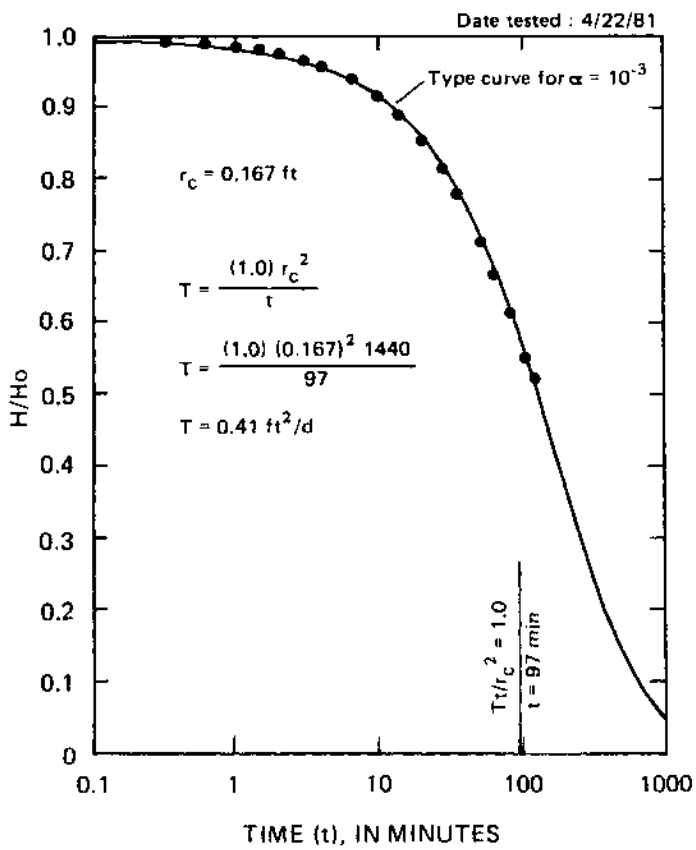


Figure 3.4-2.— Slug-test plot from well 801.

Antecedent water-level trends determined for several hours prior to a slug test were useful for correcting the slug-test water-level response. The slug test has limitations in that it provides hydraulic properties of an aquifer only very close to the well borehole. Furthermore, the determination of storage coefficient is quite sensitive to personal judgment in curve matching (3). Nevertheless, the slug-test method is simple, gives reasonable results in properly developed wells, and can add corroborative support to other tests.

Specific-capacity and recovery tests were also tried at well 801. Borehole storage contributed much of the water during the drawdown pumping. Drawdown data after 40 minutes of pumping gave results similar to the slug test. The recovery test resulted in a value one order of magnitude less than the transmissivity determined by the slug-test results. The transmissivity of the lower Waynesburg Member aquifer, which is 44 feet thick near well 801, is probably between 0.04 and 0.4 ft^2/d.

Periodic pumping with normal use of the Park supply well results in a drawdown response at well 801 about 2 hours after pumping starts. From this information and development-test data of well 116, a reasonable pumping rate was estimated which would provide sufficient time-drawdown data at well 801 without dewatering the pumping well 116. The Park supply well was taken offline 1½ days before the aquifer test to allow some recovery of the aquifer system from that use. Figure 3.4-3 shows the time-drawdown response of both wells as a result of pumping well 116 at a constant rate of 9.8 gal/min for 780 minutes.

With the exception of the first two measurements, the drawdown data from the observation well match the Theis type curve. However, the early time data from the pumping well match poorly to the Theis curve. Discharge was controlled to within 2 percent of 9.8 gal/min during the test except during the first minute of pumping when it was much larger. Furthermore, the water level dropped below the bottom of the casing of the pumping well early in the test. Both conditions provide a plausible explanation of the poor early time fit with the Theis curve. Use of the delayed yield from storage type-curve procedure (2, 8) or matching the Theis curve to late-time data gives a transmissivity estimate larger but in the same order of magnitude as that determined from the observation-well data.

The Jacob analysis method (10) was also applied to the same aquifer-test data (fig. 3.4-4). The value of transmissivity obtained from the pumping well is practically the same as that determined by the Theis method for the same well. However, the value of transmissivity on the observation-well data as determined from the Jacob method (false T in fig. 3.4-4) is more than twice the value. Recall that one restriction of the Jacob method (10) is that:

$$\frac{r^2}{4at} < 0.01$$

where $a = \frac{T}{S}$ for confined aquifers,

and $a = \frac{T}{S_{ya}}$ for unconfined aquifers

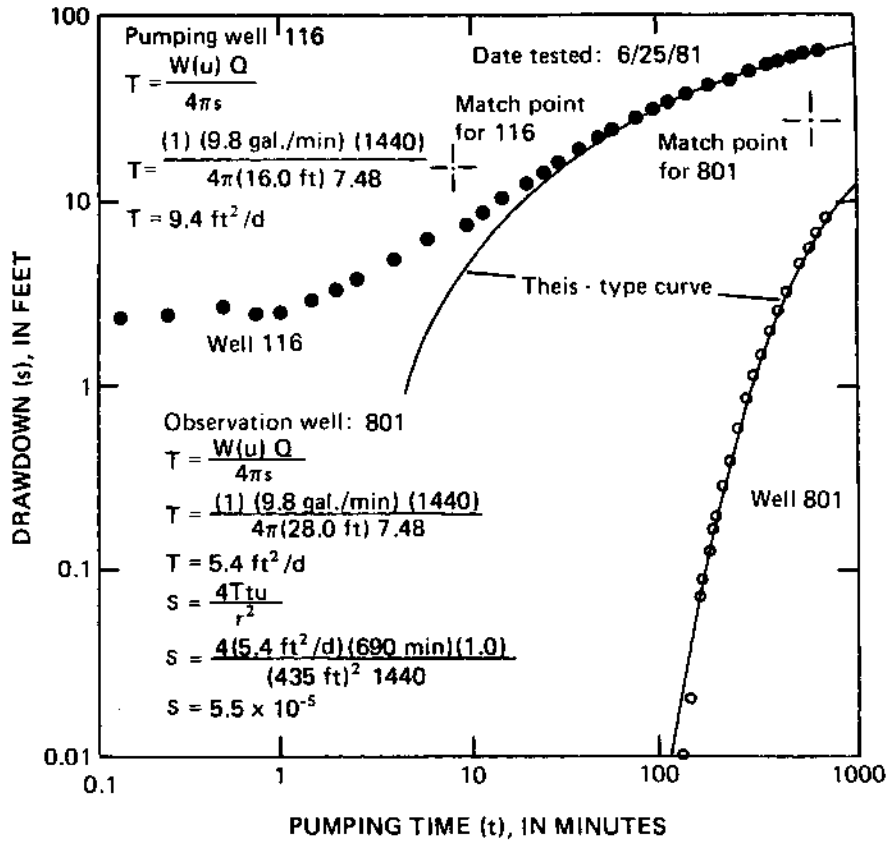


Figure 3.4-3.— Drawdown plots of pumping well 116 and observation well 801.

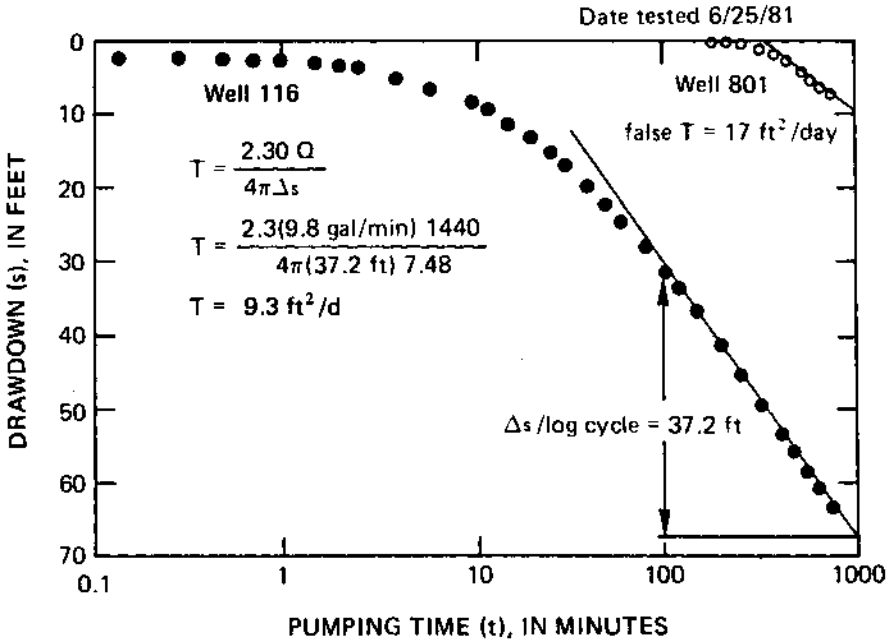


Figure 3.4-4.— Jacob method of analysis for the Ryerson Station State Park aquifer test.

Assuming T = 17ft^2/d, S = 4.9xl0^{-5} and r = 435 feet, the minimum test duration time for the Jacob method to be applicable, theoretically, would be 19,700 minutes or 13.7 days.

Recovery data were measured at a different well, which is completed in the Waynesburg Sandstone Member on a hillside. Well 811 was pumped at a constant rate of 1.2 gal/min for 720 minutes. The drawdown data did not plot in a smooth curve so recovery data were collected to corroborate the specific-capacity results. The Theis recovery method (10) was used on the late-time data (fig. 3.4-5). Theoretically, the data will fall on a line passing through the point where s= 0 and $\frac{t}{(t-t_2)} = 1$

where t = time since pumping began, and

t_2 = time when pump was turned off and water level started recovering. Deviations from this, as indicated in figure 3.4-5, may be explained by storage changes during pumping (6).

Specific capacity after 1 hour of pumping was compared to transmissivity estimated for the same well at several sites in Greene County (fig. 3.4-6). The theoretical relationships described in (14) and (15) are also shown. To minimize the effects of borehole storage, most of the transmissivity values are derived from pumping longer than 1 hour or from recovery data. The 1-hour specific capacities have not been corrected for borehole storage, which probably explains the lack of fit of the data to the theoretical relationship. The effects of borehole storage decrease with pumping time, and a consistent method of correcting the effects is difficult to determine. Transmissivity estimated by the specific-capacity method may be as much as two orders of magnitude too large if well-bore storage is not considered. The specific-capacity method, nevertheless, can provide rough estimates of transmissivity.

The hydraulic characteristics determined from well 801 data in response to controlled pumping of well 116 are the most representative results of the well methods presented. Such multiple-well tests give the best average results over the largest volume of the aquifer tested. In addition, the effects of well-bore storage are practically negligible and overall aquifer homogeneity, isotropy and continuity can be evaluated. Two-well aquifer tests performed in valley settings commonly produce a time-drawdown response that plot nearly as straight lines on log-log paper. Such a response is probably due to the drawdown cone intercepting lesser permeability aquifer zones beneath the hills adjacent to the valley. Such test results are difficult to analyze for hydraulic coefficients by the usual documented methods.

With regard to overall method application and accuracy of results, the order of preference among the single-well tests presented are: (1) Theis recovery, (2) specific capacity or Theis and Jacob drawdown, and (3) slug. A combination of single-well methods, such as specific capacity and recovery, provided added data for comparison at small additional cost. Thus, for well 801, T = 5.4 ft^2/d determined from the Theis method is preferred over T = 0.41 ft^2/d determined from the slug test (figs. 3.4-2 and 3.4-3).

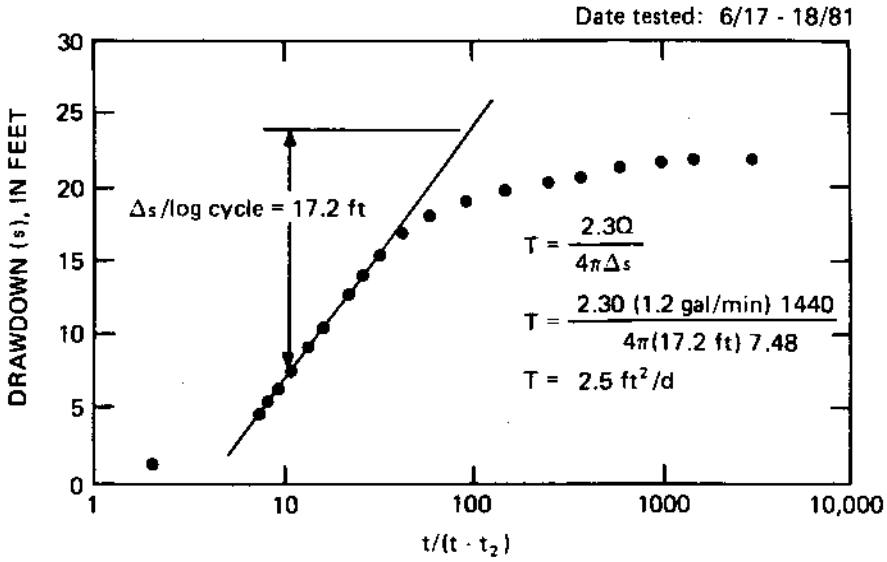


Figure 3.4-5.— Theis recovery method of analysis on well 811 test.

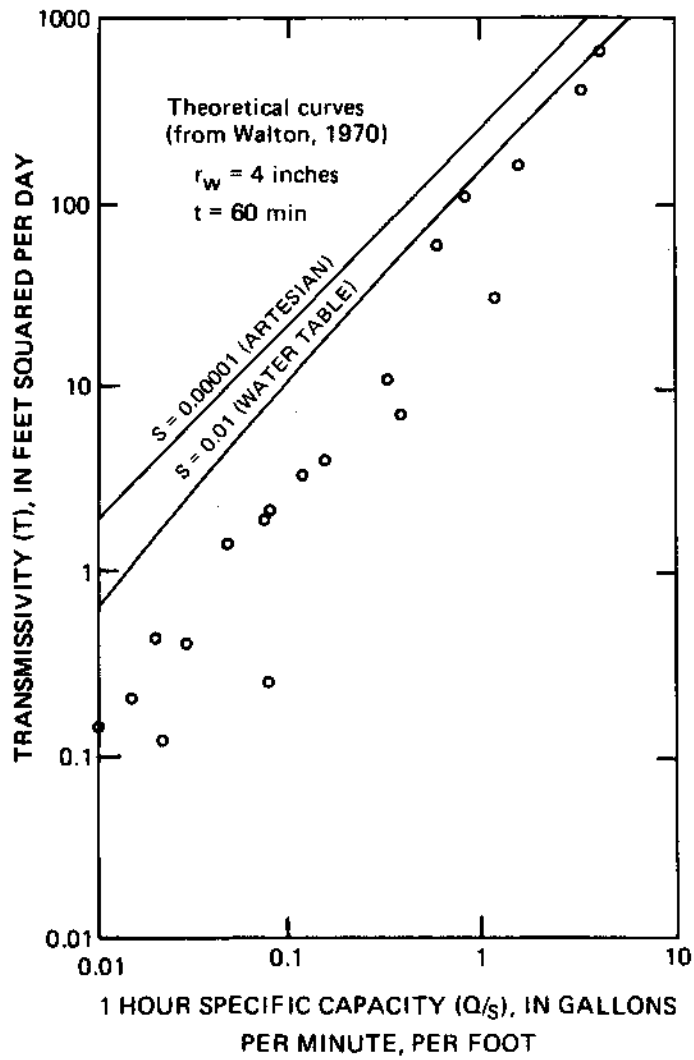


Figure 3.4-6.— Comparison of transmissivity to one-hour specific capacity determined by pumping tests in Greene County.

3.0 GROUND-WATER HYDROLOGY

3.5 CHEMICAL QUALITY OF GROUND WATER

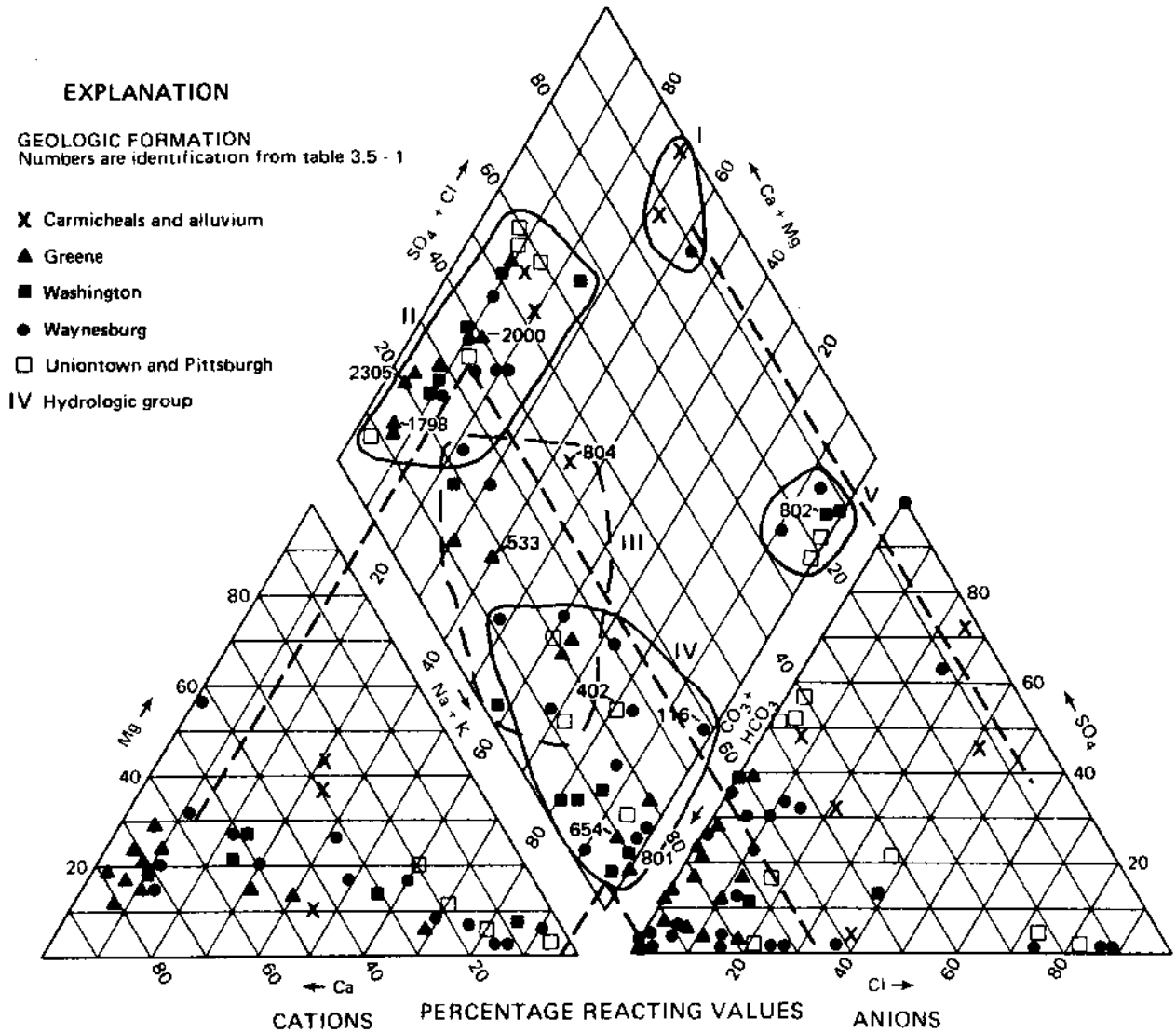
CHEMICAL CHARACTER VARIES ALONG FLOW PATH

The percentages of calcium, magnesium, and sulfate decrease, whereas sodium, bicarbonate, and chloride increase with time and distance from areas of recharge. Dissolved solids and pH generally increase with residence time.

Chemical data pertaining to ground water in Greene County were collected to determine natural variation and to establish general baseline conditions from which the changes attributed to future mining could be determined. Table 3.5-1 shows the analyses and associated pertinent information for representative samples collected from wells and springs. Other data relevant to ground-water sampling include the site latitude and longitude, land-surface altitude, well depth and diameter, and the open or perforated interval of the well. This information was included in the well and spring inventory tables of section 3.3.

All the well samples were collected after at least two times the volume of well-bore storage was removed in order to obtain representative aquifer water. For small-capacity wells, the well was allowed to recover before repumping it to collect the sample. Domestic wells, which receive daily use, were pumped until plumbing was flushed. Storage tanks were bypassed when possible, and samples were not collected if the water had been treated by softening or filtering. Standard U.S. Geological Survey methods were used for field determinations, sample preparation, and laboratory analysis, (12, 16).

The results of 61 analyses were plotted on a trilinear diagram (5) and (11) to evaluate possible chemical trends in natural ground water. The basic water types appear to be independent of the individual geologic formations sampled (fig. 3.5-1). Coal aquifers commonly yield sulfate water and limestone aquifers commonly contain large concentrations of bicarbonate. Evaluation of the data shows a general trend along the ground-water-flow path. Moving from recharge (Group I) through intermediate residence time (Group III) to regional discharge (Group V), the principal ions change from mostly calcium, magnesium, and sulfate to sodium, bicarbonate, and chloride. Furthermore, dissolved solids and pH generally increase with residence time (fig. 3.5-1).



	------> INCREASING RESIDENCE TIME-------->			------>	
	HYDROLOGIC SETTING				
	Recharge	Intermediate			Discharge
Group	I	II	III	IV	V
Topographic Setting	Terrace Hilltop	Hilltop	Hillside Upland Valley	Valley	Valley
Relative Depth of Sample (feet)	0 - 50	25 - 175	10 - 150	10 -	100 -
Group Means of dissolved solids (milligrams per liter)	120	280	425	527	5450
Field pH (units)	5.6	6.7	7.5	8.3	7.7

Figure 3.5-1.— Trilinear plot and characterization of natural ground-water quality sampled in Greene County.

Table 3.5-1– Chemical quality of ground water from selected springs and wells in Greene County,
[ft, feet; gal/min, gallons per minute; mg/L, milligrams per liter]

General Data						Field Determinations						
Site type	Local number	Date	Time	Aquifer	Lithology	Static water level (ft below land surface]	Discharge (gal/min)	Temperature (˚C)	Total alkalinity (mg/L)	Total acidity (mg/L)	Specific conductance (micromhos)	PH (units)
Spring	1798	8-28-81	1230	Wsng	Lssdshl	—	0.1	18.0	200	14	450	7.3
Spring	2000	9-01-81	1000	Gren	Sdshl	—	1.0	16.0	66	8.0	235	7.5
Spring	2305	8-27-81	1330	Gren	Sdshl	—	.1	19.0	120	0	325	8.2
Well	116	6-25-81	1500	Wbrg	Snds	36.50	9.8	13.5	640	0	2,190	8.6
Well	402	8-26-81	1300	Pbrg	Lssdshl	F	1.1	20.5	310	9.0	735	7.9
Well	533	3-05-80	1430	Gren	Shale	54.21	2.0	12.0	87	10	425	7.5
Well	654	5-15-80	1340	Gren	Shale	.28	6.7	13.0	320	0	690	9.1
Well	801	7-10-80	1015	Wbrg	Sdshl	50.70	1.1	13.5	770	0	1,750	8.6
Well	802	10-02-80	1330	Wbrg	Sdshl	9.70	11	12.0	790	50	11,000	7.6
Well	804	9-29-80	1545	Alum	Sgvc	4.67	4.4	13.5	200	1.0	725	7.4

Remarks:
Aquifer formation names:
Wsng, Washington; Gren, Greene; Pbrg, Pittsburgh; Wbrg, Waynesburg; Alvm, alluvium.
Lithology: Snds, sandstone;
Sdshl, sandstone and shale;
Lssdshl, limestone, sandstone, and shale;
Sgvc, sand, gravel, and clay.
Static water level: F, flowing.
* ion used in trilinear plot.
< less than.

General Data					Laboratory Determinations												
Local number	Date	Time	Specific conductance (micromhos)	PH (units)	Dissolved iron (mg/L as Fe)	Total iron (mg/L as Fe)	Dissolved manganese (mg/L as Mn)	Total manganese (mg/L as Mn)	Calcium* (mg/L as Ca)	Magnesium* (mg/L as Mg)	Sodium* (mg/L as Na)	Chloride* (mg/L as Cl)	Bicarbonate* (mg/L as HCO_3)	Sulfate* (mg/L as SO_4)	Hardness as $CaCO_3$	Dissolved solids (mg/L)
1798	8-28-81	1230	408	8.1	0.02	0.15	0.01	0.01	71	13	6.6	1.0	250	30	230	254
2000	9-01-81	1000	226	8.0	.02	.13	<.01	<.01	34	38	5.2	1.4	81	42	100	148
2305	8-27-81	1330	284	8.4	.03	.35	.05	.11	46	5.4	3.0	2.8	150	29	140	196
116	6-25-81	1500	2,060	8.4	.06	.08	.01	.01	2.5	0.9	500	290	760	7.0	10	1,240
402	8-26-81	1300	720	8.1	.25	.34	.02	.01	23	3.9	140	64	380	.9	74	433
533	3-05-80	1430	448	8.3	.07	1.2	<.01	.05	50	7.6	47	1.2	260	35	160	281
654	5-15-80	1340	693	8.8	.18	7.5	.01	.23	2.3	0.3	160	29	380	6.8	7	412
801	7-10-80	1015	2,920	8.3	.01	1.5	.01	.02	1.0	0.5	430	98	910	5.2	5	1,060
802	10-02-80	1330	12,000	7.6	.41	.15	.04	.05	24	15	2,700	3,700	960	19	130	6,670
804	9-29-80	1545	696	7.5	.02	2.7	.13	.23	65	8.6	45	94	250	15	200	364

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.1 ACTIVE MINING

GROUND-WATER FLOW INTO UNDERGROUND MINES IS COMPLEX

Mining related water level declines in wells above mines depend on the thickness of bedrock between the mine and the well bottom and the amount of secondary permeability induced by coal excavation. Mining can cause increases in water acidity and mineralization.

Ground-water levels have been recorded in wells over three active underground mines in Greene County. The type of mining and the distance between the well bottom and the mined coal seam differ at each site (fig. 4.1-1). Generally, the magnitude of water-level decline is expected to be inversely proportional to the thickness of bedrock between the mine and the well bottom, as indicated by the hydrographs of wells GR 253 and GR 543. In addition, the retreat (pillar removal) and long-wall method of mining may induce fracturing above the coal seam, thus hydraulically connecting shallow aquifers to the deep mine. Such conditions may explain why no decline is seen in well GR 118, which is 240 feet above room and pillar mining, and a 10-foot decline is seen in well GR 543, which is 608 feet above long-wall mining. The 5- to 8-foot declines (labeled D in fig. 4.1-1) on the well GR-118 hydrograph are caused by summer droughts. During the time of the 1981 drought, the closest long-wall mining activity was about 620 feet distant from the vertical projection of well GR 543. The close correlation of the water-level response to the well GR 118 hydrograph indicates that the drought was the dominant cause of the water-level decline, however.

The decline and recovery observed in January 1982 at well GR 543 correlate closely with test drilling that penetrated the same formations 845 feet away. A large quantity of formation water was reportedly removed during drilling before the test hole was cased.

The third decline and recovery (March and April, 1982) correlate closely to long-wall mining directly beneath well GR 543 (fig. 4.1-1). The rapid decline probably is related to increased vertical permeability caused by mining-induced fracturing. The water level, however, recovered 8 feet in less than a day. At that time, mining had advanced beyond the vertical projection of well GR 543 by about 100 feet. The rate and appearance the recovery might be explained by (1) reduction of vertical permeability of strata overlying the mine coupled with complex interflow between various aquifers of the open-hole well, or (2) small land subsidence. Both explanations are plausible at well GR 543, although surface subsidence had not been verified.

Ground-water-quality changes caused by coal mining in Greene County usually are related to the oxidation of pyrite and subsequent increase in acidity. Greater acidity leads to increased dissolved solids including dissolution of heavy metals such as iron and manganese. Natural ground water near potential surface mines will likely have small concentrations of dissolved solids and large changes in chemistry, owing to the common acidity problem caused by mining. Table 4.1-1 is an example of post-mining water chemistry from a spring below mine spoils. The spring flows from a hillside near the altitude of the underclay to the mined coal. Underground mines, on the other hand, are near ground water of naturally large alkalinity that

neutralizes the acid. Disposal of mine inflow having large natural dissolved-solids concentration and leaching of waste refuse piles at land surface are the usual ground-water quality problems associated with subsurface mining.

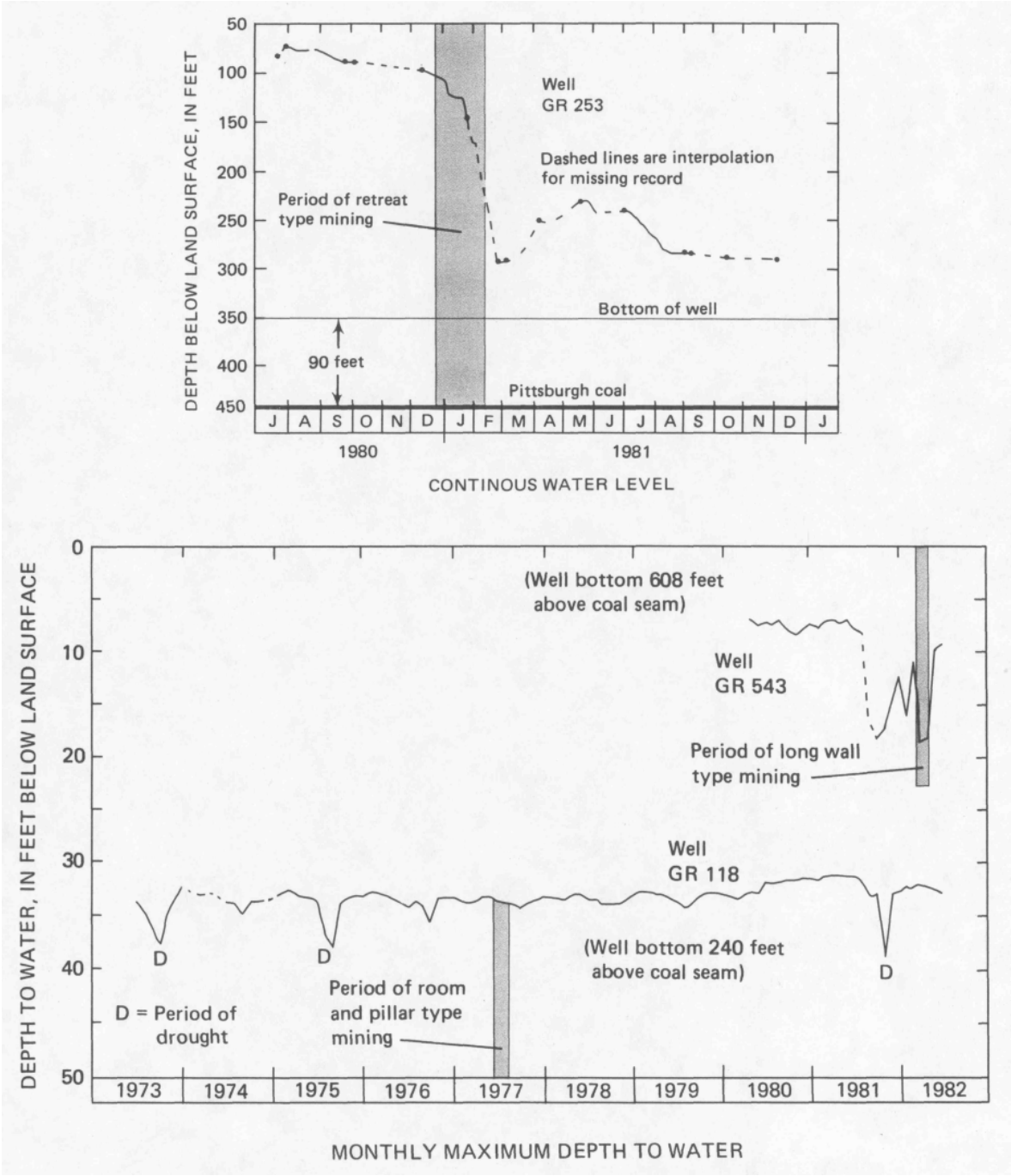


Figure 4.1-1.— Water-level changes above subsurface mining.

Table 4.1-1.– Chemical quality of spring discharge below subsurface mine spoils in Greene County
(concentrations in milligrams per liter except where indicated)
[gal/min, gallons per minute; ˚C, degrees Celcius]

GENERAL DATA	
Local number	599
Date	8-27-81
Time	0830
FIELD DETERMINATION	
Discharge (gal/min)	4.5
Temperature (˚C)	16.0
Total alkalinity	0.0
Total acidity	1,860
Specific conductance (micromhos at 25 ˚C)	7,000
pH (units)	2.8
LABORATORY DETERMINATIONS	
Specific conductance (micromhos at 25 ˚C)	5,940
pH (units)	2.6
Dissolved iron (Fe)	.27
Total iron (Fe)	.26
Dissolved manganese (Mn)	.26
Total manganese (Mn)	
Calcium (Ca)	390.29
Magnesium (Mg)	370
Sodium (Na)	11
Chloride (CD	9.1
Bicarbonate (HCO_3)	0.0
Sulfate (S04)	5,800
Hardness (as $CaCO_3$)	2,500
Dissolved soilds	9,630

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.2 FUTURE UNDERGROUND MINING

HYDROLOGIC EFFECTS CAN BE ESTIMATED WITH A CROSS-SECTIONAL FLOW MODEL

Drawdown gradients are steep near the mine opening and decrease rapidly with distance away from the mine. Vertical fracture zones could accelerate drawdowns locally.

A two-dimensional cross-section digital model was used to test general ground-water flow concepts and to estimate hydrologic effects of a hypothetical subsurface mine. The digital finite-difference program used for the model is documented in (13). Partial results and discussion from the Greene County study are presented herein to illustrate the use of a two-dimensional model for simulating ground-water flow near subsurface coal mining.

The cross section was designed to generalize the geometry and hydro-geology of western and central Greene County where future mining is expected. Boundary conditions and input data used to build the steady-state model are illustrated by figure 4.2-1. A primary assumption of this type of model is that all flow is in the plane of the section. The cross-section trace was made along the expected flow path of the shallow aquifer system, which follows the general topographic expression from hilltop to adjacent valley. The direction of flow in the regional aquifer system is probably more perpendicular to the plane of the cross section. Regional flow rates are slow relative to the local flow rates and the orientation of the cross-section is therefore most critical with the shallow-flow direction.

The errors contributed by the misalignment of regional flow direction to the model cross-section are expected to be insignificant for steady-state conditions. However, the model results for nonsteady-flow problems may significantly misrepresent actual conditions.

The water table is represented by constant head nodes located roughly along land-surface altitude. Values of head assigned to these nodes are from water-level data collected at shallow water wells located at various topographic settings. The basal and end boundaries of the model are no flow. The bottom is about 1,700 feet below average land-surface altitude, which is the average depth of the fresh water aquifer system according to oil and gas drilling data. The total width of the cross section is 16,500 feet. Coarser grids were tested, but could not be used to represent the flow system adequately near the undulating water-table surface.

The finite-difference grid indicated along the perimeter of the active flow model in figure 4.2-1 is oriented along stratigraphic bedding (flat-lying strata assumed). Grid spacing is uniform in the x-direction at 500 feet. Spacing in the z-direction increases with depth, ranging from 50 to 220 feet.

When a two-dimensional digital-model program is turned on its side to run a cross-sectional problem such as this one, the aquifer is confined and usually assigned a thickness of unity (1 foot in this example). Therefore, average hydraulic conductivity is used in place of transmissivity for the model input. Data from aquifer tests were used to set the initial framework

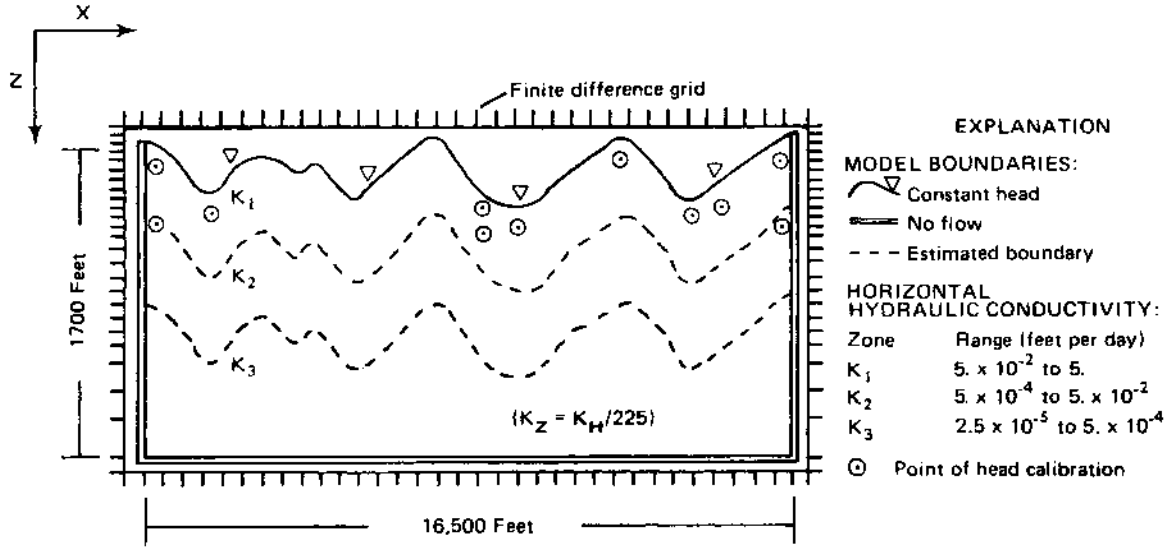


Figure 4.2-1— Input design and boundary conditions of two dimensional cross-section model.

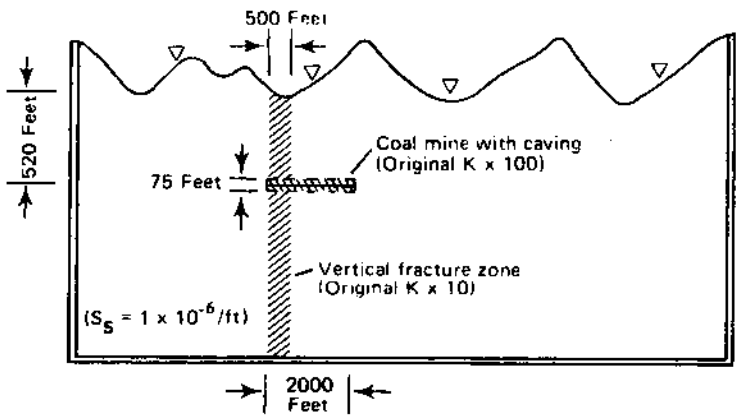


Figure 4.2-2.— Model features used to simulate subsurface mining and a vertical fracture zone.

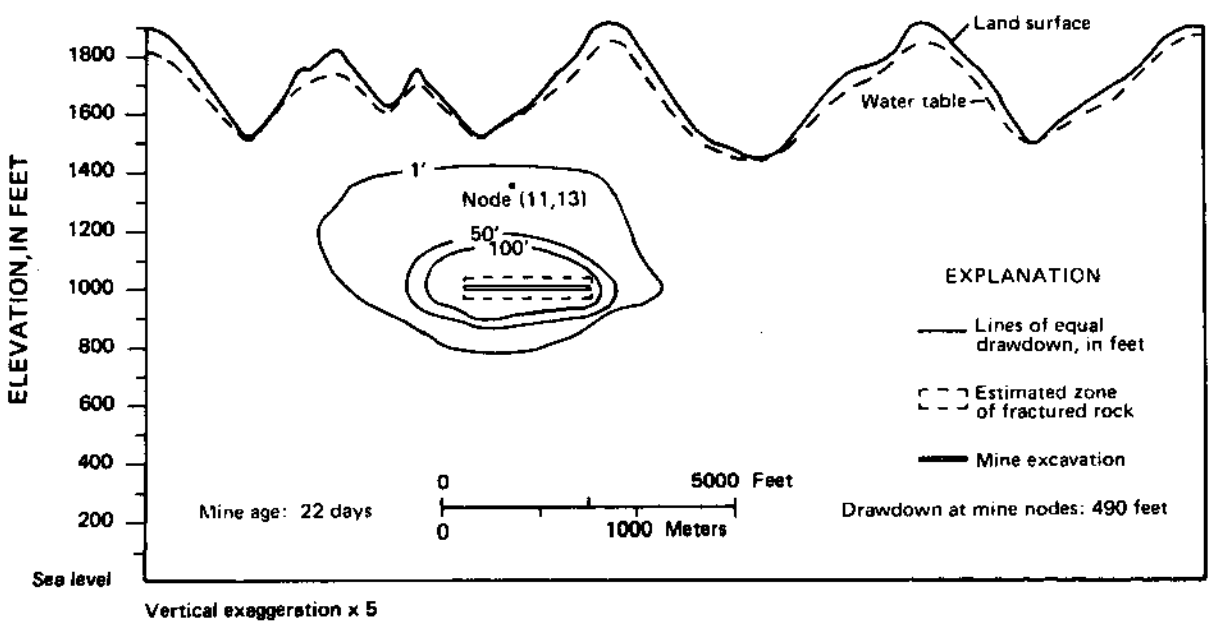


Figure 4.2-3.— Drawdown configuration 22 days after mining.

of the hydraulic-conductivity distribution throughout the cross section. These tests indicated that permeability decreased with depth below land surface and was relatively independent of geologic formation. In addition, horizontal hydraulic conductivity was allowed to be greater than vertical hydraulic conductivity in an attempt to represent the effects of multiple confining layers present in the aquifer system.

The combination of hydraulic-conductivity distribution and anisotropy shown in figure 4.2-1 gave the best overall calibration within $\pm$ 15 feet in the steady-state case and subsequent mine simulations. Steady-state calibration was accomplished by varying the average hydraulic-conductivity distribution and horizontal- to vertical-permeability ratio (anisotropy) until heads matched at the points indicated in figure 4.2-1 and discharge to hillsides and valleys matched mean annual base flow. The points of head calibration represent the average observation depth of cased wells located in similar topographic settings of Greene County. Average potentiometric heads with respect to local drainage level and land surface near the observation wells are assigned to the points shown in figure 4.2-1 for calibration. The greatest restrictions to the adjustment of hydraulic conductivity were near the water table of the model where most of the aquifer-test information was available. Hydraulic conductivity of the deep aquifers is relatively unknown and values used in the model were set closer to the higher range of expected values to provide a worst-case situation in terms of mining effects. The model is most sensitive to the anisotropy property. Although not based on field data, the ratio of 1 to 225 is within acceptable limits according to analytical models based on typical differences of hydraulic conductivity and thickness of aquifers and confining layers.

The relative position and dimensions of a hypothetical subsurface coal mine are shown in figure 4.2-2. The mine is simulated by constant head nodes with values set to the altitude of the mine nodes. This could effectively represent a typical set of entries driven in a direction perpendicular to the cross-section plane. The coal-seam thickness is not actually specified in the model, but is located near the center of a 75-foot thick zone that is assigned a horizontal and vertical hydraulic conductivity 100 times the pre-existing value. In this way, the model may better describe typical caving conditions associated with retreat or long-wall type mining.

A subsequent simulation was made to reflect the effects of a mine which intercepts a vertical fracture zone. The zone is represented in the model by assigning values of hydraulic conductivity 10 times larger than the preexisting values along a 500-foot wide column of finite difference blocks. Such a representation could be equivalent to a much narrower zone that has larger permeability. A specific storage (S_s) of $1x10^{-6}$ per foot was used for both mine simulations.

Drawdown results from the mine simulations are shown in figures 4.2-3 and 4.2-4 for mine ages of 22 days and 4 years, respectively. The drawdown is steep near the mine and gradients decrease rapidly away from the mine even after 4 years. Figure 4.2-5 shows the drawdown of the same mine that has intercepted a vertical fracture zone. Drawdown is effectively increased locally near the fracture zone and is expanded within the shallow aquifers above the mine.

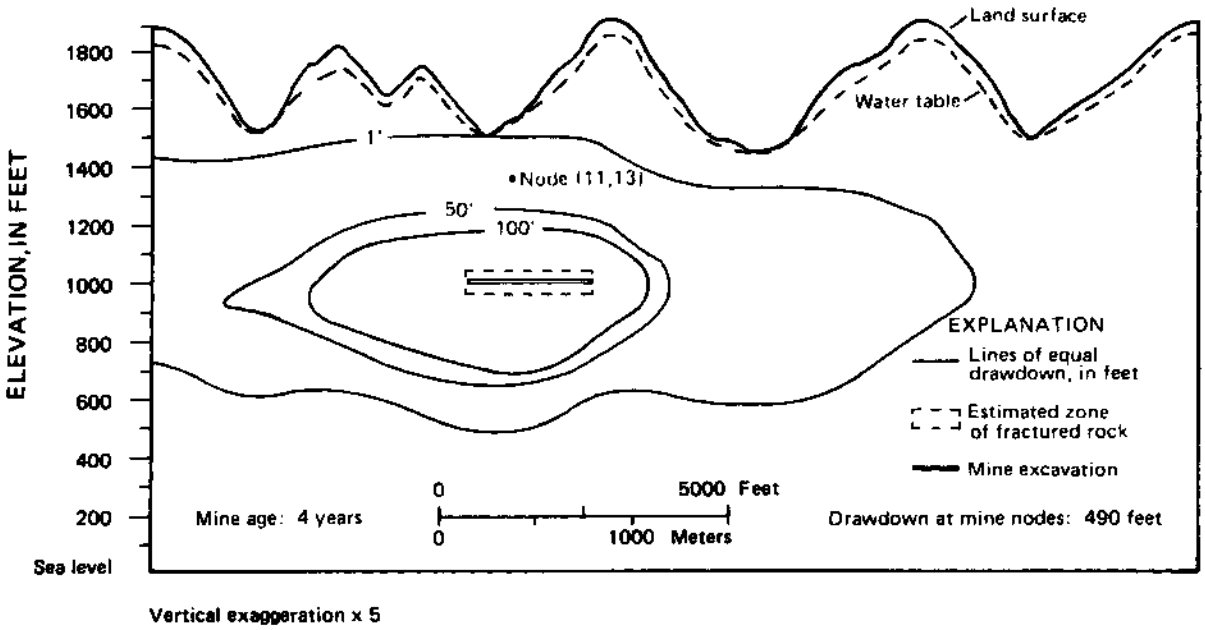


Figure 4.2-4.— Drawdown configuration 4 years after mining.

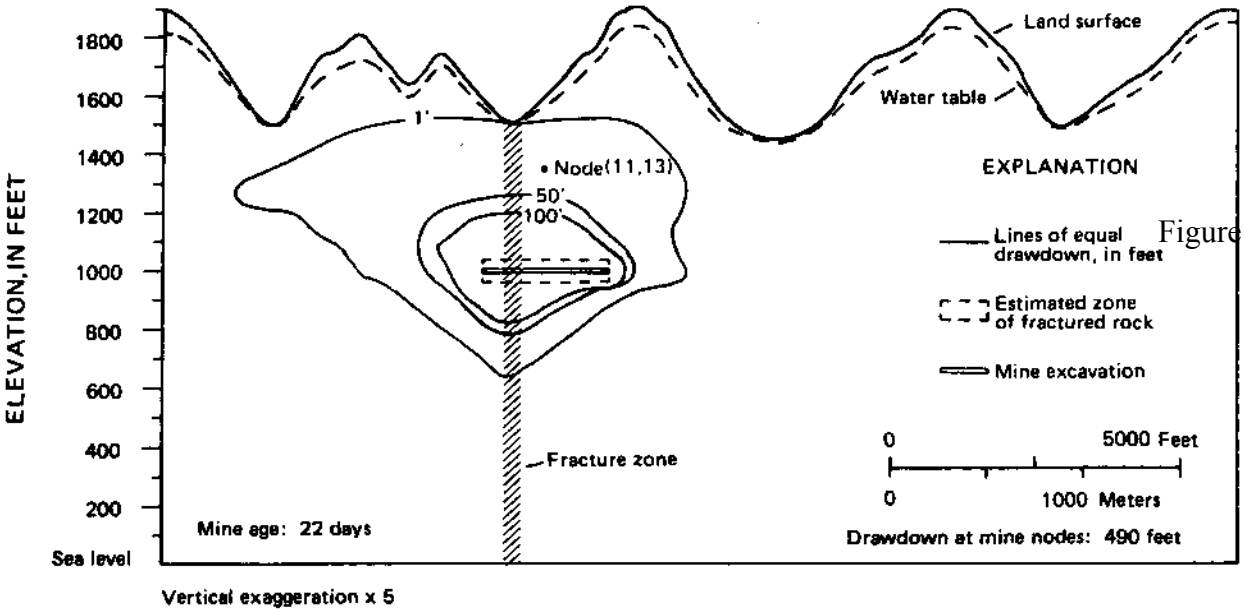


Figure 4.2-5.— Drawdown configuration 22 days after mining near a vertical fracture zone.

Drawdown at a point between the mine and land surface is plotted against time for both conditions in figure 4.2-6. As might be expected, the drawdown rate is much faster for the fracture zone condition. In both conditions, drawdown has essentially stabilized after 1 year of mine age.

Specific mine inflow has also been plotted with mine age (fig. 4.2-6). The fracture zone interconnects the mine to the shallow, more permeable aquifers, resulting in more than a two-fold increase of inflow to the mine.

Given the features described by figures 4.2-1 and 4.2-2, the cross-section-flow model indicates the following probable hydrologic effects:

1. Water levels could decline as much as 15 feet in 150-foot deep wells located along undermined valleys. The maximum effects of water-level decline would occur within 1 year of mining.

2. Springs and shallow wells above basin drainage level probably will not be affected.

3. Streamflow may be reduced by 0.6 $(ft^3/s)/mi^2$ about 1 year after undermining completion. Larger reductions could occur with vertical fracture zones of greater permeability.

4. The presence of vertical fracture zones could magnify and accelerate the drawdown effects and mine inflow.

The mine problem described above might be better handled with a three-dimensional flow model and more representative boundary conditions. However, the ground-water system is obviously complex and the accuracy gained may not justify the additional expense of data collection needed to develop the more elaborate model.

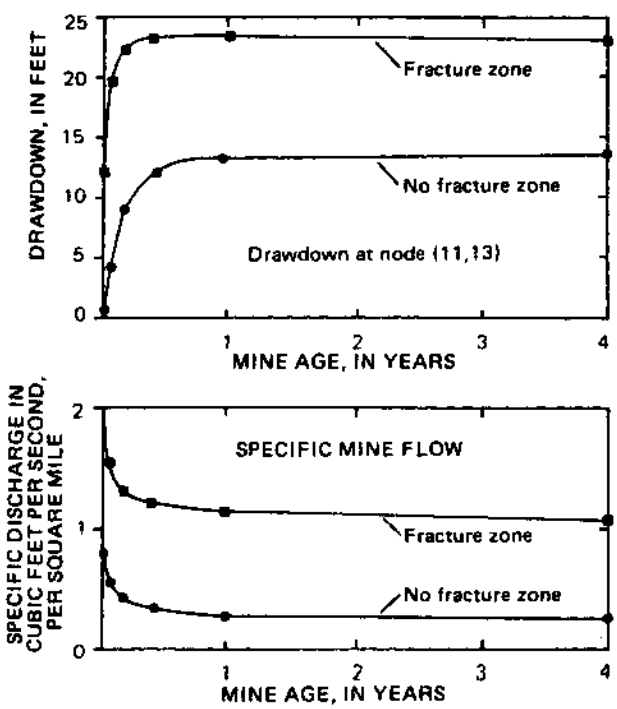


Figure 4.2-6.— Drawdown and mine inflow changes with time.

5.0 GROUND-WATER MONITORING

OBSERVATION WELLS NEEDED TO MEASURE GROUND-WATER CHANGES CAUSED BY SUBSURFACE MINING

Wells are necessary to observe the extent of drawdowns near subsurface mining and water-quality changes near waste-rock refuse sites.

A network of wells could be used to observe changes in ground-water storage and quality near a hypothetical mine plan (fig. 5.0-1), which is similar to the conditions modeled in the section 4.2. Sites M1 through M7 include wells completed in the water-table aquifer along hills and valleys and confined aquifer units above the minable coal seam. All the observation wells are located where they will not be affected by pumping of existing water wells. Altitude of land surface and reference points, from which water-levels are measured, are usually referenced to a standard vertical datum within 0.01 foot accuracy. A suitable benchmark reference is selected in an area that is not expected to subside from underground mining.

Aquifer units located more than 300 feet below land surface have not been proven and may be of marginal use in Greene County. Based on the current usefulness of deep bedrock aquifers, observation wells probably need not be completed in formations beneath the mine, which is located, on the average, 500 feet below stream altitude.

Wells designed to tap the deepest confined aquifers (fig. 5.0-1) need to be properly cased and sealed with grout or expandable clay. A poorly sealed observation well could short-circuit ground-water flow between deep and shallow aquifers, giving false indications of storage changes related to mining.

Hydrogeologic information could be collected from coal-resource exploration drilling and used to locate persistent aquifer units. For many of the deeper aquifer units, these holes could be plugged back, developed, and cased as observation wells. Mud infiltrating from deep exploration drilling tends to seal the borehole from shallow aquifer zones. Construction of shallow observation wells from such drill holes would require very thorough well development or reaming.

Unused or abandoned wells may serve as observation wells, especially in the shallow aquifer zones. Complete inventory of the well construction and water-bearing zones, in addition to well development, is needed to establish usefulness of the site for observation.

Water levels would be measured monthly in all wells located within one-half mile of mine openings (sites M1, M2, M3, and M4 for initial mining) and in wells completed in the deep aquifers. Other well sites could be measured quarterly. Annual pumping of all observation wells is needed to ensure adequate communication between the well-bore and the aquifers. A water sample could be collected at that time. More frequent sampling may be needed if water-level declines occur in the well as a result of mining.

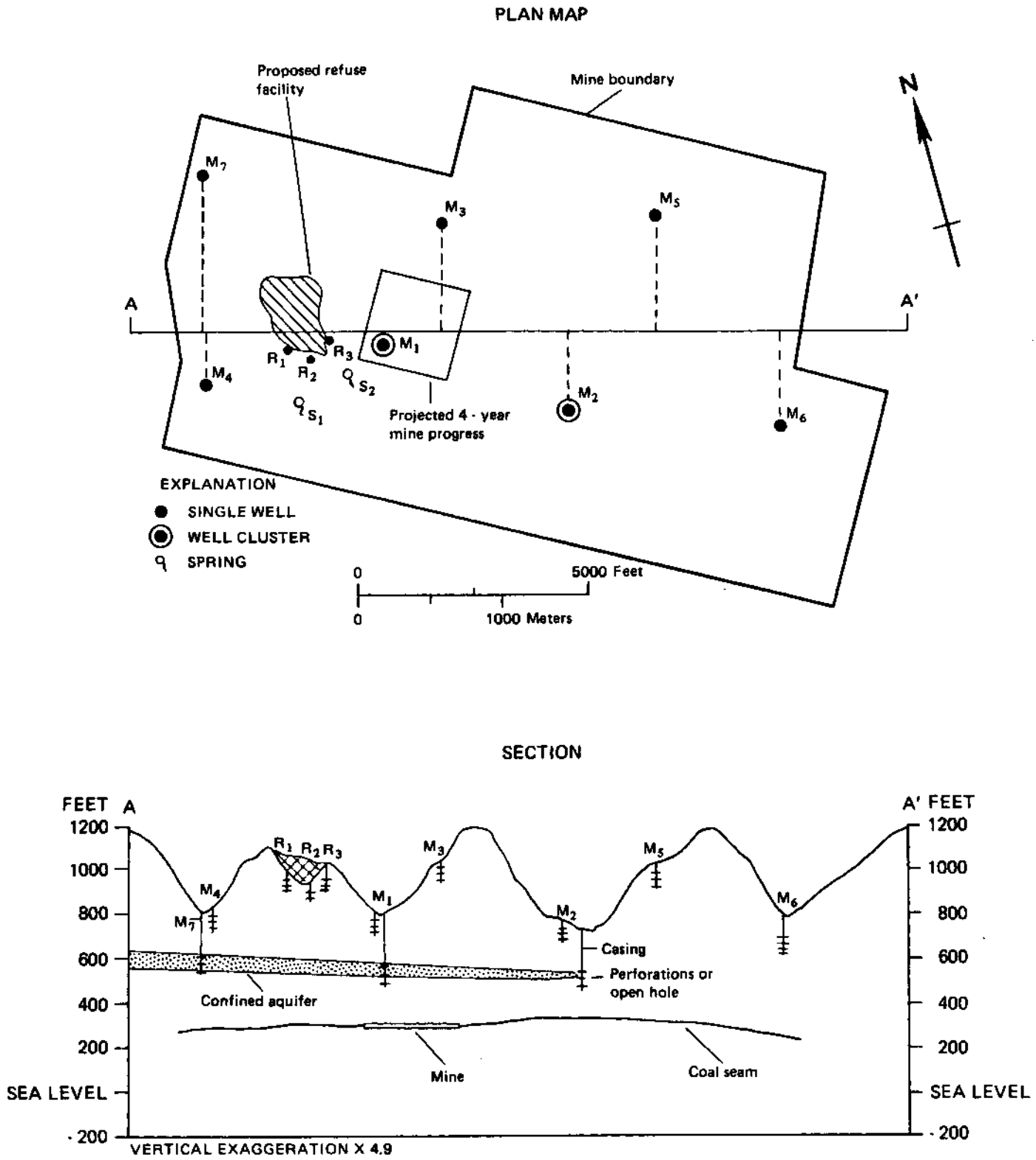


Figure 5.0-1.— Observation well network for a hypothetical subsurface mine.

Changes in ground-water chemistry resulting from the waste-rock refuse facility could be measured from well sites R1, R2, and R3 shown in figure 5.0-1. Each of these wells would penetrate the water-table aquifer downgradient from the storage pile where any changes might be expected to occur first. Additional wells could be added around the perimeter and farther from the pile if leachate infiltration into the ground-water system is determined to be extensive. Existing springs (S1 and S2 in fig. 5.0-1) downgradient from the refuse pile could also be sampled.

Samples would be collected quarterly to screen the water quality during changes in seasonal recharge rates to the aquifer. More frequent sampling may be needed if significant changes in concentrations of sulfate, iron, manganese, acidity, and dissolved solids are determined in the quarterly samples.

The common water-quality constituents analyzed for a monitoring program are shown in table 3.5-1. Trace metals determined in initial sampling, could be used as a guide to subsequent sampling.

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