WATER RESOURCES OF INDIANA COUNTY, PENNSYLVANIA

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4164

Prepared in cooperation with the

PENNSYLVANIA DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES,
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY

Lemoyne, Pennsylvania
1997

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.59	square kilometer
	Volume	
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
gallon per minute per square mile [(gal/min)/mi^2]	0.02436	liter per second per square kilometer
gallon per day (gal/d)	3.785	liter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft^3/s)/mi^2)]	0.01093	cubic meters per second per square kilometer
	Mass	
ton	0.9072	megagram
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day

Temperature

Temperature conversions for degrees Fahrenheit (°F) and degrees Celsius (°C) are given in the following equations:

°C=5/9 (°F-32)

°F=1.8 temp °C+32

Other Abbreviations

Abbreviated water-quality units used in report:

- µg/L micrograms per liter
- µS/cm microsiemens per centimeter at 25 degrees Celsius
- mg/L milligrams per liter

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Indiana County, west-central Pennsylvania, is a major producer of coal and natural gas. Water managers and residents are concerned about the effects of mining and natural gas exploration on the surface- and ground-water resources of the county. This study assesses the quality and quantity of water in Indiana County. Ground- and surface-water sources are used for public supplies that serve 61 percent of the total population of the county. The remaining 39 percent of the population live in rural areas and rely on cisterns and wells and springs that tap shallow aquifers.

Most of the county is underlain by rocks of Middle to Upper Pennsylvanian age. From oldest to youngest, they are the Allegheny Group, the Glenshaw Formation, the Casselman Formation, and the Monongahela Group. Almost all the coals mined are in the Allegheny Group and the Monongahela Group.

Ground water in Indiana County flows through fractures in the rock. The size and extent of the fractures, which are controlled by lithology, topography, and structure, determine the sustained yield of wells. Topography has a significant control over the yields of wells sited in the Allegheny Group. Properly sited wells in the Glenshaw Formation may have yields adequate for municipal, commercial, or industrial uses. The Casselman Formation yields adequate amounts of water for domestic use. Yield of the Monongahela Group is small, and the water may not be of suitable quality for most uses. Yields of hilltop wells may be marginal, but valley wells may yield sufficient amounts for large-volume users. Data on the other rock units are sparse to nonexistent. Few wells in the county yield more than 40 gallons per minute. Most of the wells that do are in valleys where alluvial deposits are extensive enough to be mappable.

Short-term water-level fluctuations are variable from well to well. Seasonal water-level fluctuations are controlled by time of year and amount of precipitation.

The quality of water from the Casselman Formation, Glenshaw Formation, and Allegheny Group tends to be hard and may have concentrations of iron and manganese that exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Levels of 0.3 milligrams per liter and 0.05 milligrams per liter, respectively. Ground water from the Glenshaw Formation is less mineralized than ground water from the Allegheny Group. Concentrations of minerals in water from the Casselman Formation are between those in water from the Glenshaw Formation and the Allegheny Group. Water from wells on hilltops has lower concentrations of dissolved solids than water from wells on hillsides. Water from valley wells is the most mineralized. Nearly half the springs tested yield water that is low in pH and dissolved solids; this combination makes the water chemically aggressive.

The 7-day, 10-year low-flow frequencies for 26 unregulated surface-water sites ranged from 0.0 to 0.19 cubic feet per second per square mile. The presence of coal mines and variations in precipitation were probably the principal factors affecting flow duration on Blacklick Creek (site 28) during 1953-88. Sustained base flows of regulated streams such as Blacklick Creek generally were larger than those of unregulated streams as a result of low-flow augmentation. The annual water loss in streamflow as a result of evapotranspiration, diversion, seepage to mines, and seepage to the ground-water system was determined at four sites (sites 8, 9, 17, and 28) and ranged from 35 to 53 percent.

The highest concentrations of dissolved solids, iron, manganese, aluminum, zinc, and sulfate were measured mostly in streams in central and southern Indiana County, where active and abandoned coal mines are the most numerous.

Streamflow was measured during low flow in two small basins; one basin almost completely deep mined (Cherry Run) and one basin unmined (South Branch Plum Creek). The measurements showed a consistent decrease in flow at main-stem sites in the mined basin. Streamflow measurements and observations made in the middle of a drought in both basins showed most of the tributaries and main-stem sites to be completely dry. Concentrations of dissolved sulfate, iron, manganese, aluminum, zinc, chloride, sodium, strontium, and dissolved solids were higher in the mined basin than in the unmined basin.

Approximately 7 percent of the wells and springs in Indiana County have been affected by acid mine drainage. Reports of brine contamination could not be documented. Natural gas is produced by some water wells, but it is not known whether its presence results from nearby natural gas production. Gas well drilling and production have had little effect on the water quality of Indiana County streams.

INTRODUCTION

During 1987, Indiana County was ranked second in Pennsylvania for coal production (Pennsylvania Coal Association, 1988). Active and abandoned surface and underground coal mines are widely distributed throughout the county. The concentration of mines is greatest in central Indiana County. Acid mine drainage from coal mines historically has degraded the quality of streams, wells, public water supplies, and lakes.

Petroleum exploration and production in western Pennsylvania have been active since 1978. During 1979-82, more gas wells were drilled annually in Indiana County than in any other county in the State (Pennsylvania Department of Environmental Resources, Bureau of Topographic and Geologic Survey, Oil and Gas Geology Division, written commun., 1989). The average number of wells drilled in the county was 400 per year. Petroleum exploration and production can degrade surface-water and ground-water quality.

Water managers and residents are concerned about the hydrologic effects of mining the remaining 1.7 billion tons of coal reserves and the hydrologic effects of continued natural gas exploration and production. A particular concern is reduced ground-water storage in shallow aquifers that overlie existing or potential underground mines. Many rural residents rely on wells and springs that tap shallow aquifers.

In response to these concerns, a study to assess the water resources of Indiana County was done by the Pennsylvania Department of Conservation and Natural Resources (PaDCNR) (formerly Pennsylvania Department of Environmental Resources), Bureau of Topographic and Geologic Survey, and the U.S. Geological Survey (USGS), in cooperation with the Indiana County Board of Commissioners.

Purpose and Scope

This report describes the ground-water and surface-water resources of Indiana County, Pa. The report includes a description of stratigraphy, water-bearing properties of aquifers, ground-water chemistry, surface-water chemistry, and hydrologic budgets of four representative study basins. Two basins, Cherry Run and South Branch Plum Creek, were instrumented specifically to determine the effects of near-surface deep mining on the hydrologic budget. The report also contains analyses of stream low-flow frequencies, flow duration, runoff, and aquifer-test results of a well field in which five wells were drilled as part of the study. Water chemistry and investigation of sites reported to PaDCNR as being contaminated were used to determine the effect of gas well drilling on ground water. Two sites where ground water is known to be contaminated by brine and natural gas are described. Included with the report is a map showing geology, well and spring locations, and locations of streamflow-measurement and water-quality sites. Surface-water quantity and quality were measured and analyzed at 31 sites (fig. 1).

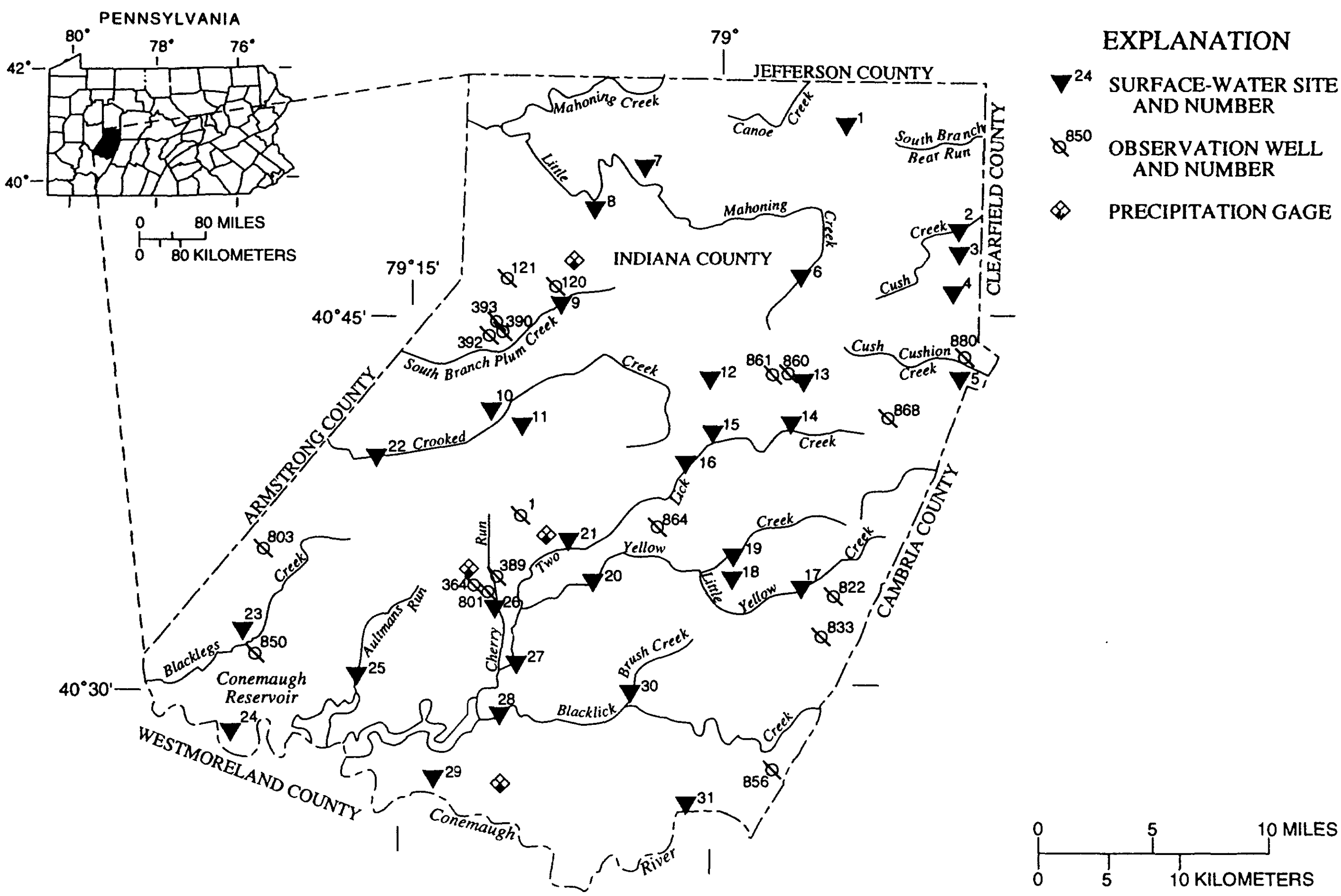


Figure 1. Data-collection sites in Indiana County, Pennsylvania. (See table 1 for identification of surface-water sites.)

Methods of Investigation

Geology for the county was completely revised during the study by use of structure contours and stratigraphic intervals supplied by the Coal Section of the Pennsylvania Geologic Survey. Alluvial deposits were mapped for this report (pl. 1). The mapped geology was used to establish the framework for ground-water occurrence, flow, and quality. The availability of ground water with respect to geologic formation and topographic position was defined by use of information from 517 inventoried wells and 128 inventoried springs. Water-level recorders were installed on 19 observation wells (fig. 1). The recorders documented water-level fluctuations.

Samples for water-quality analyses were collected from 18 observation wells after the wells were pumped. In addition, unfiltered and unsoftened samples from 300 domestic wells and 120 domestic springs were collected for water-quality analyses.

Field measurements of water from the wells and springs included temperature, pH, and specific conductance. Spring-discharge rates were measured where possible. Laboratory determinations included specific conductance; pH; hardness; acidity; and concentrations of calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, fluoride, silica, dissolved solids, nitrate, aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, and zinc.

The Mann-Whitney U-test, a nonparametric statistical test, was used for analysis of well yields and ground-water chemistry. Parametric statistical techniques require data on an interval or a ratio scale, fairly large sample sizes, and normal (Gaussian) distribution. These conditions are commonly not satisfied by the data available for ground water in Indiana County. Nonparametric tests, such as the Mann-Whitney U-test, do not require a normal distribution of data; even nominal and ordinal data can be used (Siddiqui and Parizek, 1972).

Surface-water sites 8, 9, 17, 20, 24, 26, 27, 28, and 31 were streamflow-measurement stations where continuous streamflow data were recorded (fig. 1 and table 1). Streamflow data for more than 10 years are available for all of the above sites except sites 9 and 26. Instantaneous streamflow was measured at the other 22 sites. Sites 10, 14, 15, 19, 23, and 30 were part of the USGS Coal Hydrology network that was sampled during 1979-81. The data are published in the USGS annual water-resources data reports for those years (U.S. Geological Survey, 1980-82).

Water samples for chemical analysis were collected five times during 1986-88 at all surface-water sites during base flow. Field and laboratory analyses for surface-water samples were similar to those for ground-water samples. The PaDEP laboratory analyzed all ground-water and surface-water samples.

The effects of coal mining on the water resources were determined by comparing the hydrologic conditions in a deep-mined basin (Cherry Run) and an unmined basin (South Branch Plum Creek). Surface-water discharge from each basin was recorded at a streamflow-gaging station. Ground-water discharge in each basin was measured by means of four seepage runs made during base-flow periods in 1987-88. Continuous water-level data were recorded at three observation wells in the Cherry Run Basin and at one observation well in the South Branch Plum Creek Basin. Recording rain gages in each basin measured precipitation. The precipitation data were compared with long-term records from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) station at Indiana, Pa. (1949-88), and with short-term records from the NOAA station at Blairsville, Pa.

The effect of gas-well drilling on well water quality was determined by studying natural gas contamination of wells. In particular, the water quality of a domestic well was analyzed where pre-drilling and post-drilling data were available.

Previous Investigations

A geologic reconnaissance of southwestern Pennsylvania was done by the First Pennsylvania Geological Survey between 1836 and 1847 (Rogers, 1858). This survey was the first general description of the stratigraphy, structures, and mineral resources of the area. The geology of Indiana County was first described by Platt in 1877. In 1904, the USGS published folios for the Latrobe and Indiana quadrangles by Campbell and Richardson, respectively. Stone's Elders Ridge quadrangle folio (1905) also was published by the USGS. The compilation maps for the 1980 state geologic map were published in an atlas (Berg and Dodge, 1981) that contains geologic information on all the 7 1/2-minute quadrangle maps of Indiana County.

In 1933, Piper published the first comprehensive ground-water investigation in southwestern Pennsylvania. His work involved the collection of well data and interpretation of ground-water quantity and quality with respect to rock formations and structure. He also discussed the best methods of well construction and recovery of ground water. In 1962, Poth summarized the occurrence and chemical quality of brine in western Pennsylvania. In 1975, Beall did a stream reconnaissance of nutrients and other water-quality constituents in the Greater Pittsburgh Region, which included streams in Indiana County. In 1977, Page and Shaw examined selected sites in Indiana County as part of their work on the low-flow characteristics of Pennsylvania streams. From 1979 through 1981, the USGS measured streamflow and sampled for water chemistry and aquatic invertebrates at selected stream sites in a coal region that included Indiana County (Herb and others, 1981; 1983).

Table 1. Surface-water sites in Indiana County, Pennsylvania

[USGS, U.S. Geological Survey; mi^2, square mile]

Site number	Station number	Station name	USGS quadrangle	Latitude (°,′,″)	Longitude (°,′,″)	Drainage area (mi^2)
1	03033350	Tributary to Canoe Creek at Rossiter	Punxsutawney	40 53 05	78 55 04	1.46
2	01540705	Cush Creek at Glen Campbell	Burnside	40 48 51	78 49 28	15.8
3	01540670	Rock Run near Glen Campbell	Burnside	40 48 01	78 48 28	2.13
4	01540660	Shryock Run near Arcadia	Burnside	40 46 12	78 49 43	.42
5	01540649	Cush Cushion Creek at Cherry Tree	Barnsboro	40 43 25	78 48 58	12.2
6	03034300	Little Mahoning Creek near Rochester Mills	Rochester Mills	40 47 48	78 55 41	19.7
7	03034400	Mudlick Run near Georgeville	Marion Center	40 51 15	79 04 24	5.88
8	[1] 03034500	Little Mahoning Creek at McCormick	Marion Center	40 50 10	79 06 37	87.4
9	[1] 03037400	South Branch Plum Creek near Home	Plumville	40 45 35	79 08 20	9.38
10	03036995	Crooked Creek above McKee Run at Creekside	Ernest	40 40 59	79 11 27	53.4
11	03036997	McKee Run at Ernest	Ernest	40 40 26	79 19 20	12.0
12	03042055	Unnamed Tributary to Dixon Run at Dixonville	Clymer	40 42 45	79 00 51	.11
13	03042045	Unnamed Trib. to N. Br. Two Lick Cr. at Commodore	Commodore	40 42 44	78 56 25	.39
14	03042040	South Branch Two Lick Creek near Wandin Junction	Commodore	40 40 29	78 56 41	19.7
15	03042061	Dixon Run at Clymer	Clymer	40 40 13	79 00 54	10.7
16	03042075	Two Lick Creek near Clymer	Clymer	40 38 44	79 02 12	51.4
17	[1] 03042200	Little Yellow Creek near Strongstown	Strongstown	40 33 45	78 56 44	7.36
18	03042190	Laurel Run near Nolo	Strongstown	40 34 43	78 59 59	5.21
19	03042185	Yellow Creek near Pikes Peak	Brush Valley	40 34 58	79 00 10	21.8
20	[1] 03042280	Yellow Creek near Homer City	Brush Valley	40 34 18	79 06 13	57.4
21	03042120	Ramsey Run near Indiana	Brush Valley	40 35 51	79 06 35	4.48
22	03037150	Curry Run at Shelocta	Elderton	40 39 15	79 16 53	11.2
23	03047480	Blacklegs Creek at Clarksburg	Avonmore	40 32 14	79 22 33	21.6
24	[1] 03044000	Conemaugh River at Tunnelton	Saltsburg	40 27 16	79 23 28	1,358
25	03043990	Aultmans Run near Lewisville	McIntyre	40 30 02	79 17 39	19.9
26	[1] 03042700	Cherry Run near Homer City	Indiana	40 33 15	79 11 31	10.5
27	[1] 03042500	Two Lick Creek at Graceton	Indiana	40 3102	79 10 19	171
28	[1] 03042000	Blacklick Creek at Josephine	Bolivar	40 28 24	79 11 01	192
29	03041675	Toms Run near Blairsville	Bolivar	40 25 48	79 13 17	5.21
30	03041900	Brush Creek at Claghorn	New Florence	40 29 48	79 04 03	21.8
31	[1] 03041500	Conemaugh River at Seward	New Florence	40 25 09	79 01 35	715

[1] Streamflow-gaging station.

Description of the Study Area

Indiana County is an area of 825 mi^2 in west-central Pennsylvania (fig. 1). The county is bordered on the north by Jefferson County, on the east by Clearfield and Cambria Counties, on the south by Westmoreland County, and on the west by Armstrong County.

Most of Indiana County is drained to the west by streams in the Allegheny River Basin; major streams in the basin include Mahoning Creek, Little Mahoning Creek, South Branch Plum Creek, Crooked Creek, Blacklegs Creek, Two Lick Creek, Yellow Creek, and Blacklick Creek. The Conemaugh River forms the southern boundary of the county. The northeastern corner of the county is drained by the headwaters of the West Branch Susquehanna River; major tributaries in the basin include South Branch Bear Run, Cush Creek, and Cush Cushion Creek.

Indiana County is entirely within the Appalachian Plateaus Physiographic Province: the northern and western three-fourths of the county is in the Pittsburgh Low Plateau Section of the province, the southeastern part is in the Allegheny Mountain Section, and the northwestern corner is in the mountainous High Plateau Section (Berg and others, 1989). Local topographic relief ranges from 200 to 500 ft near the main-stream channels in the Pittsburgh Low Plateau Section and from 200 to 700 ft in the Allegheny Mountain Section. Land-surface elevation ranges from about 2,200 ft above sea level on the Chestnut Ridge of the Allegheny Mountains on the south-central border of the county (pl. 1) to about 800 ft in the Kiskiminetas River Valley on the southwestern corner of the county.

The 1984 population of Indiana County was 93,573 (Pennsylvania County Data Book, 1987). The county is divided into 24 townships and 15 boroughs (fig. 2). About 29 percent of the population reside in boroughs. The main population centers are Indiana Borough (15,206 population) in the central part of the county and Blairsville Borough (4,067 population) on the south-central border of the county.

Agricultural land, which includes pasture and cropland, accounts for about 30 percent of the total land use. Forest covers about 54 percent of the total county area. Forest cover includes many Christmas tree plantations scattered throughout the county, which produce more than 20 million trees each year. County and community parks, surface mines, state game lands, commercial areas, industrial areas, and residential development make up the remaining land use.

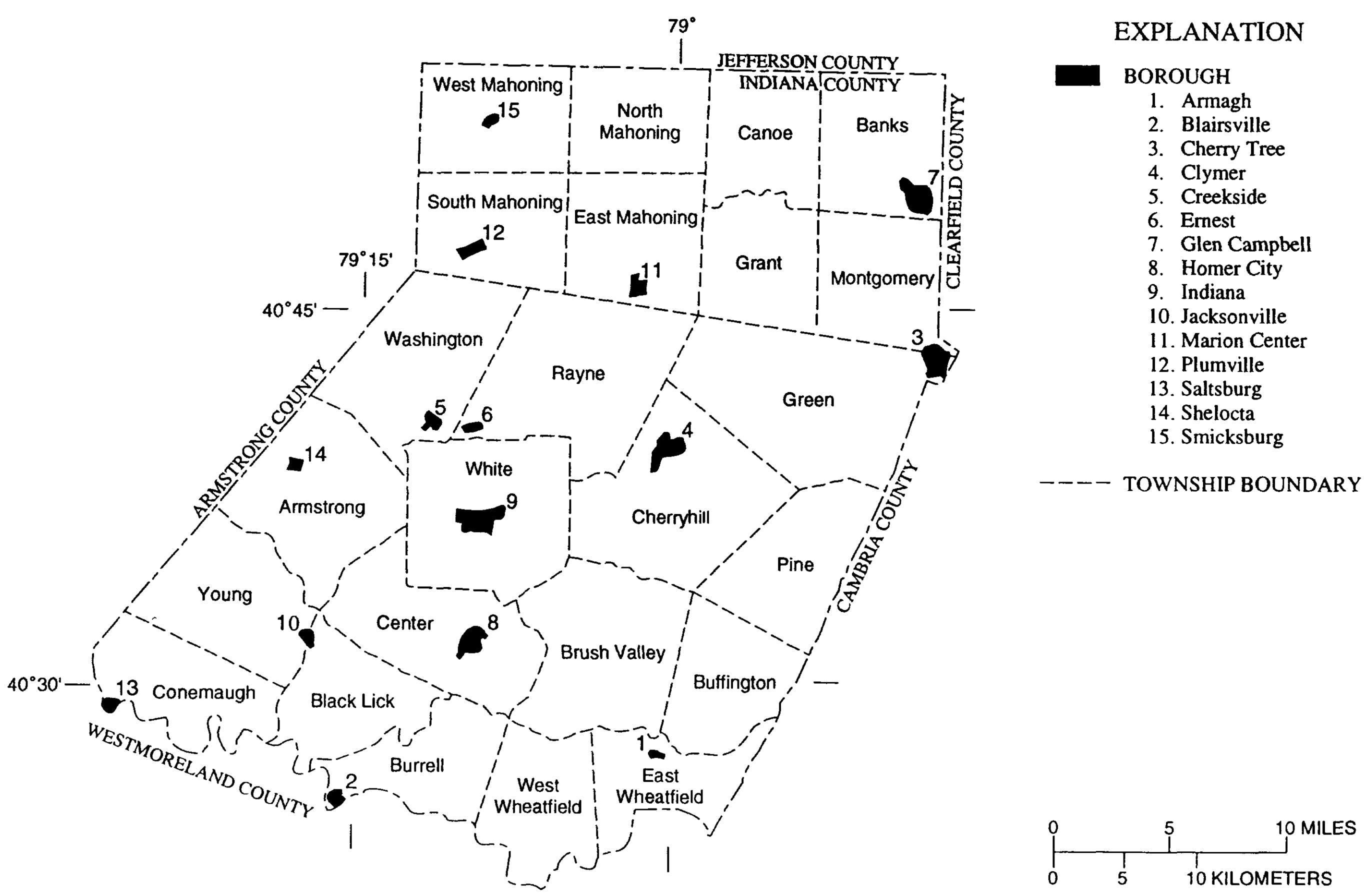


Figure 2. Townships and boroughs of Indiana County, Pennsylvania.

The climate of Indiana County is humid continental. Weather is dominated by air masses originating in the central United States or Canada; these air masses are usually carried eastward by the prevailing winds aloft. Annual precipitation from 1949 to 1988 averaged 44.7 in. at Indiana (U.S. Department of Commerce, 1949-88). Summers generally are warm and humid, and occasional heavy thunderstorms pass through the county. Prevailing winds in the summer are west to southwest. Winters are generally cold and cloudy, and temperatures may fall below 0°F for short periods. The mean annual temperature at Indiana during 1949-88 was 50°F; the mean winter temperature was 30°F, and the mean summer temperature was 69°F.

Water Use

In 1987, withdrawals for public water supplies in Indiana County averaged about 6.2 Mgal/d. About 61 percent of the total population was served by public water supplies, and the remaining population depended on wells, springs, and cisterns for their domestic supply. The water-supply companies in Indiana County and the average daily consumption by water use are listed in table 2. In 1987, domestic use accounted for 36 percent of the public supply, and commercial and industrial use accounted for 22 percent. Streams and reservoirs provided 93 percent of the water for public-supply systems; wells provided 6.9 percent of the water, and springs provided less than 0.1 percent.

Acknowledgments

We gratefully acknowledge the interest and cooperation of the many individual landowners, companies, and municipalities throughout the county who provided access to private and public property for the field data collection. A special thanks goes to the following persons and organizations who permitted us to install hydrologic monitoring equipment on their property: Mike Bertolino, Kevin Bracken, George Coy, T. Graham, George Gresh, George Harbrige, Charles Heglund, Rich Karlinsey, John King, Sr., G. Elmer Little, Dennis McCoy, James McMillan, Frank Novak, Clinton Pierce, Robert Repine, Charles Shultz, Fred Tost, George Wyant, Center Township, Cherry Tree Water Authority, Indiana University of Pennsylvania, and the Pennsylvania Department of Transportation.

We also thank the geology department at Indiana University of Pennsylvania for providing spring locations for water-quality testing.

Table 2. Water use by public-supply systems in Indiana County, Pennsylvania, calendar year 1987

[From the State Water Plan Division of Pennsylvania Department of Conservation and Natural Resources]

Water company	Water source	Average daily consumption, in gallons per day				
		Domestic	Commercial and industrial	Other	Unaccounted for	Total
Pennsylvania-American Water Company	Whites Run Two Lick Creek	1,056,000	880,000	1,056,000	528,000	3,520,000
Blairsville Water Authority	Conemaugh River Trout Run	202,840	18,440	9,220	230,500	461,000
Central Indiana Water Authority	Two Lick Creek Yellow Creek	191,760	39,480	135, 360	197,400	564,000
Southeastern Indiana County Water Authority	Unnamed stream	41,180	11,660	7,770	17,090	77,700
Lower Indiana County Municipal Authority	Blacklick Creek	118,800	19,800	1,980	57,420	198,000
Indiana County Municipal Services:						
Rossiter	Unnamed stream	28,700	0	0	53,500	82,200
Home	Yellow Creek	66,440	0	0	9,060	75,500
Creekside	Well and spring	19,140	0	0	13, 860	33,000
Pine Township	Wells	32,200	0	0	37,800	70,000
Fulton Run	Spring	1,750	0	1,470	3,780	7,000
Jacksonville	Wells	51,940	0	0	1,060	53,000
Iselin	Wells and spring	9,500	0	0	4,900	14,400
Arcadia	Shryock Run	4,110	0	0	21,590	25,700
Cherry Tree Borough Municipal Authority	Cush Cushion Creek Peg Run	30,030	780	0	8,190	39,000
Clymer Borough Municipal Authority	Wells	62,730	12,300	2,460	45,510	123,000
Nowrytown Water Association	Well	7,680	320	0	0	8,000
Nineveh Water Company	Findley Run Risinger Run	74,460	350,400	0	13,140	438,000
Glen Campbell Municipal Waterworks	Well	24,030	580	9,960	24,030	58,600
Greene Township Municipal Authority:						
Barr-Slope	Unnamed stream	14,550	450	0	0	15,000
Commodore	Unnamed stream	6,930	1,320	0	2,750	11,000
Alverda Community Water Association	Well	3,490	0	0	0	3,490
Ernest Borough Council	McKee Run Well	65,270	0	0	1,330	66,600
Saltsburg Borough Waterworks	Conemaugh River	52,200	15,660	67,860	38,280	174,000
West Lebanon Water Association	Wells	5,840	0	60	0	5,900
Yellow Creek State Park	Well	2,870	0	2,000	0	4,870
Miscellaneous small companies (mobile home parks, rest homes, and small businesses)	Wells	46,400	0	0	0	46,400
Total		2,220,840	1,351,190	1,294,140	1,309,190	6,175,360

ANNUAL HYDROLOGIC BUDGET

Water enters the hydrologic system in Indiana County mainly as precipitation or streamflow. A small amount of the water is held as soil moisture or is stored in ponds and reservoirs. The remainder leaves as water vapor to the atmosphere, as overland runoff, or as ground-water discharge. Ground water eventually discharges to streams within the county and streams bordering the county. A generalized representation of the hydrologic cycles of several stream basins in Indiana County is shown in figure 3. The hydrologic system is thus composed of dynamically related parts, and the amount of water that remains in and moves through each part places natural limits on the development and management of the water resources. Neither the ground-water part nor the surface-water part of the system can be developed without one affecting the other.

A water budget is the quantification of the hydrologic system. If one assumes that no ground water transfers across basin boundaries, the annual water budget for a particular basin can be expressed as follows:

$$P = Rg + Rs + ET + WS \,, \qquad (1)$$

where P is precipitation,
$(Rg + Rs)$ is total streamflow,
Rg is ground-water discharge to streams,
Rs is surface runoff,
ET is evaporation and transpiration, and
WS is change in ground-water storage.

WS can be eliminated from the equation if water levels are the same at the beginning and the end of the period for which the budget is being calculated.

A water budget was computed for parts of four basins above the streamflow-gaging stations. The basins are Little Mahoning Creek (site 8), South Branch Plum Creek (site 9), Cherry Run (site 26), and Little Yellow Creek (site 17). The drainage areas of the four basins are 87.4, 9.38, 10.5, and 7.36 mi^2, respectively.

Precipitation data for sites 8 and 9 were obtained from the USGS precipitation gage in the South Branch Plum Creek Basin. Precipitation data for site 26 were obtained from the USGS precipitation gage in the Cherry Run Basin. Precipitation data for site 17 were obtained from the NOAA precipitation gage at Indiana, Pa.

Streamflow data were available from the streamflow-gaging stations at the four sites. The ground-water (Rg) and surface-water (Rs) components of streamflow were separated by the use of the fixed-interval method of a hydrograph separation program called HYSEP (Sloto, 1991). Ground-water contribution to streamflow primarily reflects geology and ground-water-flow paths on the streamflow of a basin. Surface runoff primarily reflects topography and land use of a basin.

The amount of evapotranspiration (ET) varies with the length of the growing season, average temperature, amount and timing of precipitation, wind velocity, and humidity. The amount of water lost to ET was determined by computing the difference between precipitation and streamflow [ET = P-(Rg+Rs)].

In basins unaffected by large withdrawals and mining, net changes in ground-water storage tend to average out over the years. The change in ground-water storage (*WS*) was disregarded in the water-balance equation because there were no large withdrawals or mine discharges in three of the basins. In the Cherry Run Basin, there were no known withdrawals; however, a significant mine discharge was above the streamflow-gaging station, and about 80 percent of the basin was deep mined. These factors had a significant effect on the water budget.

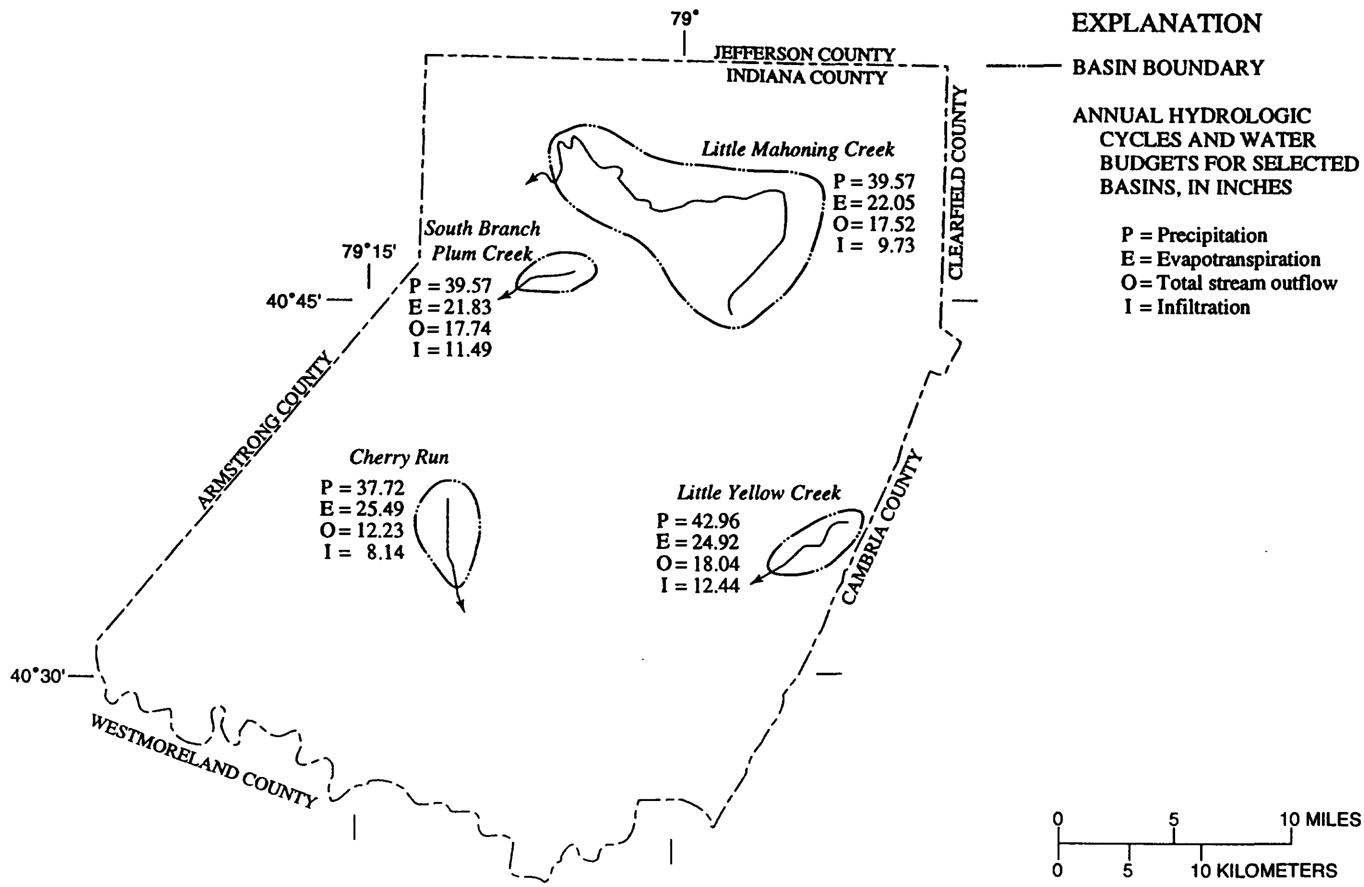


Figure 3. Annual hydrologic cycles and water budgets for selected basins, Indiana County, Pennsylvania.

Water budgets of the four basins are listed in table 3. In the Cherry Run Basin, much of the rainfall is assumed to percolate through the soil and rock structure and into the deep mine openings. Some of this water is presumably transferred out of the basin through the mines; in the water budget analyses, this transferred water is considered part of the evapotranspiration component. Therefore, the value of the evapotranspiration component in the Cherry Run Basin is larger than the actual value. Differences between the budgets of the basins can be attributed to many factors, such as precipitation, geology, land use, topography, temperature, and mining. However, the amount of precipitation probably causes the most difference. The basin above site 17 received the greatest amount of precipitation and also had the greatest ET (excluding site 26). The drainage area above site 17 is more forested than the drainage areas above sites 8 and 9; this greater amount of forest accounts for the higher amount of evapotranspiration above site 17.

Table 3. Annual water budgets for Little Mahoning Creek, South Branch Plum Creek, Little Yellow Creek, and Cherry Run Basins, Indiana County, Pennsylvania, calendar year 1987

[All values are in inches; numbers in parentheses are percentages]

Precipitation P	= Surface runoff Rs	+ Ground-water discharge Rg	+ Evapotranspiration ET
Little Mahoning Creek (site 8)			
39.57 (100)	7.79 (19)	9.73 (25)	22.05 (56)
South Branch Plum Creek (site 9)			
39.57 (100)	6.25 (16)	11.49 (29)	21.83 (55)
Little Yellow Creek (site 17)			
42.96 (100)	5.60 (13)	12.44 (29)	24.92 (58)
Cherry Run (site 26)			
37.72 (100)	4.09 (11)	8.14 (22)	25.49 (67)

Monthly values for precipitation, ground-water discharge, and surface runoff for calendar year 1987 for sites 8, 9, 17, and 26 are shown in figure 4. In addition, the difference between monthly precipitation and the sum of ground-water discharge and surface runoff is shown in figure 4 as a residual term. On an annual basis, this residual term was used to approximate evapotranspiration (table 3); however, on a monthly basis, changes in storage within the hydrologic system connot be ignored. Thus, this term represents the sum of evapotranpiration, change in soil moisture storage, change in ground-water storage, change in surface-water storage, and ground-water pumpage (fig. 4). Although the drainage area above site 8 is more than nine times that of the drainage area above site 9, the water budgets for both of the basins are similar. (The two basins are adjacent, and the precipitation input to both budgets was determined from the rain gage in the South Branch Plum Creek Basin.)

At all four sites, the residual term that includes consumptive losses of ET generally was at a minimum from early fall to late spring because much of the plant cover was gone. Evapotranspiration was generally at a maximum during the summer. This pattern of annual variation in ET is the reason a shortage in precipitation from fall to spring (first killing frost to last) will have a more severe effect on ground-water recharge than a shortage in precipitation during the growing season (when little or no recharge usually occurs). The ET rates generally are proportional to the precipitation rates in three of the four basins. The ET consumption on an annual basis (table 3) was 56 percent in the Little Mahoning Creek Basin (site 8), 55 percent in the South Branch Plum Creek Basin (site 9), and 58 percent in the Little Yellow Creek Basin (site 17).

The ground-water discharge in all four basins ranged from 22 to 29 percent of precipitation, which is equivalent to 269 (gal/min)/mi^2 and 411 (gal/min)/mi^2, respectively. These figures are rough approximations of total ground-water availability. Because of the low yields of wells in the county, however, withdrawal of the total ground water available is not feasible.

Surface runoff was largest in the Little Mahoning Creek Basin (site 8) at 19 percent and smallest in the Cherry Run Basin (site 26) at 11 percent. The differences in surface runoff from the four basins unaffected by mining are attributed to differences in topography and land use.

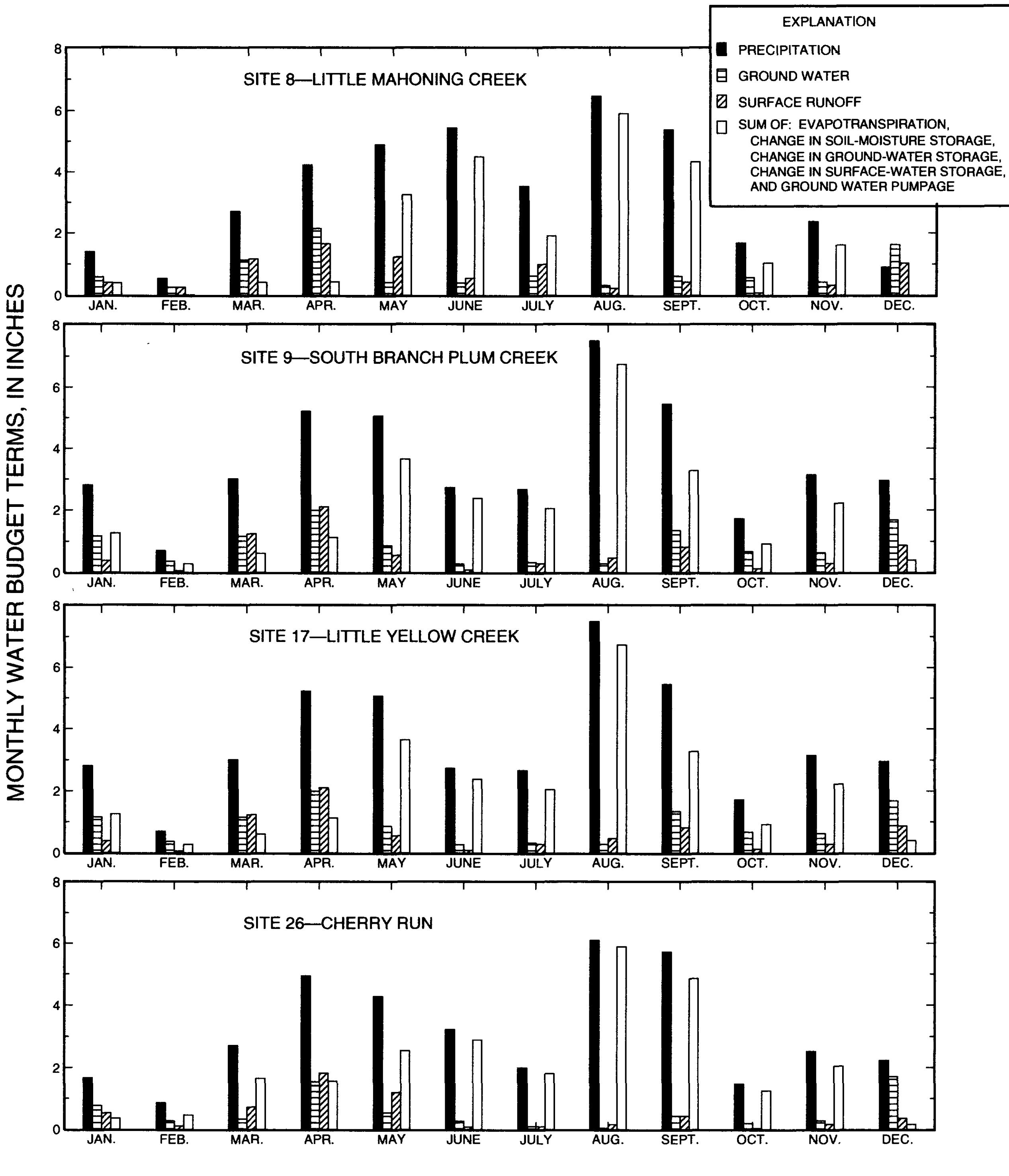


Figure 4. Average monthly precipitation; ground-water discharge; surface runoff; and the sum of evapotranspiration, change in soil-moisture storage, change in ground-water storage, change in surface-water storage, and ground-water pumpage for sites 8, 9, 17, and 26, Indiana County, Pennsylvania, calendar year 1987.

GROUND-WATER RESOURCES

Geologic Setting

Indiana County is underlain by a sequence of sedimentary rocks consisting of shale, siltstone, sandstone, claystone, and minor amounts of limestone and coal. Overlying the sedimentary rocks are unconsolidated deposits. The Rockwell Formation of Mississippian and Devonian age is the oldest rock unit exposed in the county. Above it, from oldest to youngest, are the Burgoon Sandstone, Loyalhanna Formation, and Mauch Chunk Formation, all of Mississippian age; rocks of Pennsylvanian age, from oldest to youngest, are the Pottsville Group, Allegheny Group, Conemaugh Group (Glenshaw and Casselman Formations), and the Monongahela Group. An igneous dike of Jurassic age was intruded near Dixonville. The unconsolidated deposits are the Carmichaels Formation of Pleistocene age and alluvium of Holocene age. The major coal beds in the county are in the Monongahela and Allegheny Groups.

The geologic structure is characterized by simple, open folds that generally strike N. 30° E. Four major anticlines and five major synclines are present (pl. 1). From west to east, these features are Caledonia Syncline, Dutch Run Anticline, Elders Ridge Syncline, Jacksonville Anticline, Dixonville and Nashville Synclines, Chestnut Ridge Anticline, Brush Valley Syncline, Nolo Anticline, and Ligonier Syncline. Amplitude of folding on Chestnut Ridge approaches 2,100 ft, and bedrock dips are commonly about 7°. Elsewhere in the county, the amplitude of folding is reduced, typically 500 to 1,000 ft, and dips are about 2.5°. Dips steepen slightly to the east.

Factors That Affect the Yields of Wells

Lithology

Lithology has a significant effect on well yield in Indiana County but only in valleys. This relation was determined by comparing the yields of wells in identical topographic settings but with different dominant lithologies (sandstone and fine-grained rock). The wells were not classified by geologic unit because (1) the depositional environment for all Pennsylvanian rocks was similar; thus, all rocks should be similar; and (2) the data base would have been too small to be statistically significant.

The distinction between sandstones and fine-grained rocks was the only one made, because drillers describe all noncarbonate rocks with grain sizes smaller than sand as "shale."

Yields are reported for 37 inventoried wells whose dominant lithology is sandstone. Of these wells, 8 are in valleys, 11 are on hillsides, and 9 are on hilltops; the remaining 9 wells are in other topographic settings. Yields are also reported for 94 inventoried wells whose dominant lithology is "shale." Of these wells, 25 are in valleys, 47 are on hillsides, and 22 are on hilltops. The Mann-Whitney U-test was used to determine whether differences in yield between populations in the categories were statistically significant (Siddiqui and Parizek, 1972). The 95-percent confidence level used in these tests is a common criterion for establishing whether or not two samples are from different populations. Medians and ranges of yields in each category are given in table 4, and the results of the Mann-Whitney U-tests are summarized in table 5.

Sandstones are expected to yield greater volumes of ground water than finer grained rocks, because the sandstones are more brittle and are thus more likely to develop fractures through which ground water can flow. The results of the statistical tests show that valleys are the only topographic setting where wells in sandstone have significantly higher yields than wells in the finer grained rocks.

Table 4. Median, minimum, and maximum yields of wells completed in sandstone and in finer grained rocks, Indiana County, Pennsylvania

[<, less than; yields in gallons per minute]

Topographic setting	Sandstone			Finer grained rocks		
	Median	Minimum	Maximum	Median	Minimum	Maximum
Valley	37.5	4	100	15	3	50
Hillside	5	3	25	7	<1	50
Hilltop	8	<1	30	4.5	1	15

Table 5. Summary of Mann-Whitney U-test for well yield as a function of lithology, Indiana County, Pennsylvania

[<, less than; confidence level is 95 percent]

Test of yields of wells in sandstone as a function of yields of wells in finer grained rocks	Percent probability of significance difference
Valley wells	98
Hillside wells	<50
Hilltop wells	78

Topographic Setting

Several studies in Pennsylvania have established a relation between the topographic setting of wells and their yields (Meisler and Becher, 1971; Becher and Taylor, 1982; McElroy, 1988). Wells in valleys have larger yields than those on hillsides and hilltops. Valleys and draws are commonly formed along zones of weakness, which are susceptible to more rapid erosion than is the surrounding land. These zones may be caused by the presence of joints, faults, cleavage, or bedding plane separations, all of which increase well yield by providing secondary porosity. Some investigators have suggested that the removal of rock by erosion allows fractures to open by relieving the weight of the overburden (Wyrick and Borchers, 1981). Comparisons of yields in wells in the Glenshaw Formation in Indiana County show that valley wells are consistently more productive than hilltop or hillside wells (p. 33).

Geologic Structure

Geologic structure refers to the shape or geometry of rock units and includes features produced by movement after deposition. Fractures and folds are major features that affect well yields. Fractures in the rock include faults, joints, and cleavage. Fracture openings may yield significant amounts of water to a well. Fold hinges may be associated with areas of increased fracturing. The attitude of beds affects the water that flows along bedding-plane separations. Because bedding-plane separations coincide with the dip of the rocks, the direction of flow along these bedding-plane separations is controlled by the regional structure.

Ground-Water Occurrence and Flow

The source of ground water in Indiana County is precipitation. Most precipitation is evaporated, transpired by plants, or conveyed overland as runoff. The remainder seeps through pores in surface soils and weathered bedrock and through fractures in unweathered bedrock, becoming ground water. Flow is chiefly downward to the top of the zone of saturation (water table). Ground water then flows laterally toward areas of lower head. Two general systems of ground-water flow are present in the county: a deep, regional system and a shallow system (less than 300 ft deep in most places).

Regional ground-water flow is predominantly lateral, toward major river valleys, and is much slower than local flow. Few wells are deep enough to tap the deep flow system, so little is known about it. Discharge is upward, into major valleys such as the Conemaugh River Valley on the southern border of Indiana County. Because of the slow flow rate and the long distances traveled, residence time of ground water in the regional flow system is long. Water is an efficient solvent, so mineralization of ground water that has passed through the regional system is commonly high. The Borough of Saltsburg, which is adjacent to the Conemaugh River, got its name from wells drilled in the Borough that supplied salt water. These wells very likely were tapping regional ground-water flow moving upward into the Conemaugh River Valley.

The shallow system provides almost all ground water used in Indiana County. In this system, water-bearing fractures in the rock are numerous enough and large enough to supply useful quantities of ground water. System depth is inferred from analysis of the depths of fractures intersected by water wells. Most fractures, which drillers report as water-bearing zones, are at depths of 100 ft or less, and almost none are deeper than 300 ft.

At a small scale, head controls flow in the shallow system. At a large scale, lithology and the number, size, and extent of interconnections of fractures have a substantial effect on ground-water-flow volume and direction. Discharge is to streams or lakes, where the water table intercepts land surface. A conceptual model of shallow-system ground-water flow in Indiana County, at small and large scales, is shown in figure 5.

A perched water table, which is the top of a zone of saturation with an unsaturated zone beneath it, is shown in the upper left of figure 5. Inhibition of downward flow of ground water, caused in this case by a poorly permeable claystone underlying a coal seam, creates perched ground water. Permeability of claystones is low because they are commonly plastic, and this plasticity can result in "healing" of fractures that pass through them. Ground water flows laterally through the overlying coal and along the top of the claystones to their outcrop, where the ground water discharges as springs. Although claystones probably underlie most perched ground-water bodies in Indiana County, any unfractured rock can create perched ground water. The range in size of perched ground-water bodies in Indiana County is not known.

Poorly permeable rocks may also be a barrier to upward flow of ground water, creating a confined, or artesian, aquifer. Water levels in wells drilled into an artesian aquifer will rise above the top of the aquifer. If the water level rises above land surface, the well is a flowing artesian well. Artesian conditions are found most commonly in valleys, where there may be an upward component of flow. Few flowing wells are present in Indiana County; only 1 of the 517 wells inventoried for this report is flowing.

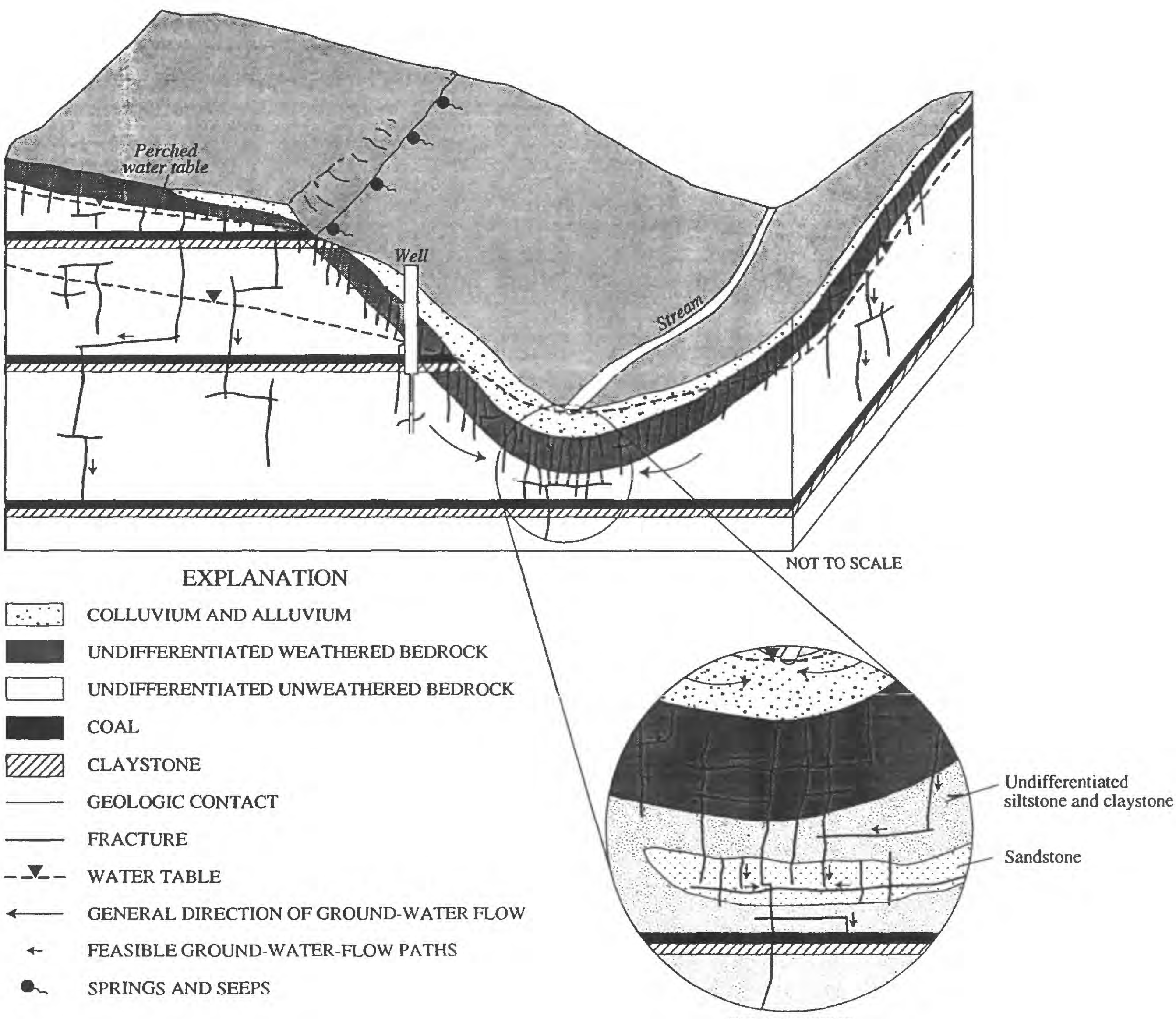


Figure 5. Conceptual ground-water-flow system in Indiana County, Pennsylvania. (Modified from Harlow and LeCain, 1993.)

The well shown diagrammatically on figure 5 is typical of domestic wells in Indiana County. The well is cased a few feet into unweathered bedrock and is open below the casing. The well intercepts a small fracture. If the fracture is small enough, then aquifer-test results for the well would be similar to those for well IN 447, which is an example of the control of ground-water flow by fractures (fig. 6). For the first 20 minutes of the test, drawdown was minimal. After 20 minutes, the small fracture that supplies most of the ground water to the well was dewatered; thereafter, drawdown increased significantly.

The enlargement in figure 5 shows how lithology can vary laterally and how lithology can affect fracturing. The enlargement shows a noncontinuous sandstone that is more heavily fractured than the surrounding rock. Sandstone is more brittle than finer grained lithologies, such as siltstone, and thus is more likely to develop fractures. The setting is similar to that of a well field drilled as part of the Indiana County study. Aquifer tests of the well field demonstrate local control of ground-water flow by fractures and lithology.

The well field, designated the Reddings Run well field, was drilled to study the flow of ground water through the Pennsylvanian rocks that predominate in the county. It is in Washington Township, on the western edge of Indiana County (fig. 7).

The site is on a lineament. The valley containing Reddings Run is a surface manifestation of this lineament (fig. 7). Lineaments are thought to exist where a concentration of vertical fractures weaken the rock and enable accelerated erosion.

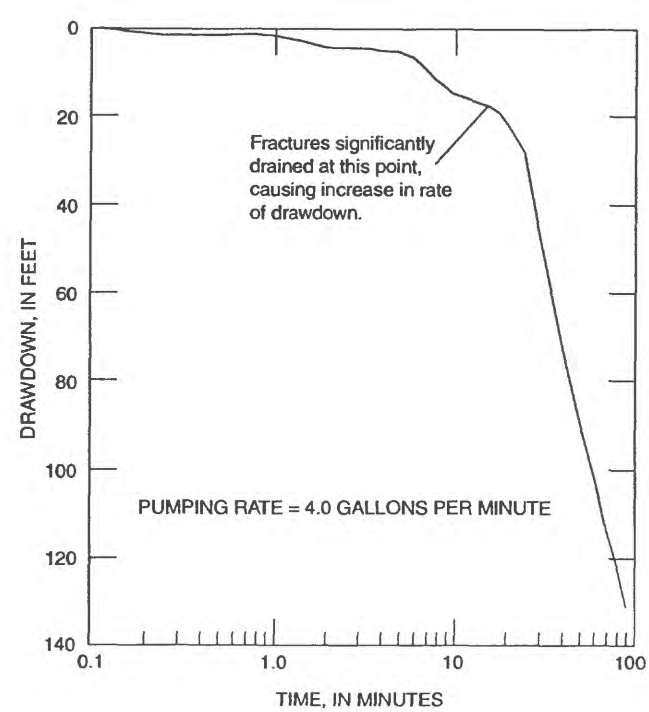


Figure 6. Drawdown caused by pumping of well IN 447, Indiana County, Pennsylvania.

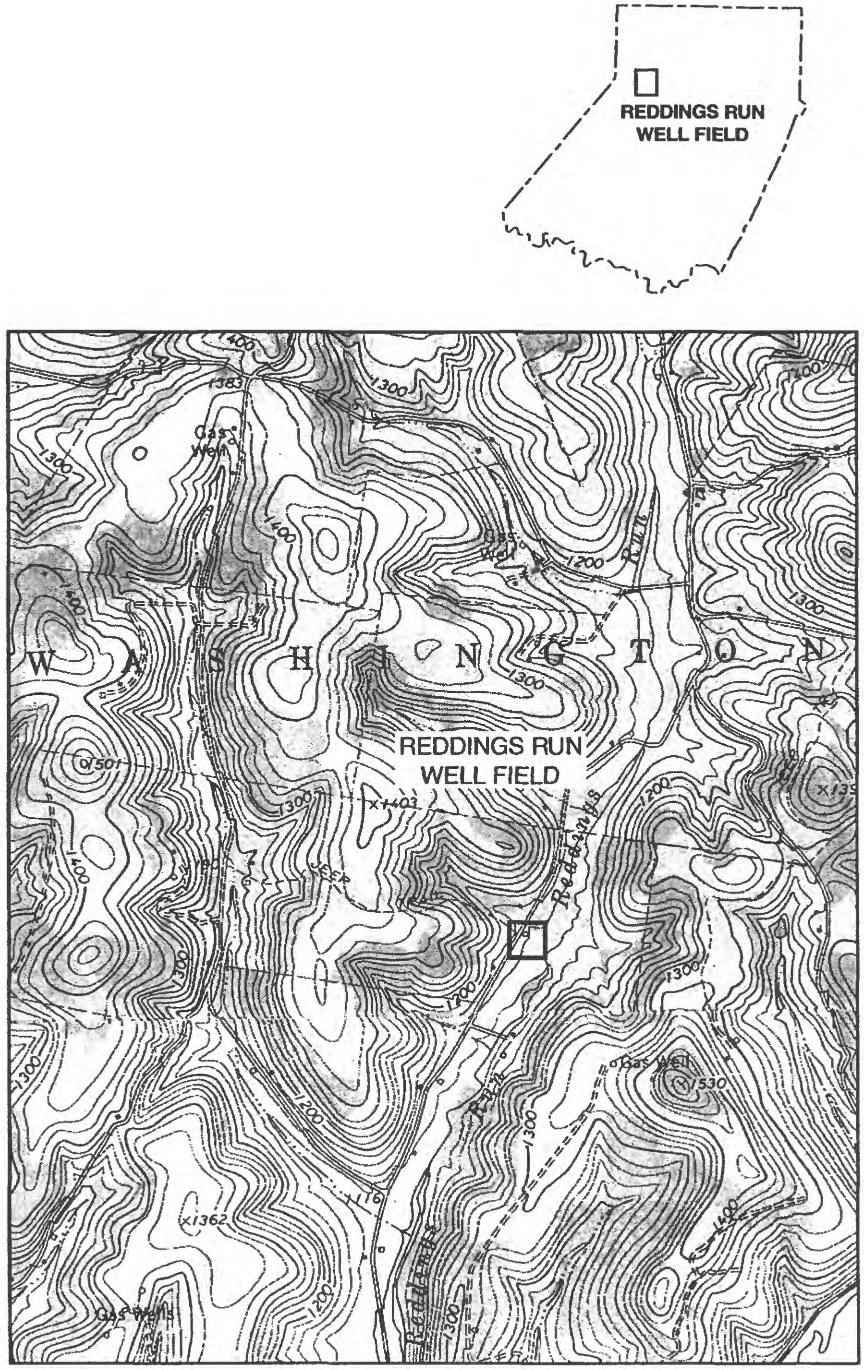


Figure 7. Location of Reddings Run well field, Indiana County, Pennsylvania.

In November 1986, an air-rotary drill was used to construct five wells to a depth below the base of the Upper Freeport coal, which is the uppermost unit of the Allegheny Group. The configuration of the well field is shown in figure 8. All the wells except for well IN 234 are at a land-surface elevation of 1,140 ft; well IN 234 is 10 ft higher. During the drilling, rock chips were collected and used to describe lithology. The wells were geophysically logged for resistivity, spontaneous potential, natural-gamma radiation, borehole diameter, fluid temperature, and fluid conductivity. Intervals of the Upper Freeport coal are present in all wells: 10 in. in well IN 230, 26 in. in well IN 231, 17 in. in well IN 232, 40 in. in well IN 233, and 47 in. in well IN 234. Well IN 235 is a 40-ft-deep well used by the landowner; geophysical logging of the well was not possible because a pump is in place.

The Upper Freeport coal at the site dips one-half degree to the southeast. On a small scale, geology of the area is "layer cake," as shown in the unenlarged part of figure 5. On a large scale, lateral lithologic changes are significant, as shown in the enlargement in figure 5. The depositional model for the sediments shows the reason for the lithologic changes (fig. 9). Of note are the discontinuous peat beds (which become coal) and the irregular sand lenses, which are deposited in stream channels.

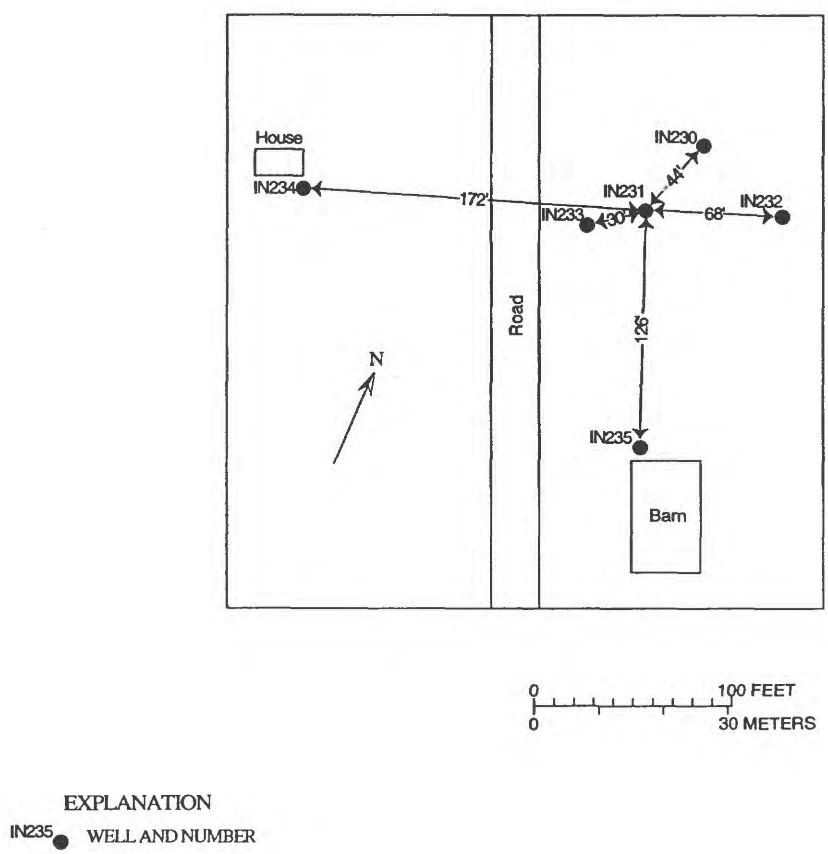


Figure 8. Plan view of Reddings Run well field, Indiana County, Pennsylvania.

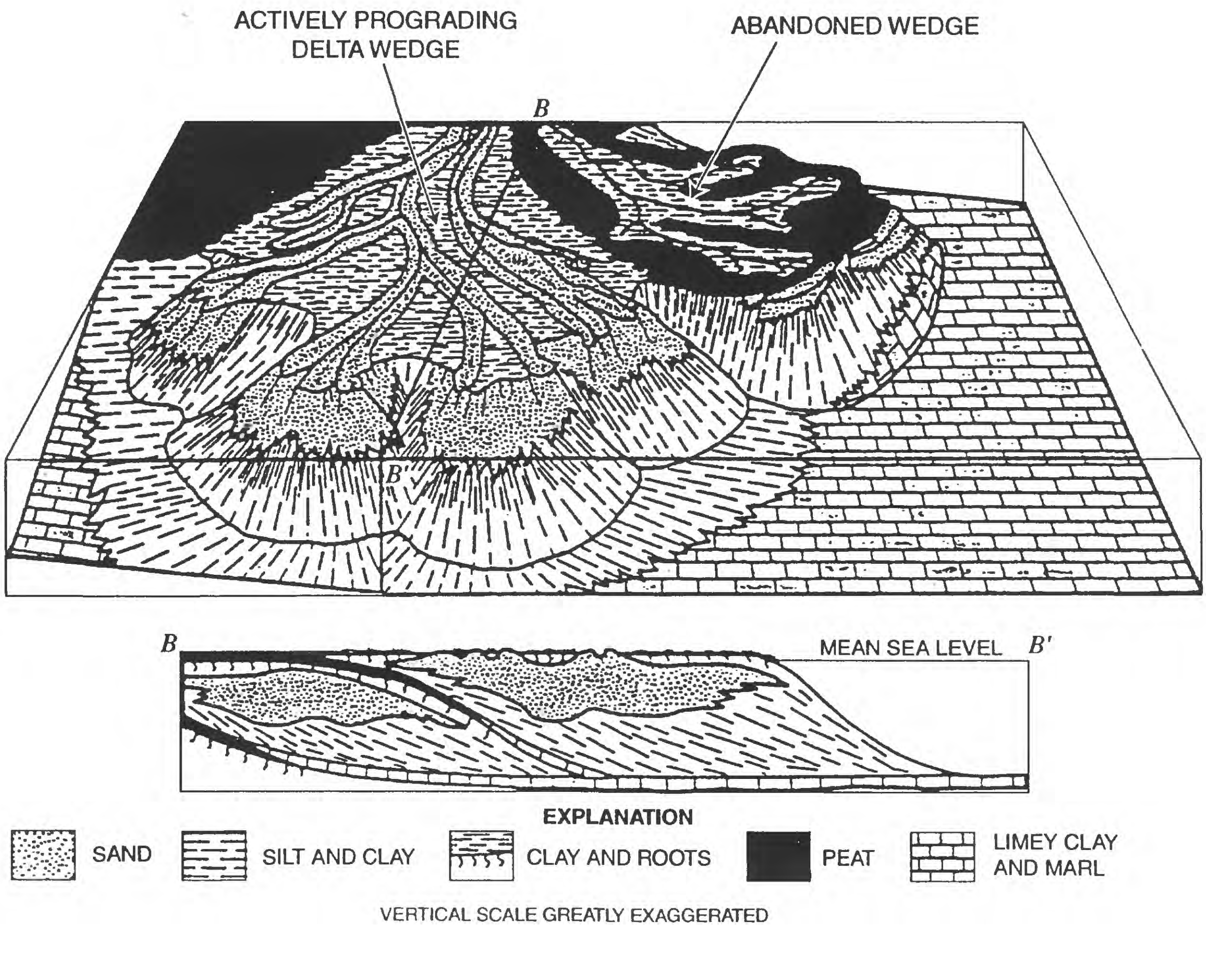


Figure 9. Depositional model for rocks of Pennsylvanian age, Indiana County, Pennsylvania. (From Ferm, 1970.)

Expected yield of the wells was only 5 to 10 gal/min; however, wells IN 230, IN 231, and IN 232 are surprisingly productive, with estimated yields in the 60- to 80-gal/min range. Well IN 233, which is only 30 ft from well IN 231, yields only 10 gal/min. The yield of well IN 234 is 15 gal/min. The major water-bearing zone in wells IN 230, IN 231, and IN 232 is in a channel sandstone at about 75 ft below land surface. The channel sandstone is not tapped by wells IN 233 and IN 234, which yield water only in zones above 58 ft depth (table 6). A fence diagram of the well field, drawn by use of lithologic data from wells IN 230, IN 231, IN 232, and IN 233, is shown in figure 10.

Table 6. Depth to water-bearing zones and well depth, Reddings Run well field, Indiana County, Pennsylvania

[Location of wells shown in figure 9; dash indicates that water-bearing zone is not present at the same approximate depth as in other wells]

Well or aquifer characteristic	IN 230	IN 231	IN 232	IN 233	IN 234
Depth to water-bearing zones, in feet	--	--	--	27	25, 29
	--	--	38	--	--
	--	48	--	--	--
	60	--	58	58	--
	75	77	70	--	--
	--	90	--	--	--
Depth of well, in feet below land surface	[1] 130	107	110	110	123

[1] Drilled to 20 ft below Upper Freeport coal.

The first of five aquifer tests of the well field was an attempt to hydrologically isolate the Upper Freeport coal to determine its water-bearing properties. A pump was installed in well IN 231 at the depth of the coal, and a packer was installed above it. A packer is an inflatable tube that blocks off part of the well. During preliminary testing, drawdown above the packer indicated that the pumping was removing water from above the packer. Packer operation was checked, and the packer was determined to be working properly. Because isolation of the coal was impossible, the aquifer test was discontinued.

For the second aquifer test, the pump was reinstalled in well IN 231 adjacent to the major water-bearing zone at 77 ft. Packers were installed above and below the pump. Again, drawdown was noted in the zone above the upper packer, and the test was discontinued. A hydrologic connection is necessary for drawdown to occur above a section of borehole isolated by packers. Therefore, ground water was determined to be moving through vertical fractures.

The three subsequent aquifer tests lasted for periods of 4, 24 and 72 hours. Water levels were measured in all wells. In all of the tests, well IN 231 was the pumped well, and the pump was installed below the water-bearing zone at 90 ft. The 4-hour test was done at a pumping rate of 24 gal/min. The 24-hour and 72-hour tests were done at pumping rates of 33 and 30 gal/min, respectively.

Initial water-level responses to pumping varied from well to well. During the 4-hour test, no measurable drawdown occurred in well IN 233 until 1 minute into the aquifer test. Drawdown in well IN 235 was first measurable 40 seconds after pumping began. During the 72-hour test, no drawdown was measured in well IN 233 until 5 minutes had elapsed. The first measurement in well IN 235 was made at 5 minutes; the water level had declined 0.20 ft. Drawdown in wells IN 230 and IN 232 began immediately for all of the aquifer tests, with the possible exception of the 24-hour test. It is not known how long wells IN 232, IN 233 and IN 235 took to react to pumping during the 24-hour test. Personnel limitations prevented measurement of drawdown in the wells until after 10 minutes had elapsed.

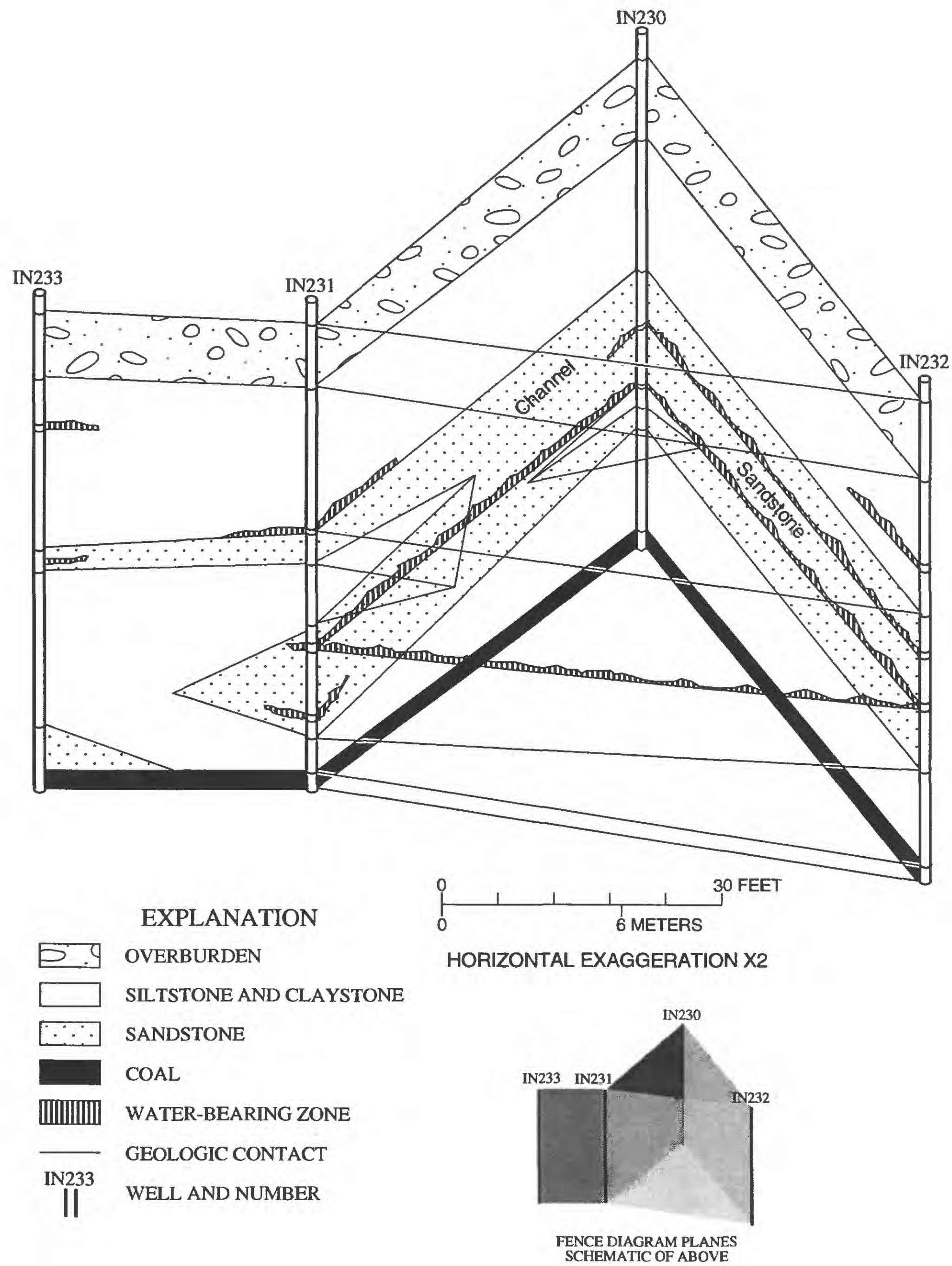


Figure 10. Fence diagram of Reddings Run well field, Indiana County, Pennsylvania (view looking north).

Drawdown and water-level-elevation curves for the 24-hour aquifer test are shown in figure 11. The curves of the 4-hour test are similar to the 24-hour curves, but not identical, because of the lower pumping rate. At well IN 233, the well closest to the pumped well, drawdown was the least, and static water level in the well was 7 ft higher than in wells IN 230, IN 231, IN 232, and IN 235. Water levels in wells IN 230, IN 231, IN 232, and IN 235 were all at nearly equal elevation. Well IN 235 is four times as far from the pumped well as well IN 233 and does not penetrate to the major water-bearing zone, but drawdown at well IN 235 was twice that at well IN 233. Water level in well IN 230 declined rapidly for the first minutes of the test. After 20 minutes of pumping, water levels in wells IN 230, IN 232, and the pumped well (IN 231) all decreased in nearly equal increments for the duration of the aquifer test. No drawdown was recorded at well IN 234. All the drawdown curves for the 24-hour aquifer test, except for well IN 232, are steeper than for the 4-hour aquifer test. The drawdown curves for well IN 232 are nearly identical for both aquifer tests; the cause of the similar response to the different pumping rates may be a restriction in a fracture connecting well IN 232 to well IN 231.

Recharge to the well field from precipitation is rapid but uneven. Vertical fracturing allowed the rapid recharge. Drawdown and water-level-elevation curves for the 72-hour aquifer test are shown in figure 12. Hard rain fell twice during the aquifer test, beginning at about 420 minutes and 1,000 minutes. The rate of drawdown slowed for only wells IN 230 and IN 231 after the first rainfall. The second rainfall caused all of the drawdown rates to slow, except for that at well IN 235. Well IN 235 is adjacent to a large barn; rain gutters on the barn may have directed recharging precipitation away from well IN 235. Water level in well IN 234, which was unaffected by pumping, rose 1.5 ft.

The cone of depression 60 minutes into the 24-hour test is shown in figure 13. The shape of the cone of depression clearly shows the influence of the channel sandstone. Between wells IN 231 and IN 233 is a steep gradient, caused by the poor hydrologic connection between the two wells. The connection is poor because the well-fractured channel sandstone found at well IN 231 is not present at well IN 233. The figure also indicates a north-south orientation of the channel sandstone.

The aquifer tests show how lithology and fracturing affect local ground-water flow. Yields of wells IN 230, IN 231, and IN 232 are large because of the fractured channel sandstone that they penetrate. The yield of well IN 233 is low because it does not penetrate the sandstone, and the fractures present in the sandstone do not extend into the rocks penetrated by well IN 233. Horizontal fracturing within the sandstone interconnects the wells penetrating it. The interconnection is responsible for the equal drop in water levels at wells IN 230, IN 231, and IN 232 after 20 minutes of pumping. The system behaves as if it were a reservoir. The interconnection is also the reason the water level in wells IN 230 and IN 232 reacted immediately to pumping. Withdrawal of water from the system causes water levels in all parts of the system to drop equally. Vertical fracturing allows rapid recharge and the hydraulic connection of well IN 235 to the sandstone underlying it.

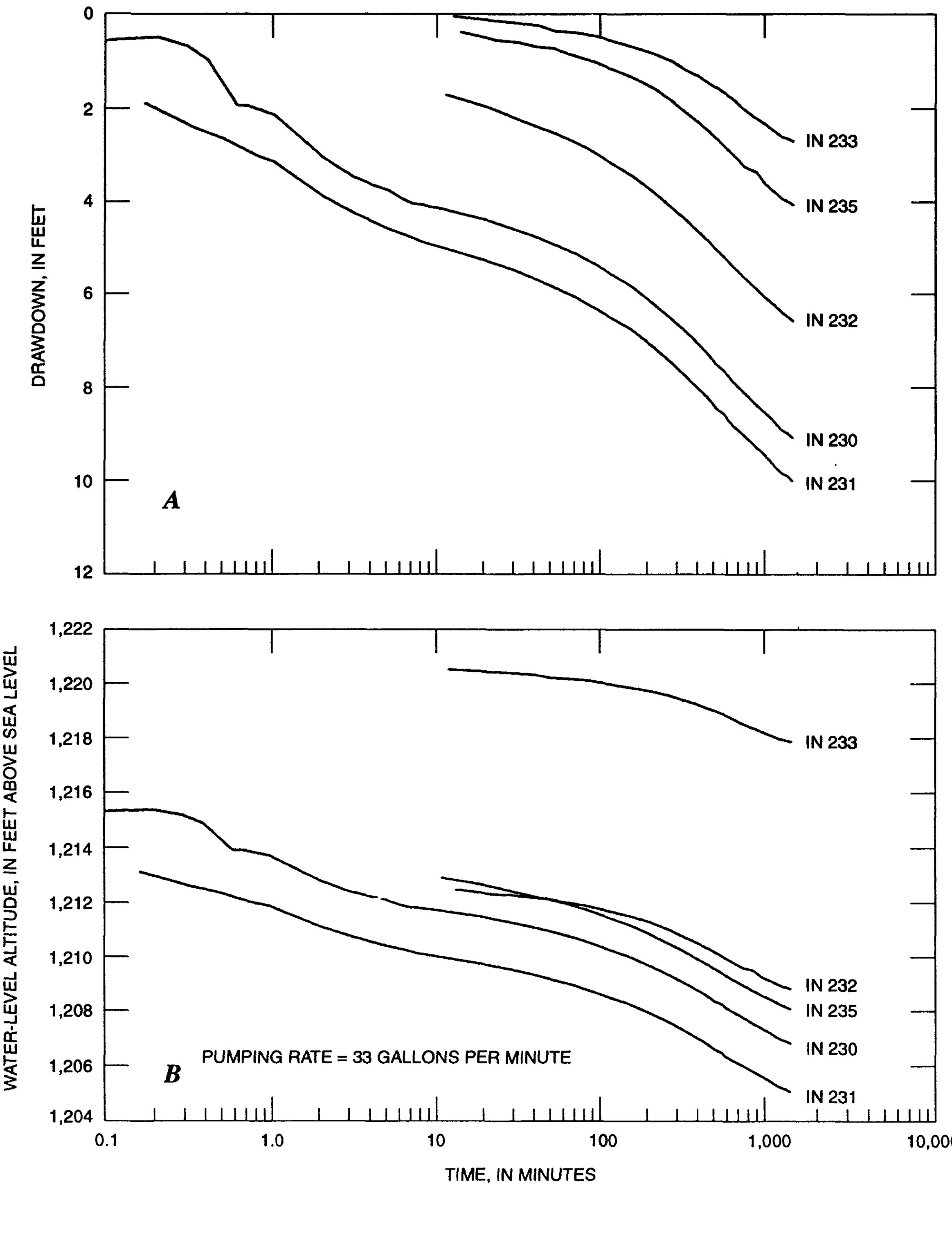


Figure 11. Response of Reddings Run well field, Indiana County, Pennsylvania, to pumping of well IN 231 for 24 hours: drawdown curves and water-level elevations.

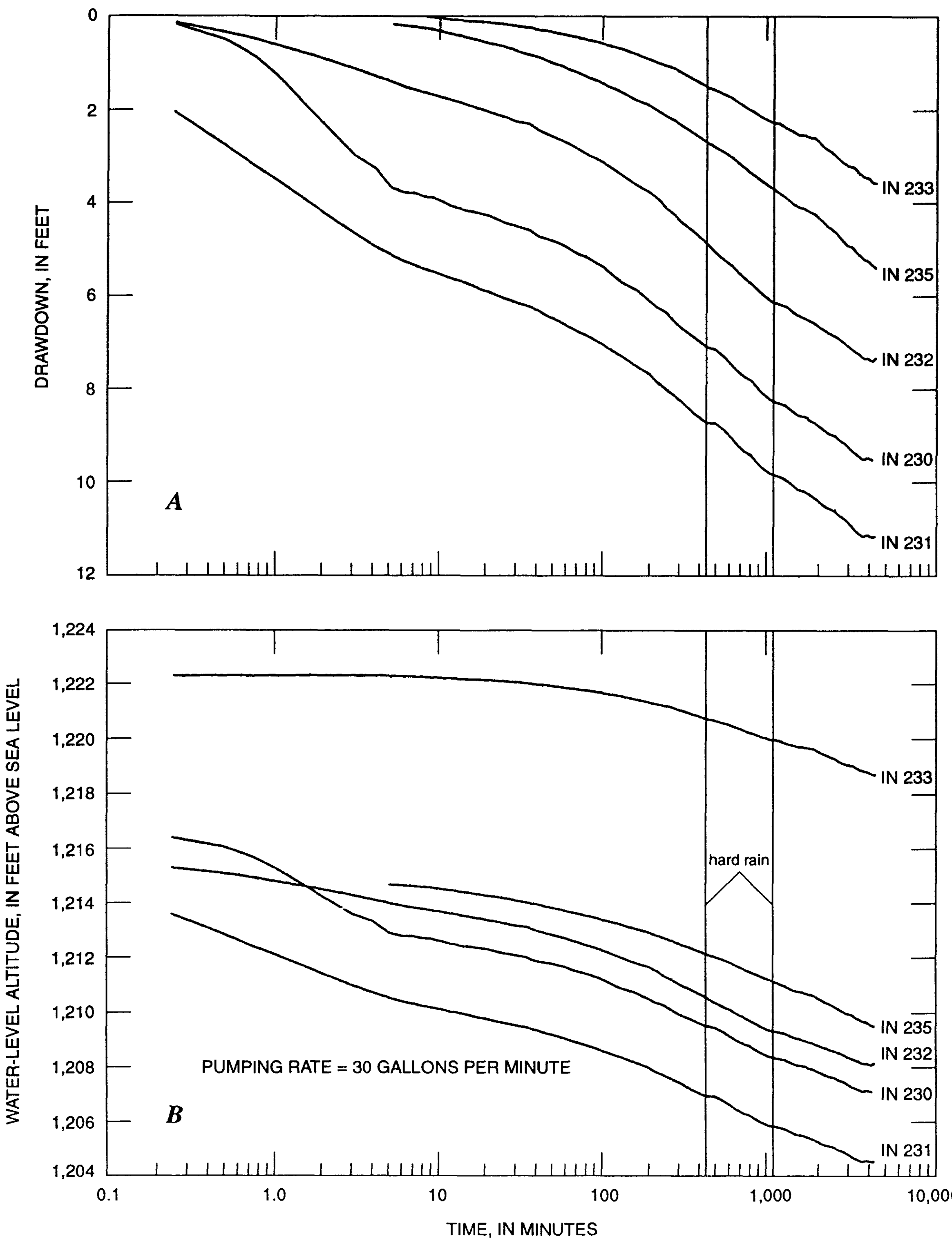


Figure 12. Response of Reddings Run well field, Indiana County, Pennsylvania, to pumping of well IN 231 for 72 hours: drawdown curves and water-level elevations.

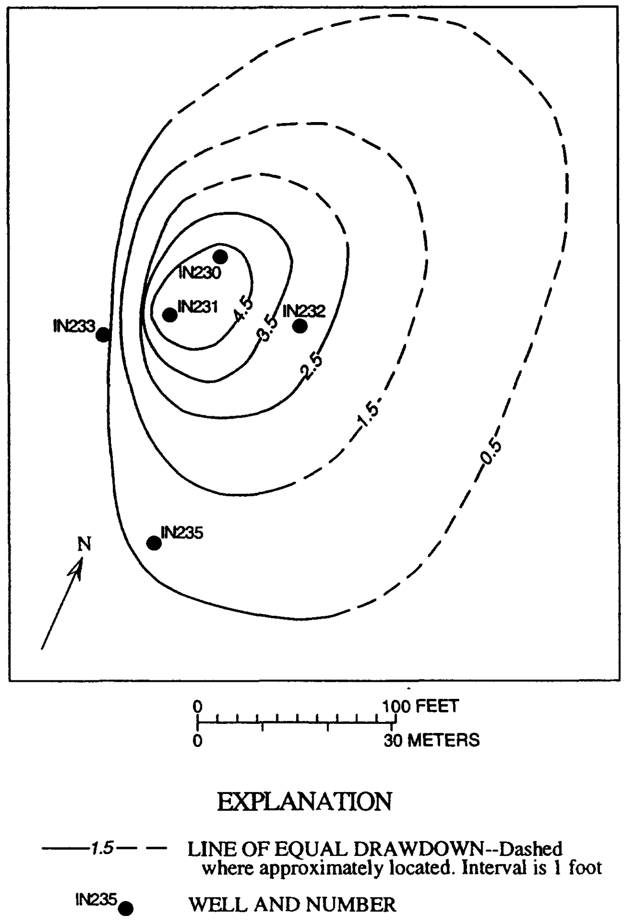


Figure 13. Contour map of drawdown at the Reddings Run well field, Indiana County, Pennsylvania, after 1 hour of pumping well IN 231 at a rate of 33 gallons per minute.

Stratigraphy, Water-Bearing Properties of the Rocks, and Water Quality

The geology and geologic structure of Indiana County are shown on plates 1 and 2. Stratigraphic nomen-clature is modified from Berg and others (1980).

The mandatory and recommended limits for public water supplies and the significance of chemical constituents in water are given in table 7. Drinking-water criteria are from the U.S. Environmental Protection Agency (USEPA) unless otherwise noted. In table 8, methods of treatment are presented for constituents that may be present in concentrations that impair water for drinking or other domestic uses.

Water-bearing characteristics are discussed for domestic and nondomestic wells. Nondomestic wells are drilled for large-volume users. They are more likely than domestic wells to represent the largest volume of ground water that a well in a given rock unit can produce.

Table 7. Source and significance of selected dissolved constituents in and properties of ground water, Indiana County, Pennsylvania

[Modified from Lloyd and Growitz, 1977, p. 51-54; concentrations in milligrams per liter (mg/L) except as indicated; 1,000 µg/L = 1 mg/L; USEPA MCL, U.S. Environmental Protection Agency Maximum Contaminant Level; USEPA SMCL, U.S. Environmental Protection Agency Secondary Maximum Contaminant Level]

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils (commonly less than 30 mg/L).	Forms hard scale in pipes and boilers. When carried over in steam of high-pressure boilers, it forms deposits on blades of turbines.
Aluminum (Al)	Dissolved in small quantities from aluminum-bearing rocks. Acidic waters commonly contain large amounts.	May be troublesome in feed waters because of scale formation on boiler tubes. The USEPA SMCL is 200 µg/L.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 300 µg/L stains laundry, porcelain, and utensils reddish brown. Objectionable for food and textile processing, ice manufacturing, brewing, and other processes. The USEPA SMCL is 300 µg/L.
Manganese (Mn)	Dissolved from many rocks and soils. Commonly associated with iron in natural waters but not as common as iron.	More than 200 µg/L precipitates upon oxidation. Manganese has the same undesirable characteristics as iron but is more difficult to remove. The USEPA SMCL is 50 µg/L.
Cadmium (Cd)	Dissolved in small quantities from cadmium-bearing rocks. Excessive concentrations are generally from contamination by industrial wastes from metal-plating operations.	Concentrations greater than 5 µg/L may be toxic and are considered grounds for the rejection of a water supply.
Chromium (Cr)	Dissolved in minute quantities from chromium-bearing rocks. Excessive concentrations are generally from contamination by industrial wastes.	The USEPA MCL is 100 µg/L.
Copper (Cu)	Dissolved from copper-bearing rocks. Small amounts (less than 1.0 mg/L) generally found in natural waters. Small amounts are commonly added to water in reservoirs to inhibit algal growth.	Copper is essential and beneficial for human metabolism. May impart metallic taste to water in concentrations greater than 1.0 mg/L. The USEPA SMCL is 1.0 mg/L.
Lead (Pb)	Dissolved in small quantities from lead-bearing rocks. Less than 0.01 mg/L generally found in natural waters. Excessive concentrations are caused by contamination from lead plumbing, lead picked up from the atmosphere by rain, and other artificial sources.	Lead is accumulated by the body and may cause sickness and even death in excessive concentrations. The USEPA MCL is 15 µg/L.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Sewage and industrial wastes are also major sources.	Concentrations of less than 50 mg/L have little effect on usefulness of water for most purposes. More than 50 mg/L may cause foaming in steam boilers and limit the use of water for irrigation.
Zinc (Zn)	Dissolved from zinc-bearing rocks. May be dissolved from galvanized pipe; is present in many industrial wastes.	Concentrations greater than 30 mg/L have been known to cause nausea and fainting and to impart metallic taste and a milky appearance to water. The USEPA SMCL is 5 mg/L.
Nickel (Ni)	Dissolved from nickel-bearing rocks, commonly associated with iron and manganese.	Nickel is considered to be relatively nontoxic to humans.

Table 7. Source and significance of selected dissolved constituents in and properties of ground water, Indiana County, Pennsylvania—Continued

Constituent or property	Source or cause	Significance
Arsenic (As)	Dissolved in small quantities from arsenic-bearing rocks. Excessive concentrations are generally due to improper waste-disposal practices. Arsenic is also present in certain insecticides and herbicides.	Concentrations above 50 µg/L exceed USEPA MCL and may be toxic.
Alkalinity (CO_3, HCO_3)	The bicarbonate ion may result from the solution of atmospheric carbon dioxide and the solution of carbon dioxide produced during the decomposition of soil. The major source, however, is from the solution of limestone.	Bicarbonate (HCO_3) and carbonate (CO_3) produce alkalinity. Bicarbonates of calcium and magnesium decompose in boilers and hot water facilities to form scale and release corrosive carbon dioxide gas (see "Hardness").
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Particularly associated with acid mine drainage. Commonly present in some industrial wastes and sewage.	Sulfates in water containing calcium may form hard Ca-SO_4 scale in steam boilers. Can have laxative effect on persons unaccustomed to high-sulfate water. The USEPA SMCL is 250 mg/L.
Chloride (Cl)	Dissolved from rocks and soils in small quantities. Relatively large amounts are derived from sewage, industrial wastes, highway-salting practices, and oil and gas production water.	In large quantities chloride increases the corrosiveness water. Large amounts in combination with sodium result in a salty taste. The USEPA SMCL is 250 mg/L.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	About 1.0 mg/L of fluoride in drinking water is believed to be helpful in reducing incidence of tooth decay in small children; larger concentrations cause mottling of enamel. The USEPA MCL is 4.0 mg/L and the SMCL is 2.0 mg/L.
Nitrate (NO_3)	Decaying organic matter, sewage, and fertilizers are principal sources.	Small concentrations have no effect on usefulness of water. The limit for drinking water is 10 mg/L of NO_3-N. Water containing more than this level may cause methoglobinemia (a disease often fatal in infants) and, therefore, should not be used in infant feeding.
Hardness ($CaCO_3$)	In most waters, nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness. There are two classes of hardness: carbonate (temporary) and noncarbonate (permanent). Carbonate hardness refers to the hardness resulting from cations in association with carbonate and bicarbonate; it is called temporary because it can be removed by boiling the water. Noncarbonate hardness refers to that resulting from cations in association with other anions.	Hardness consumes soap (before a lather will form and deposits soap curds on bathtubs). Carbonate hardness is the cause of scale formation in boilers, water heaters, radiators, and pipes, causing a decrease in heat transfer and restricted flow of water. Waters whose hardness is 60 mg/L or less are considered soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L hard; more than 180 mg/L, very hard. Very soft water with a low pH may be corrosive to plumbing. Milligrams per liter divided by 17.1 yields the concentration in grains per gallon.

Table 7. Source and significance of selected dissolved constituents in and properties of ground water, Indiana County, Pennsylvania—Continued

Constituent or property	Source or cause	Significance
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all rocks and soils, especially from limestone, dolomite, and gypsum.	Cause of most of the hardness in water and, in combination with bicarbonate, is the cause of scale formation in steam boilers, water heaters, and pipes (see "Hardness"). Water low in calcium and magnesium is desired in electroplating, tanning, dyeing, and in manufacturing. Maximum concentrations of 100 mg/L calcium and 50 mg/L magnesium are recommended for drinking-water supplies.
Dissolved solids	A measure of all the chemical constituents dissolved in a particular water.	The USEPA SMCL for total dissolved solids is 500 mg/L, but water containing as much as 1,000 mg/L may be used where less mineralized supplies are not available.
Specific conductance	A measure of the capacity of a water to conduct an electrical current. It varies with concentration and degree of ionization of the constituents.	Can be used to obtain a rapid estimate of the approximate dissolved-solids concentration of water. The sum of dissolved-solids concentration for ground water in the study area is approximately equal to 0.55 times the specific conductance.
pH	The negative logarithm of the hydrogen-ion concentration.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline solutions; values lower than 7.0 indicate acidic solutions. Corrosiveness of water generally increases with decreasing pH. The pH of most natural waters ranges from 6 to 8.
Temperature		The temperature of ground water between the water table and about 60 feet below the water table is approximately the same as the average annual air temperature[1]; below this point, ground-water temperatures increase with depth about 1°F for each 50 to 100 feet.

[1] Lovering and Goode, 1963, p.5.

Table 8. Suggested methods of treatment for domestic drinking water

[mg/L, milligrams per liter]

Constituent	Treatments[1] (commercial units are available for home installation)
Iron and (or) manganese	Polyphosphate feeders (less than 2 mg/L). Ion exchange softeners (less than 2 mg/L). Water must first be chlorinated, or softener will become clogged. Greensand filter (less than 2 mg/L). Continuous chlorination (any concentration).
Arsenic	Ferric sulfate coagulation; works best for pH of 6 to 8.
Barium	Ion exchange.
Chromium +3	Ferric sulfate coagulation; works best for pH of 6 to 9. Alum coagulation; works best for pH of 7 to 9.
Chromium +6	Ferrous sulfate coagulation; works best for pH of 7 to 9.5.
Cadmium	Ferric sulfate coagulation; works best if pH is greater than 8.
Fluoride	Ion exchange with activated alumina or bone char media.
Lead	Ferric sulfate coagulation; works best for pH of 6 to 9. Alum coagulation; works best for pH of 6 to 9. Reverse osmosis.
Sulfate	Reverse osmosis. Ion exchange. Electrodialysis.
Zinc	Reverse osmosis. Ion exchange. Electrodialysis. Softening.
Aluminum	Reverse osmosis[2]. Electrodialysis[2].
Dissolved solids	Reverse osmosis. Ion exchange. Electrodialysis.
Magnesium	Ion exchange.
Calcium	Ion exchange.
Hardness	Ion exchange.

Alum coagulation.—Alum is mixed with the water to be treated, causing negation of the repulsive forces between particles, and allowing the small particles to join together to form larger particles, which settle readily (flocculation).

Continuous chlorination.—Chlorine is added to water to convert dissolved constituents to insoluble oxidized forms, which can then be filtered.

Electrodialysis.—Water is demineralized by the removal of ions through membranes that have a direct current applied to them.

Ferric/ferrous sulfate coagulation.—The same as alum coagulation except that iron sulfates are used instead of alum.

Greensand filter.—Also known as zeolite, greensand filters oxidize and filter water. The greensands must be backwashed periodically and reoxygenated by the addition of a solution of potassium permanganate.

Ion exchange.—Objectionable ions are removed by exchanging them with other ions. The most common use of ion exchangers is water softeners, in which calcium and magnesium, which are the principal causes of hardness, are exchanged for sodium. Softeners must be periodically regenerated by back-washing, application of a salt solution, and rinsing. These units are not recommended for individuals on low-sodium diets. Ion exchangers may also be used to remove ions other than calcium and magnesium.

Polyphosphate feeder.—Polyphosphate is added to water either by diverting part of the water through a chamber of powdered chemical or by injecting a small amount of concentrated solution into the line. Polyphosphate does not remove iron or manganese, but it prevents the formation of the solid oxides of these metals.

Reverse osmosis.—A semipermeable membrane is used to separate water to be treated from purer water. Pressure applied to the more heavily mineralized water causes relatively pure water to flow through the membrane.

[1] Treatments are from Landers (1976) and U.S. Environmental Protection Agency (1977 a, b).

[2] Little work has been done on removing dissolved aluminum from water. These treatments should be effective, but treated water would have to be tested to ensure adequate aluminum removal.

Alluvium

Alluvium consists of unconsolidated deposits of gravel, sand, silt, and clay of Pleistocene to Holocene age. These deposits occupy the flood plains of streams and, in some places, form low terraces above the floodplains. A seismic line shot on the main stem of Plum Creek just north of State Route 85 indicated an alluvium thickness of 25 ft. Only one inventoried well, IN 355, draws its supply from alluvium. The well, which is in the Blacklegs Creek Valley, penetrated 40 ft of sand and gravel. Well yield was 30 gal/min; field data indicated that the water was of suitable quality for domestic use.

Carmichaels Formation

The Carmichaels Formation of Pleistocene age consists of sand, gravel, silt, clay, and boulders and is found on terraces above the flood plain of the Conemaugh River and Crooked Creek at elevations of 900 to 1,000 ft. Thickness of the formation is not known. Well IN 422 penetrates 15 ft of the Carmichaels, and well IN 558 penetrates 25 ft. Although sand and gravel deposits may be productive aquifers, the potential for development of the Carmichaels Formation is low, because the deposits are on the surface and are thus not likely to be saturated.

Dixonville Dike

A dark, coarse-grained igneous dike is the only igneous rock found in Indiana County. It is about 1.5 mi west of Dixonville, in the central part of the county. It is thin (less than 10 ft) and discordant. A similar dike (the Gates-Adah), in Greene and Fayette Counties, is estimated to be about 185 million years old (Pimentel and others, 1975). No ground-water data are available. Because peridotite has a very low permeability, the dike may be a local barrier to ground-water flow.

Monongahela Group

The Monongahela Group is present in southern Indiana County along the axes of the Latrobe and Elders Ridge Synclines (pl. 1). No data are available to differentiate the group by formation. The Pittsburgh coal, which lies at its base, has been completely mined out. The Redstone and Sewickley coals also have been mined. The group consists of bluish-gray, hard, compact limestone with subconchoidal fracturing; gray to dark-gray shales and sandy shales; thin-bedded to massive, light- to very light gray, fine- to medium-grained sandstone; carbonaceous shale; and coal. The group is approximately 350 ft thick 0.5 mi west of Iselin.

Water-bearing properties

Four wells that tap the Monongahela Group were inventoried. All are used for domestic supply. Depths ranged from 118 to 140 ft, and the two water-bearing zones were reported, at 28 ft and at 66 ft. Yields were low, ranging from 1 to 5 gal/min.

Water quality

Wells—Two wells, IN 380 and IN 802, were sampled for complete analyses. Well IN 380 yields hard water with a manganese concentration exceeding the USEPA Secondary Maximum Contaminant Level (SMCL) of 50 μg/L; the lead concentration exceeded the USEPA Maximum Contaminant Level (MCL) of 50 μg/L. Well IN 802 also yielded hard water, but constituent concentrations met all USEPA MCL's and SMCL's.

Springs—All of the four springs sampled yield hard, alkaline water. None of the constituent concentrations in the samples exceeded any USEPA MCL or SMCL.

Utility as an aquifer

Because of the extensive deep mining of the Pittsburgh coal, probably only shallow wells can be developed in the Monongahela Group. This restriction limits the potential of the group as a productive aquifer (McElroy, 1988). Ground water from the group is hard and may contain iron and manganese in concentrations that exceeded the USEPA SMCL's.

Casselman Formation

The Casselman Formation is the upper formation of the Conemaugh Group. In most places, it is about 380 ft thick. Major exposures are on the Elders Ridge, Latrobe, and Dixonville Synclines. Local outcrops are also found on the axes of the Caledonia, Mudlick Run, and Brush Valley Synclines and on the flanks of the Ligonier Syncline (pl. 1). The Casselman Formation consists of thin-bedded, green and red claystone, which is usually calcareous; gray siltstone; locally massive fine- to medium-grained gray sandstone; freshwater limestone; and thin, discontinuous coal beds. Plant fossils are found in the Casselman Formation. The top of the formation is the base of the Pittsburgh coal, and the base of the formation is at the top of the Ames Limestone of the Conemaugh Group.

Water-bearing properties

The median yield of five nondomestic wells was 25 gal/min, and the range was 2 to 50 gal/min. The wells were from 50 to 181 ft deep. Of the five reported water-bearing zones, four were less than 100 ft below land surface.

Domestic-well yield ranged from less than 1 to 35 gal/min, and the median yield was 4 gal/min. The median depth of domestic wells in the Casselman Formation was 154 ft. Of the 29 reported water-bearing zones, 26 were 100 ft or less in depth.

Water quality

Wells—Composite stiff diagrams of well and spring water from the Casselman Formation are shown in figure 14. Stiff diagrams are used to show water composition. The width of the pattern is an approximate indication of total ionic content. The units used, milliequivalents per liter, are calculated by dividing the concentration of each ion by its atomic weight and ionic charge. The total milliequivalents of cations should equal the total milliequivalents of anions. The figure shows that well water from the Casselman Formation is a calcium bicarbonate type and is generally hard to very hard. Of the 13 wells sampled, 7 yielded water containing iron concentrations exceeding the USEPA SMCL of 300 μg/L; 5 of the same 7 also had manganese concentrations exceeding the USEPA SMCL of 50 μg/L. Water from well IN 127 also had a zinc concentration exceeding the USEPA SMCL of 5 mg/L, and water from well IN 502 had an aluminum concentration slightly greater than the USEPA SMCL of 200 μg/L.

Springs—Spring water from the Casselman Formation is a calcium bicarbonate type (fig. 14). Most of the Casselman Formation springs sampled yielded moderately hard to very hard water. Only 3 of the 12 sampled springs yielded soft water. The pH of the same three springs was less than the SMCL of 6.5. Manganese concentrations exceeding the SMCL of 50 μg/L were present in 4 of the 12 sampled springs. Nitrate concentration in water from spring IN SP 310 exceeds the MCL of 10 mg/L, and aluminum concentration in water from spring IN SP 177 exceeds the SMCL of 200 μg/L.

Utility as an aquifer

Yields from the Casselman Formation are adequate for domestic use. Water from the formation will probably be hard and may have concentrations of iron and manganese that exceed the USEPA SMCL's.

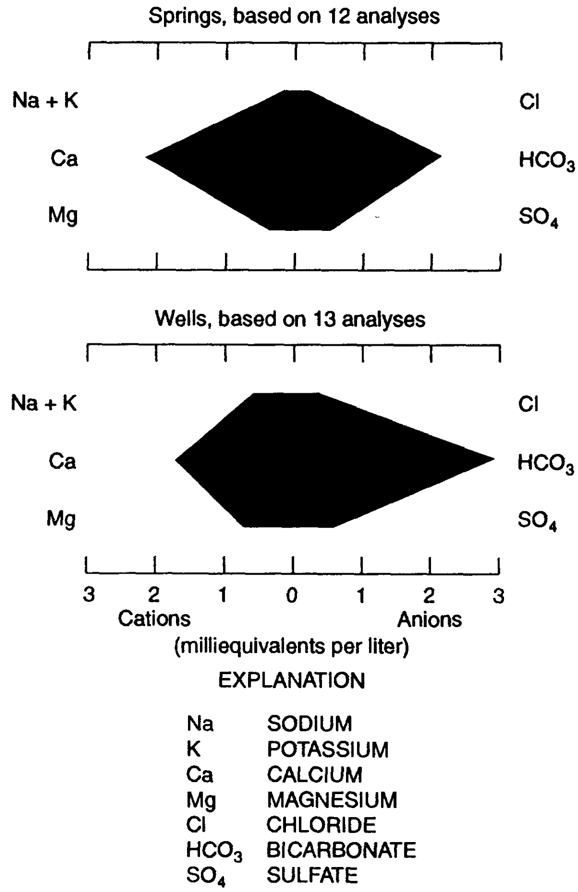


Figure 14. Median chemical characteristics of ground water from the Casselman Formation, Indiana County, Pennsylvania.

Glenshaw Formation

The Glenshaw Formation is the lowermost formation of the Conemaugh Group. It consists of olive-gray to dark-gray, thinly bedded, fossiliferous limestone and clay shale; red claystone; locally massive fine- to coarse-grained sandstone near the base; a few freshwater limestones; and generally thin coals. The Mahoning coal has been surface mined in an area 0.5 mi east of Two Lick Reservoir. The formation is 390 ft thick in eastern Indiana County, thinning to 370 ft in the west. The base is the top of the Upper Freeport coal. The Glenshaw Formation crops out more extensively than any other rock unit in the county. It is absent only along parts of the axes of the Jacksonville, Chestnut Ridge, and Nolo Anticlines (pl. 1), where it has been eroded away.

Water-bearing properties

The median yield of 15 nondomestic wells was 20 gal/min, and the range was 3 to 100 gal/min. Well depth ranged from 40 to 213 ft. The deepest well, IN 472, is on a hilltop. Well IN 472 also was the only well where water-bearing zones were reported to be deeper than 100 ft. The median yield of domestic hilltop and hillside wells was 6 gal/min; yields ranged less than 1 to 30 gal/min for hilltop wells and less than 1 to 100 gal/min for hillside wells. Only 2.5 percent of the hilltop and hillside wells had yields greater than 25 gal/min. Domestic valley wells had a significantly greater median yield, 15 gal/min. Of 42 domestic valley wells, 10 had yields greater than 25 gal/min. A frequency-distribution graph of Glenshaw Formation domestic-well yields, grouped by topographic position, is shown in figure 15. Yields of hilltop and hillside wells were nearly identical, and valley wells were significantly more productive. The median of valley-well depths was significantly less (85 ft) than the median depth of hillside wells (120 ft) and hilltop wells (137.5 ft). Only 11 of 331 reported water-bearing zones were deeper than 150 ft, and 263 were at a depth of 100 ft or less.

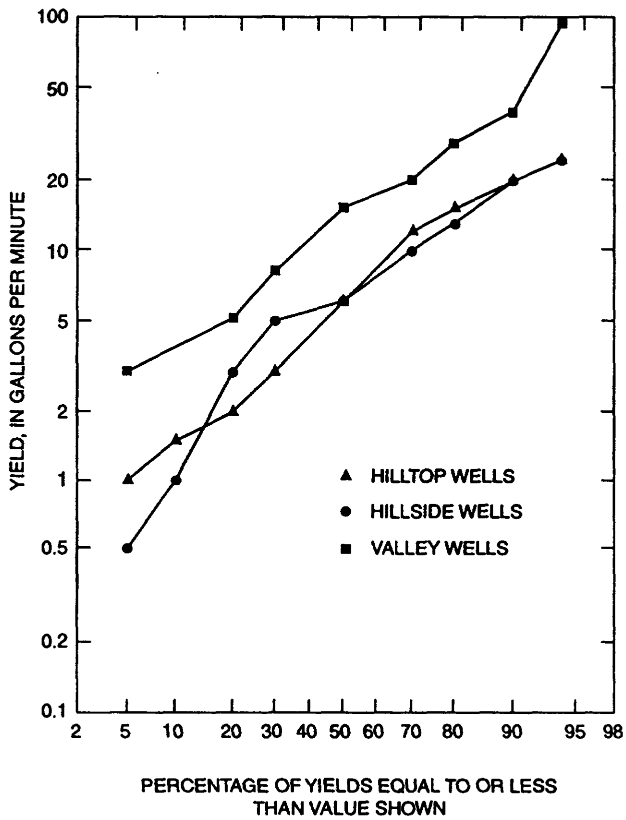


Figure 15. Frequency distribution of Glenshaw Formation domestic well yields, Indiana County, Pennsylvania.

Water quality

Wells—Ground water from the Glenshaw Formation is a calcium bicarbonate type. Most wells in the Glenshaw Formation yielded water that was moderately hard to hard. Only 18 percent of the wells tested yielded soft water. Iron and manganese were commonly present in excessive concentration; 62 percent of all wells yielded ground water with iron concentrations greater than the SMCL of 300 μg/L, and 48 percent of the wells yielded ground water exceeding the SMCL of 50 μg/L for manganese. Of the wells sampled, 10 percent yielded water exceeding the SMCL of 200 μg/L for aluminum. Fourteen percent of the pH's were less than the SMCL of 6.5. Most of the low pH's were measured in water from wells in topographic positions where ground-water residence time is short (hilltop). Only three wells produced water whose sulfate concentration was greater than the SMCL of 250 mg/L. Water in another well had a chloride concentration large enough to impart a salty taste. All other properties and constituents analyzed for were within water-quality guidelines (table 7).

Springs—Water samples were collected from 84 springs flowing from the Glenshaw Formation. Half of the springs yielded water with a pH less than the SMCL of 6.5. Precipitation in western Pennsylvania typically has a pH less than the SMCL (E.C. Witt, III, U.S. Geological Survey, written commun., 1990). When the precipitation enters the ground-water system, it dissolves alkaline material, and the pH increases. The Glenshaw contains less alkaline material than do the overlying units (V.W. Skema, Pennsylvania Department of Environmental Resources, Bureau of Topographic and Geologic Survey, oral commun., 1990); this factor, combined with the short residence time of spring water, results in low-pH springwater. Most of the Glenshaw Formation springs yielded soft to moderately hard water. Only 11 of the 84 sampled springs yielded hard to very hard water. Manganese concentrations in 25 percent of the sampled springs were greater than the SMCL of 50 μg/L. Only 5 percent of the springs yielded water whose iron concentrations exceeded the SMCL of 300 µg/L. Aluminum concentrations in 8 percent of the samples were greater than the SMCL of 200 µg/L. Spring IN SP 263 yielded water whose nitrate concentration exceeded the MCL of 10 mg/L.

Changes along flow path

As noted previously, the longer the residence time of ground water, the more heavily mineralized ground water should be. Springwater generally circulates in the shallow subsurface only; thus, its residence time is shorter than that of well water. For well water, residence time is least in the recharge (highest) areas (hilltops, flats), intermediate on hillsides, and greatest in areas of discharge (valleys). Thus, springwater should be the least mineralized, water from wells on hilltops and flats should be less mineralized than water from wells on hillsides and valleys, and hillside-well water should be less mineralized than valley-well water. Because water chemistry differs among rock units, only Glenshaw Formation springs and wells were used to determine changes in water quality along the ground-water-flow path.

Stiff diagrams for Glenshaw Formation springs, hilltop and flat-topography wells, hillside wells, and valley wells are shown in figure 16. The size of a diagram is indicative of total mineralization. The figure demonstrates increasing mineralization with residence time.

Statistical comparison of the concentrations of selected constituents in ground water from each topographic setting, by use of the Mann-Whitney U-test, also indicates increased mineralization. Properties and constituents statistically compared were alkalinity, calcium, chloride, hardness, iron, pH, magnesium, manganese, sodium, potassium, silica, strontium, sulfate, dissolved solids, and zinc. Several constituents that were analyzed for were not compared because concentrations in a large proportion of the samples were below laboratory detection limits. In cases where only a few constituent concentrations were below the detection limits, the detection limit was used as the sample concentration. A summary of the tests is given in table 9. Median, standard deviation, range, and number of samples for each constituent in each category are given in Appendix 1. A 95-percent confidence level was chosen as the criterion for statistical significance. For some properties and constituents, tests do not show significant differences; in only two tests were the results opposite what was expected (higher concentrations in a zone of shorter residence time).

Utility as an aquifer

The Glenshaw Formation yields adequate quantities of ground water for domestic use, and properly sited wells may yield quantities suitable for public-supply, industrial, or other high-use purposes. Methods for developing high-yield wells are discussed in "Guidelines for Developing Supplies" later in this report. Drilling deeper than 150 ft is unlikely to increase yield. Well water from the Glenshaw Formation will probably be hard and may exceed the SMCL's for iron and manganese. Springwater may have a pH less than the SMCL.

Allegheny Group

The Allegheny Group is divided into three formations. From youngest to oldest, they are the Freeport Formation, whose base is at the top of the Upper Kittanning coal; the Kittanning Formation, whose base is at the bottom of the Lower Kittanning coal; and the Clarion Formation, whose base is at the bottom of the Brookville-Clarion coal. The Allegheny Group consists of olive-gray to gray to dark-gray clay shale, silt shale, and siltstone; light-gray, thin to massively bedded, fine to coarse-grained sandstone with a few stylolites; nodules consisting of either limestone or siderite; occasional gray conglomerate; coal; and clay. Nodular limestone is found in the upper half of the group. The total thickness is 280 to 320 ft. Included in the Allegheny Group are the Upper Freeport, Lower Freeport, Upper Kittanning, Middle Kittanning, Lower Kittanning, and Brookville-Clarion coals, all of which have been mined in Indiana County. Most mining has been in the Upper and Lower Freeport coals and the Lower Kittanning coal. Fossil ostracods, *Spirorbis* and *Lingula*, and plant fossils are found in the group. The group underlies almost all of Indiana County. Major outcrops are along the axes of the Nolo, Chestnut Ridge, and Jacksonville Anticlines; smaller exposures are in the southeast and northwest corners of the county.

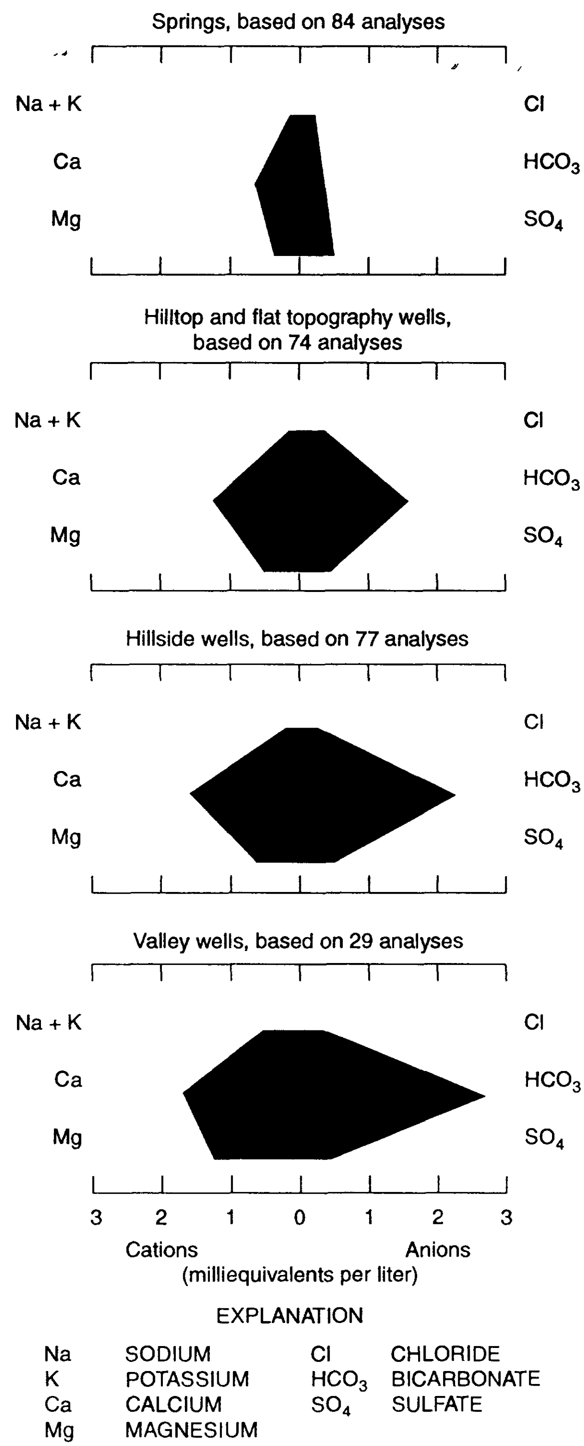


Figure 16. Median chemical characteristics of ground water from the Glenshaw Formation, Indiana County, Pennsylvania.

Table 9. Summary of results of Mann-Whitney U-test for selected properties and constituents in well water from the Glenshaw Formation, Indiana County, Pennsylvania

[H, significantly higher concentration]

Property or constituent	Topographic setting of well							
	Hilltop	Hillside	Hillside	Valley	Hilltop	Valley	Flat	Valley
Alkalinity		H		H		H		H
Calcium		H		H		H		H
Chloride								
Hardness		H		H		H		H
Iron	H			H				
pH								
Magnesium		H				H		H
Manganese	H			H				
Sodium				H		H		H
Potassium								H
Silica								
Strontium				H				H
Sulfate		H		H		H		
Dissolved solids				H		H		H
Zinc								

Water-bearing properties

The median yield of 15 nondomestic wells was 15 gal/min, and the range was from less than 1 to 60 gal/min. Well depths ranged from 44 to 205 ft. Of 14 water-bearing zones, 12 were 100 ft deep or less. The only water-bearing zone deeper than 100 ft was reported for a well that yields only 2 gal/min.

The median yield of seven domestic hilltop wells was 3 gal/min. Of the seven wells, five yielded 5 gal/min or less. The highest reported yield for a hilltop well was 15 gal/min. Depths were evenly distributed, ranging from 62 to 270 ft. The two shallowest wells had the highest yields. All but 1 of 10 reported water-bearing zones were at a depth of 150 ft or less. The deepest was at 180 ft, in a well whose reported yield was only 1 gal/min. Yields of domestic hillside wells ranged from less than 1 to 35 gal/min; the median was 6 gal/min. Depths of hillside wells ranged from 13 to 460 ft; the median was 105 ft. Three-fourths of the wells were 200 ft deep or less. Depth to water-bearing zones for hillside wells can be described by a bimodal distribution. Most water-bearing zones were at a depth of 100 ft or less, but a significant number of water-bearing zones were deeper than 150 ft. Yields of valley wells were significantly higher than yields of other wells. Valley-well yields were distributed fairly evenly around the median of 20 gal/min. Nearly all valley wells were 150 ft deep or less. The deepest was 205 ft, and its yield was 3 gal/min. Only 3 of 27 reported water-bearing zones in valley wells were deeper than 100 ft.

Water quality

Wells—Well water from the Allegheny Group is a calcium bicarbonate type (fig. 17). Only 6 of 54 tested wells in the Allegheny Group yielded soft ground water. Thirteen wells yielded moderately hard water, and 35 wells yielded hard or very hard water. Iron and manganese concentrations commonly exceeded the SMCL's of 300 µg/L and 50 µg/L, respectively, 61 percent of the wells tested having excessive iron and 72 percent having excessive manganese. Of six hilltop wells tested, five had acceptable concentrations of iron and manganese. Of 27 hillside wells sampled, 3 had aluminum concentrations greater than the SMCL of 200 µg/L, as did 2 of 15 valley wells. Of 63 wells sampled, 3 yielded water whose sulfate concentration exceeded the SMCL of 250 mg/L.

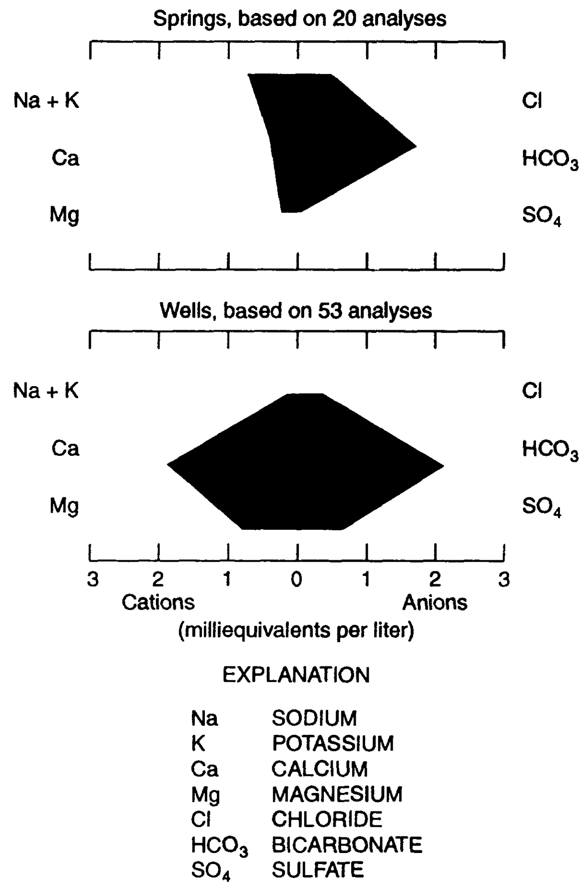


Figure 17. Median chemical characteristics of ground water from the Allegheny Group, Indiana County, Pennsylvania.

Springs—Springwater from the Allegheny Group is sodium potassium bicarbonate type (fig. 17). Its pH is commonly less than the SMCL of 6.5. Of the 20 springs sampled, 9 produced low-pH water. More than half of the springs (55 percent) yielded hard to very hard water. Manganese concentration in water from four springs was greater than the SMCL of 50 μg/L, and aluminum concentration in water from three springs was greater than the SMCL of 200 μg/L. The SMCL of 250 mg/L for sulfate was exceeded in water from two springs. Only one spring yielded water whose iron concentration exceeded the SMCL of 300 μg/L.

Utility as an aquifer

Hilltop wells may have marginal yields. Hillside wells will probably have adequate yields for domestic purposes. Valley wells may have sufficient yield for large-volume users of ground water. Little additional yield is gained at depths greater than 250 ft. Water from wells in the Allegheny Group will probably be hard, and iron and manganese concentrations in excess of the USEPA SMCL will be common. Springwater may have a low pH and be hard.

Pottsville Group

The Pottsville Group underlies nearly all of Indiana County. The Pottsville Group contains, from youngest to oldest, the Homewood Sandstone, the Mercer coal, and the Connoquenessing Sandstone. The Mercer coal has been mined 3 mi south of Clymer. The Pottsville Group contains minor amounts of shale, siltstone, and claystone. In places, the Mercer coal is replaced by a black shale. Thickness of the group can be locally variable but generally ranges from 175 to 200 ft. The group is exposed along the axes of the Chestnut Ridge, Jacksonville, and Nolo Anticlines and in the extreme northwest and southeast corners of the county. Only one well inventoried, IN 566, taps the Pottsville Group. Generally, in western Pennsylvania, yields of wells tapping the group are adequate for domestic supplies and may be adequate for high-volume users. Water from the Pottsville Group is commonly soft and not highly mineralized, but it tends to have high concentrations of iron or manganese or both (Taylor and others, 1983; McElroy, 1988).

Mauch Chunk Formation

The Mauch Chunk Formation consists of grayish-red shale, siltstone, sandstone, and some conglomerate. It contains some medium- to light-gray sandstones and siltstones. The formation thins from southeast to northwest and is not present in western or northern Indiana County. The maximum thickness, 280 ft, is in the Conemaugh River gorge of Laurel Hill. It is 130 ft thick on the eastern flank of Chestnut Ridge and pinches out on the western flank. In the north, Richardson (1904) inferred the Mauch Chunk Formation is exposed in the Yellow Creek gorge of Chestnut Ridge, although none of the characteristic red beds were found during field checking for this report. No wells inventoried for this report were drilled into the Mauch Chunk Formation. Its area of outcrop is small and is in remote areas. Elsewhere in western Pennsylvania, the Mauch Chunk yields water in adequate volumes and of suitable quality for domestic purposes (Taylor and others, 1983; McElroy, 1988).

Loyalhanna Formation

The Loyalhanna Formation is an intensively cross bedded, gray, siliceous limestone, which is approximately 60 ft thick in southern Indiana County. No confirmed exposures are north of the Conemaugh River in Indiana County. Platt (1877) reported 50 ft of Loyalhanna Formation in the Blacklick Creek gorge, but Shaffner (1958, p. 45) could not find any evidence of it and did not show it on his geologic map. No wells inventoried for this report tap the Loyalhanna, and its water-bearing characteristics have not been studied elsewhere in Pennsylvania. Because the Loyalhanna Formation is known to be cavernous (Shaffner, 1958, p. 45), it may be possible to develop large-volume supplies by means of wells that intercept caverns below the water table.

Burgoon Sandstone

The Burgoon Sandstone is buff, cross-bedded, and medium grained, and it contains some conglomerate in places at its base. The unit is 300 ft thick along the Conemaugh River, where it is exposed in the Laurel Hill and Chestnut Ridge gorges. The only other exposures in the county are in the Blacklick Creek gorge and where Mahoning Creek crosses the Jacksonville Anticline. At the Mahoning Creek exposure, the sandstone is unconformably overlain by the Pottsville Group. As the two cannot be readily distinguished, the contact is inferred. No data are available in Indiana County for the Burgoon Sandstone's water-bearing characteristics or the quality of water obtained from it. Elsewhere in western Pennsylvania, the Burgoon Sandstone yields sufficient supplies of water for industrial and public uses, but this water may contain concentrations of iron and manganese that exceed the USEPA SMCL's (Taylor and others, 1983).

Rockwell Formation

The Rockwell Formation consists of medium-light-gray or light-olive-gray to buff sandstone and interbedded dark shale. Some thin red shale and greenish shale is present in the Rockwell Formation, as is greenish-black or bluish-black marine shale. The formation is exposed only in the Laurel Hill and Chestnut Ridge gorges of the Conemaugh River, where it is 700 ft thick. No reported wells are in the Rockwell Formation. Its small, remote, and steep exposure make it an aquifer of little to no potential in Indiana County.

Comparison of the Chemistry of Ground Water from Selected Aquifers

To determine whether the aquifers in Indiana County produce ground water with distinguishable differences in chemistry, values of selected properties and constituents in water from each aquifer were statistically compared. Samples were grouped by aquifer. Samples from the Glenshaw Formation and Allegheny Group were further subdivided so that water from wells on hillsides and in valleys could be compared. Categories whose sample size was less than 10 were not considered, so the Monongahela Group was eliminated from consideration. Because only 13 samples were collected from the Casselman Formation, data were not grouped by topography. The Mann-Whitney U-test was used to determine which populations of samples were significantly different. A 95-percent confidence level was chosen as the criterion for statistical significance. Properties and constituents statistically compared were alkalinity, calcium, chloride, hardness, iron, pH, magnesium, manganese, sodium, potassium, silica, strontium, sulfate, dissolved solids, and zinc. Several constituents that were analyzed for were not compared because concentrations in a large proportion of the samples were below laboratory detection limits. In cases where a few constituent concentrations were below the detection limits; the detection limit was used as the sample concentration. A summary of the tests is given in table 10. Median, standard deviation, range, and number of samples for each constituent in each category are given in Appendix 1.

For grouped topographic settings, ground water from the Allegheny Group is more heavily mineralized than ground water from the Glenshaw Formation. The tests showing that ground water from the Casselman Formation is indistinguishable from ground water from either the Allegheny Group or the Glenshaw Formation seem contradictory to the tests of the Allegheny Group against the Glenshaw Formation; however, examination of medians and ranges of the data show that constituent concentrations for the Casselman Formation fall about halfway between the concentrations for the Allegheny Group and those for the Glenshaw Formation.

The results may be biased by the low number of Allegheny Group hilltop wells; however, the tests of Allegheny Group hillside wells against Glenshaw Formation hillside wells produced virtually the same results as the overall rock-unit tests. Samples from Allegheny Group valley wells were found to have chemistry similar to that of samples from Glenshaw Formation valley wells. The reason for this similarity is unknown.

Table 10. Summary of results of Mann-Whitney U-test for selected properties and constituents in well water from the Casselman Formation, Glenshaw Formation, and Allegheny Group, Indiana County, Pennsylvania

[H, significantly higher concentration; Pcg, Glenshaw Formation; Pa, Allegheny Group; Pcc, Casselman Formation]

Property or constituent	All wells						Hillside wells		Valley wells	
	Pcg	Pa	Pcc	Pcg	Pcc	Pa	Pcg	Pa	Pcg	Pa
Alkalinity			H							
Calcium		H						H		
Chloride										
Hardness		H						H		
Iron		H						H		
pH										
Magnesium		H						H	H	
Manganese		H						H		
Sodium						H				H
Potassium								H	H	
Silica	H					H				H
Strontium										
Sulfate		H						H		
TDS		H						H		
Zinc								H		

Water-Level Fluctuation

Water levels were recorded continuously at 13 wells during the study (fig. 1). One of the wells was drilled as part of the project. The remainder of the wells were privately owned and not in use.

Short-Term Fluctuation

Water levels in wells fluctuate during the short term in response to changes in barometric pressure, precipitation, discharge of ground water, and pumping of nearby wells. Hourly water levels for the arbitrarily selected period August 15-28, 1988, are shown in figures 18-22, for the 13 wells. The wells are grouped topographically because the topographic setting is a control on depths to water table (fig. 5).

Water-level fluctuations differ from well to well. In both hilltop wells (IN 822 and IN 859), a general, slow decline in water level is evident. The decline at well IN 822 is greater, but the water level at well IN 859, which is deeper, is more variable.

The topography around wells IN 833, IN 860, and IN 861 is flat. Well IN 860 is 100 ft from well IN 861. Well IN 833 may be an artesian well. Water levels in artesian wells fluctuate with changes in barometric pressure. At the two adjacent wells, water-level changes were markedly different. The level at well IN 861 declined by 0.40 ft overall, with considerable variation from hour to hour. The level at well IN 860 was steady until 6:00 p.m., August 23. In 3 hours, the water level rose 4.40 ft. After 4 days, it had returned to slightly above its former level. The spike was caused by infiltration from a storm on August 23.

Five wells are on hillsides. Well IN 121 is the shallowest of the hillside wells (49 ft). The water level at well IN 121 showed little response until August 25, when it began a steady rise of a total of 0.22 ft. Wells IN 801, IN 803, IN 856, and IN 864 all responded similarly, with total fluctuation of about 0.2 ft and lows on August 18, 23, and 27.

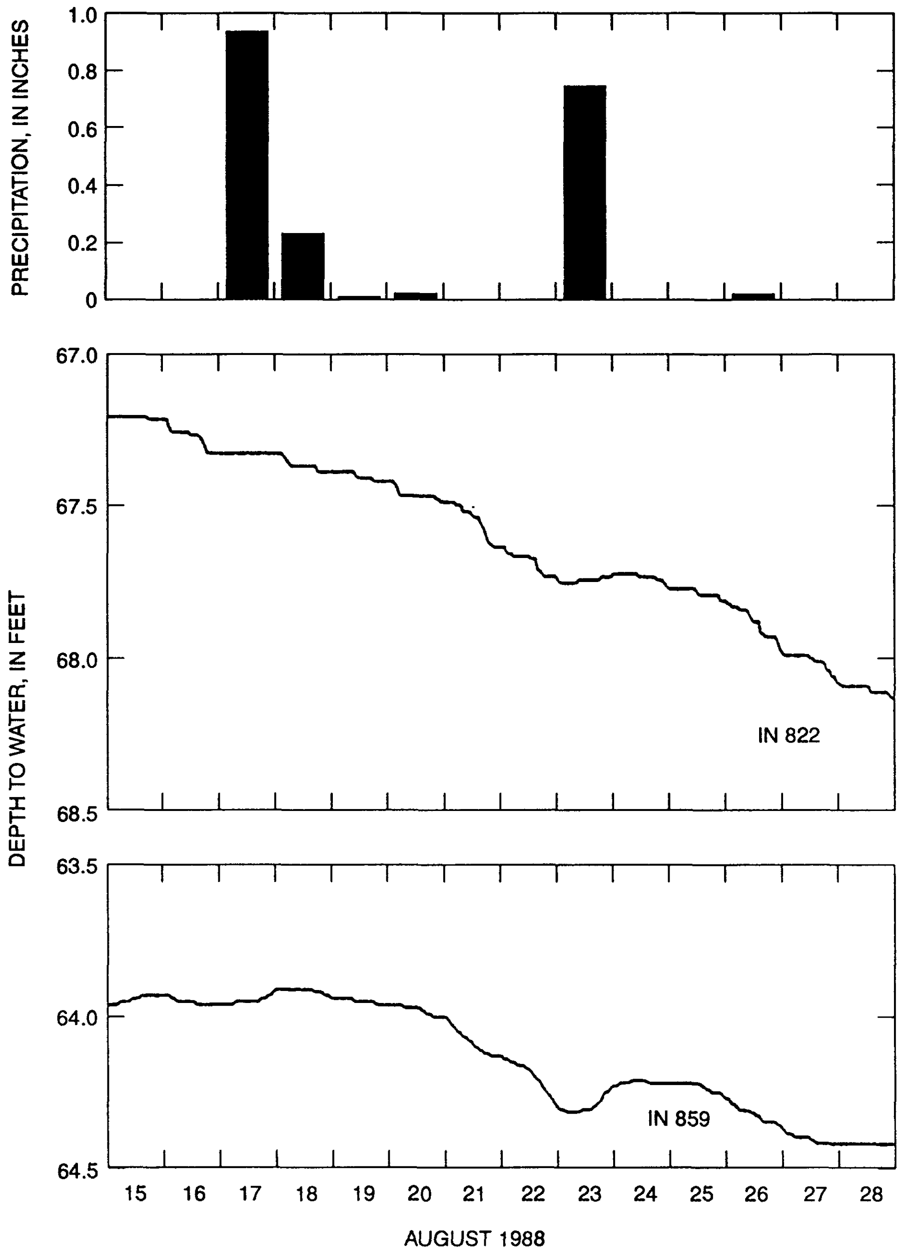


Figure 18. Short-term fluctuations in water levels of hilltop wells IN 822 and IN 859, Indiana County, Pennsylvania.

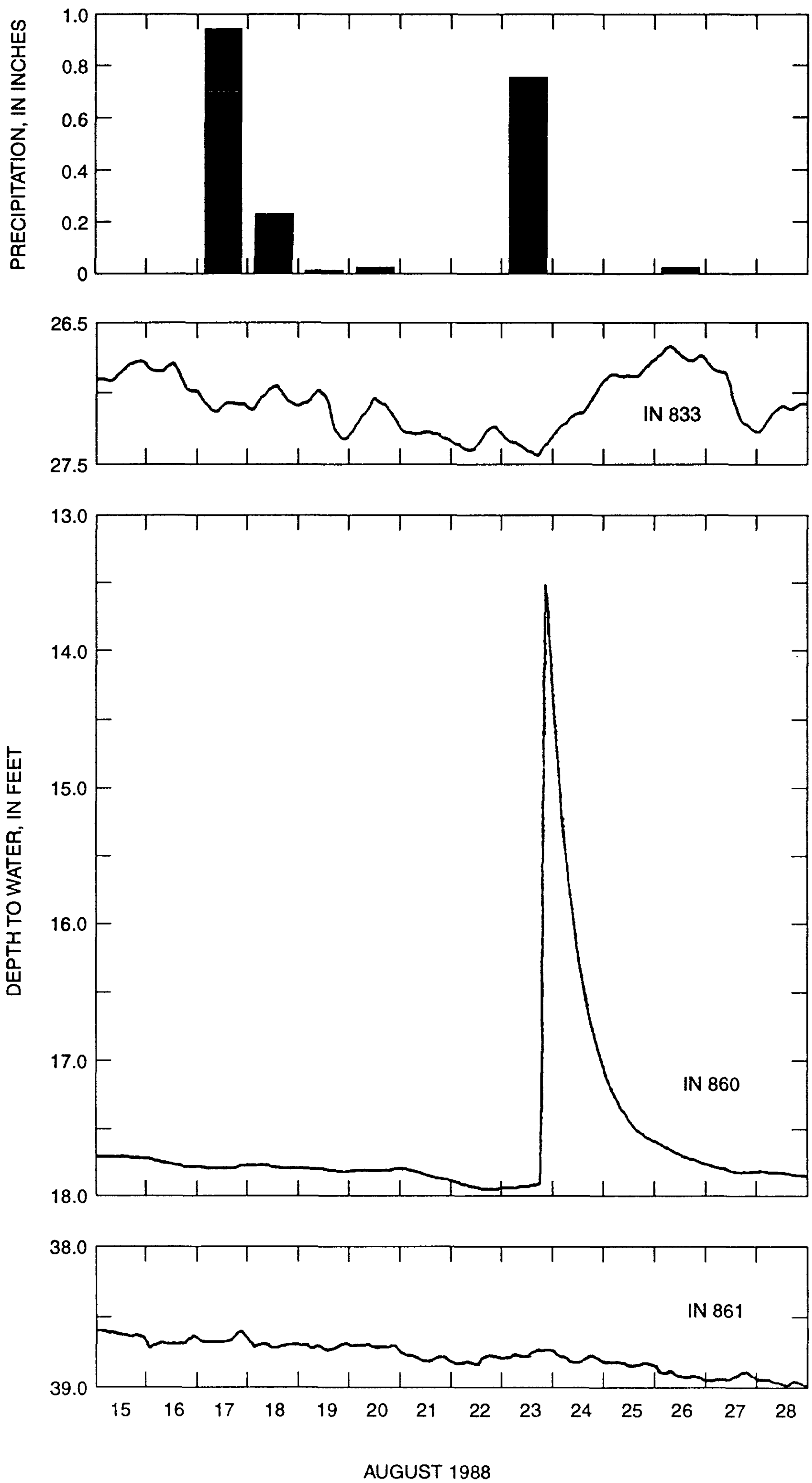


Figure 19. Short-term fluctuations in water levels of flat-topography wells IN 833, IN 860, and IN 861, Indiana County, Pennsylvania.

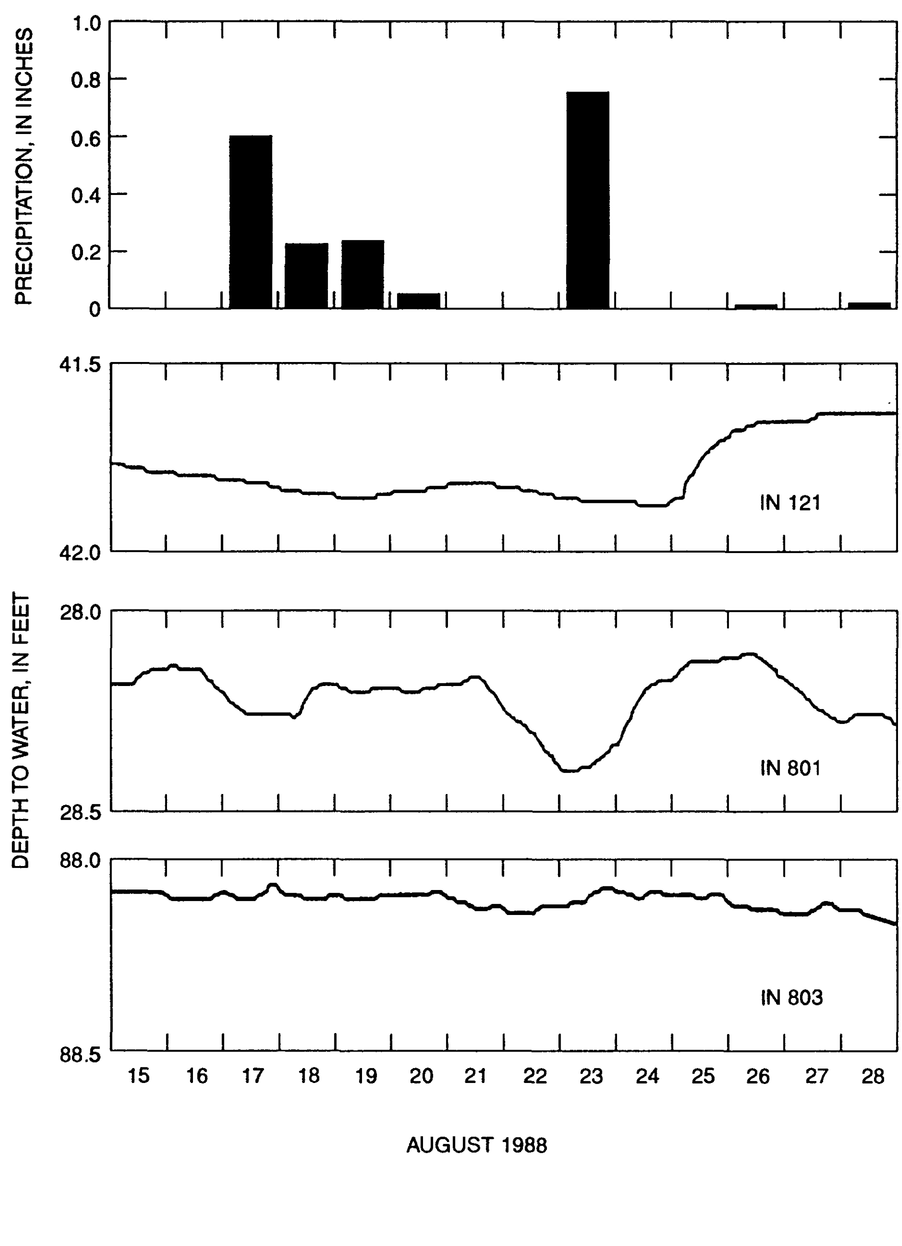


Figure 20. Short-term fluctuations in water levels of hillside wells IN 121, IN 801, and IN 803, Indiana County, Pennsylvania.

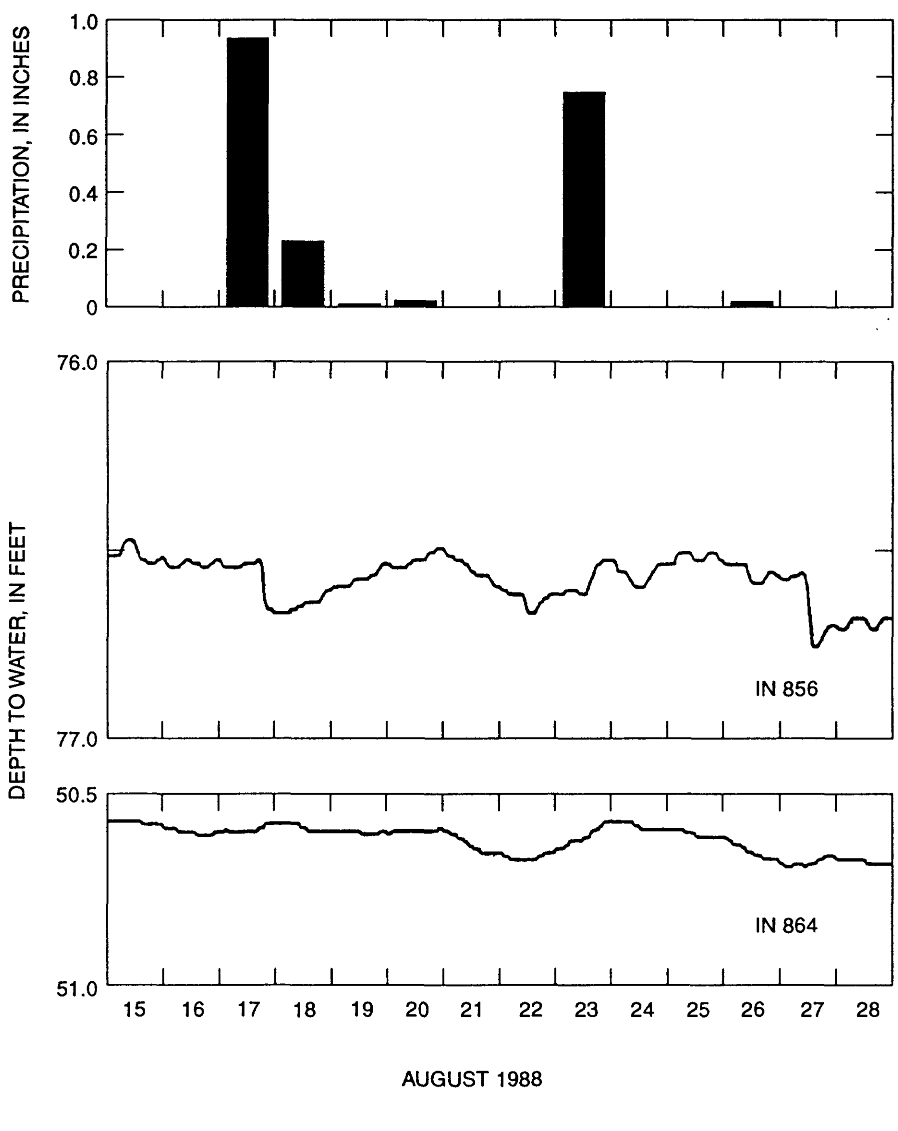


Figure 21. Short-term fluctuations in water levels of hillside wells IN 856 and IN 864, Indiana County, Pennsylvania.

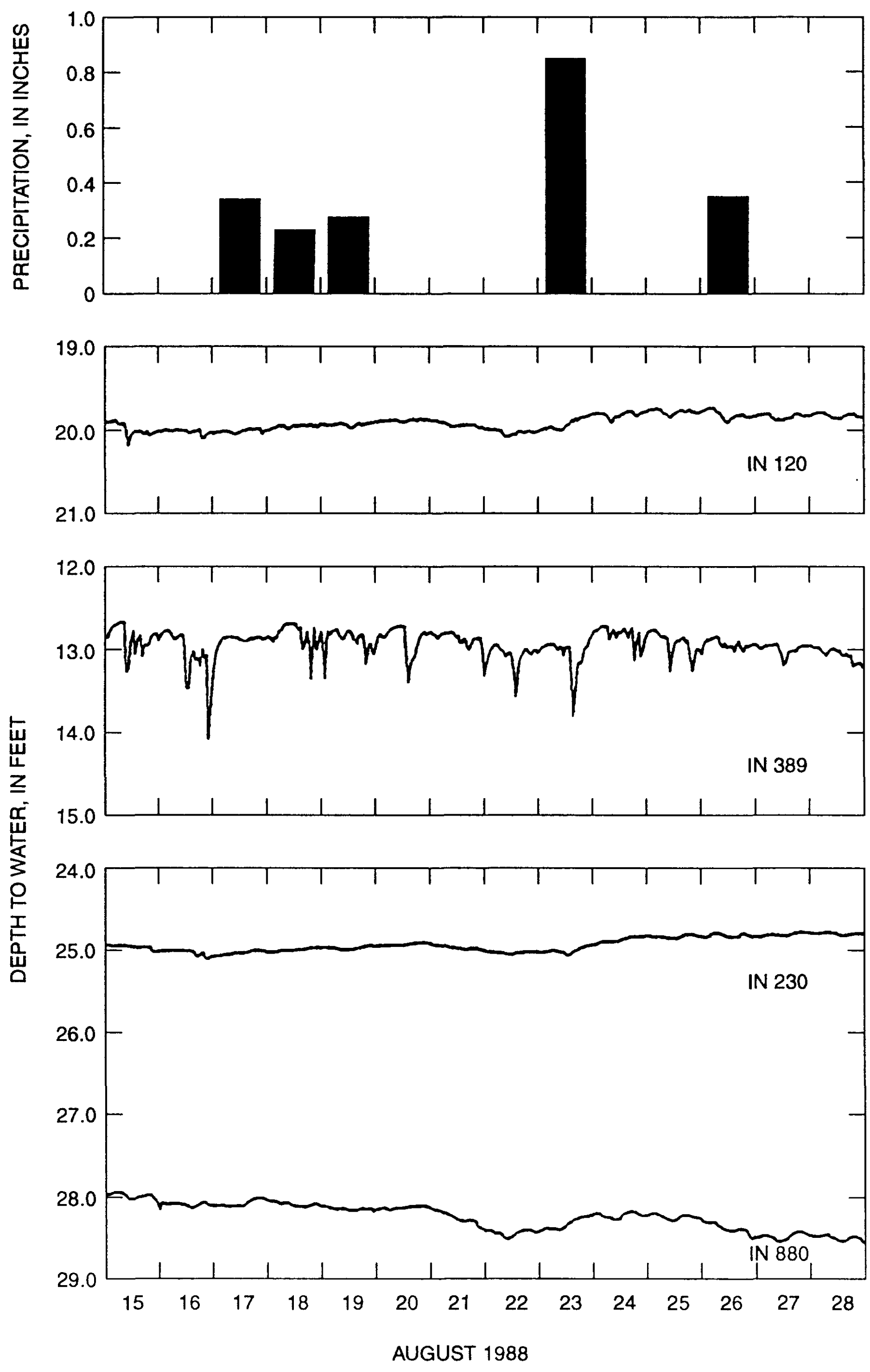


Figure 22. Short-term fluctuations in water levels of valley wells IN 120, IN 230, IN 389, and IN 880, Indiana County, Pennsylvania.

Wells IN 120, IN 230, IN 389, and IN 880 are in valleys. Many rapid declines in water level were noted at wells IN 389 and IN 120. The declines at well IN 389 were caused by the pumping of a well only 28.4 ft away. The cause of the rapid water-level declines well IN 120 is unknown. Water level at well IN 230 is similar to that at well IN 120, except that the rapid, short-term declines did not occur. Although the water levels at wells IN 880 and IN 120 declined from August 21 to 23, water level for the 2-week period in well IN 120 rose overall, while that at well IN 880 was declining. Water level at well IN 880 is 20 ft below the streambed of the adjacent Cush Cushion Creek, so it is probably not in hydraulic connection to the creek.

Seasonal Fluctuation

The daily maximum depth to water for observation wells used for this study is shown in figures 23-29. Wells are grouped topographically. Water levels are generally deepest in September, October, and November. Evaporation of surface water and transpiration of plants are commonly highest during late summer and early fall; the result is reduced recharge to ground water. Water levels are generally highest in February, March, and April, when cool temperatures reduce evaporation, plants are in a dormant state, and snowmelt provides recharge. During severe winters, water levels generally decline, because frozen ground inhibits recharge.

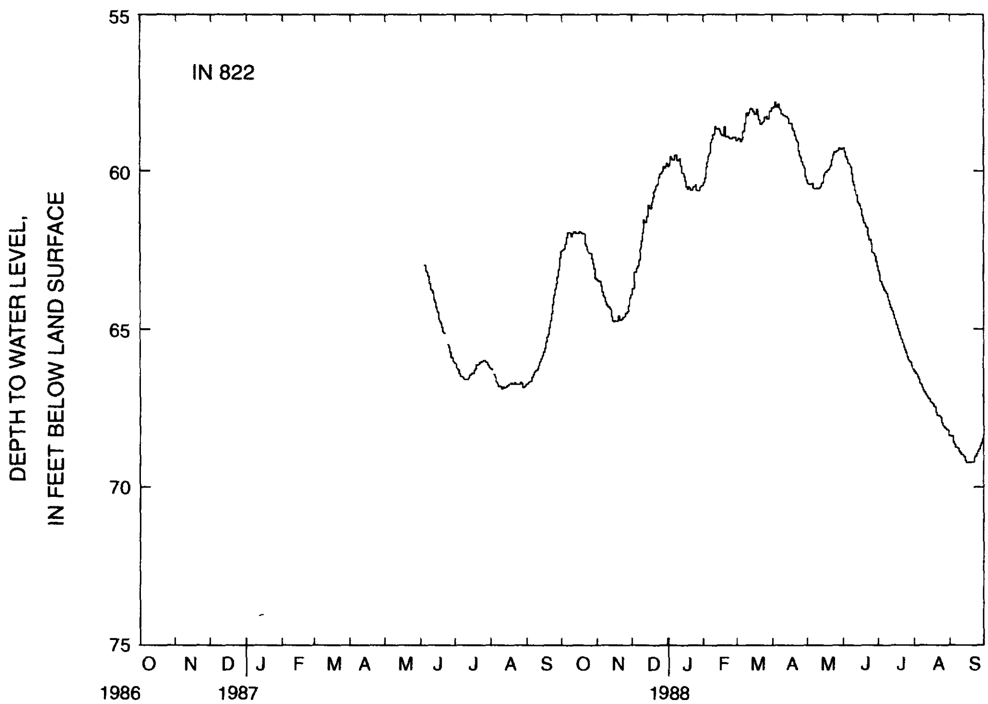
Several of the hydrographs include pronounced spikes. The spikes result from rapid entry of precipitation into water-table aquifers through fractures. The high-amplitude spikes at well IN 801 (fig. 26) are the result of a low storage coefficient, which causes a substantial rise in water level for a small amount of recharge. The well has a very small yield (less than 1 gal/min). The wells where variations in water level are small (wells IN 120 and IN 230) tap confined aquifers. The confining layers restrict recharge to the aquifer. The sharp drop and recovery of water level in well IN 864 was caused by aquifer tests.

Precipitation has a significant effect on water-level fluctuations. Monthly precipitation at four precipitation-monitoring sites throughout the county are shown in figure 32. There was a drought in Indiana County in summer 1988. In August 1988, water levels in almost all the wells were at the lowest level of the 2 years of record.

Guidelines For Developing Supplies

All Well Types

Wells drilled in most areas of Indiana County will yield adequate amounts of water for domestic uses. Nevertheless, steps can be taken to optimize the probability of obtaining a ground-water supply of sufficient quantity. Topographic position is the most important factor in determining well yield in Indiana County. Valley wells are consistently more productive than wells in other topographic settings. Most landowners, however, will not have a large enough piece of property to allow selection of a site on the basis of topography. If selection of topographic setting is not an option, than the landowner's remaining strategy is to drill a well during the time of year when the water level is lowest. In Indiana County, this corresponds to the end of the growing season. Well yield is lowest and water quality is worst at this time. Information on the geologic formation can be gathered in advance, to determine optimum well depth. The deepest reported water-bearing zone is a guide for depth of drilling for a given formation. If a well is drilled to the optimum depth but a sufficient supply is not obtained, then the most economical alternative is probably to abandon the well and try drilling at another site. Quality of ground water from the formation should be checked to determine the probability of needing water-treatment equipment. Subsurface coal mines, if they are close to the surface, can intercept ground water and drain it off, resulting in a dry hole. If the mines are flooded, water in them is likely to be highly contaminated. Pennsylvania Geological Survey Mineral Resource Report M 98, "Coal Resources of Indiana County, Pennsylvania, Part 1, Coal Crop Lines, Mined Out Areas, and Structure Contours," (Bragonier and Glover, 1996) can be used to determine whether an area has been deep mined and at what depth.



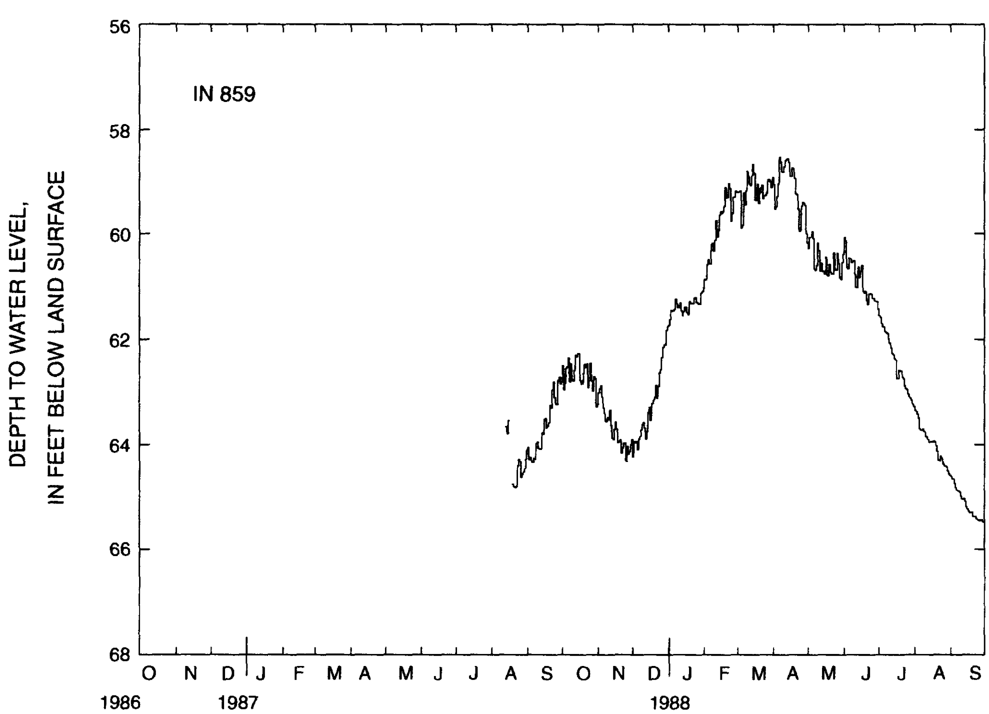


Figure 23. Maximum daily depth to water level in hilltop wells IN 822 and IN 859, Indiana County, Pennsylvania, water years 1987-88.

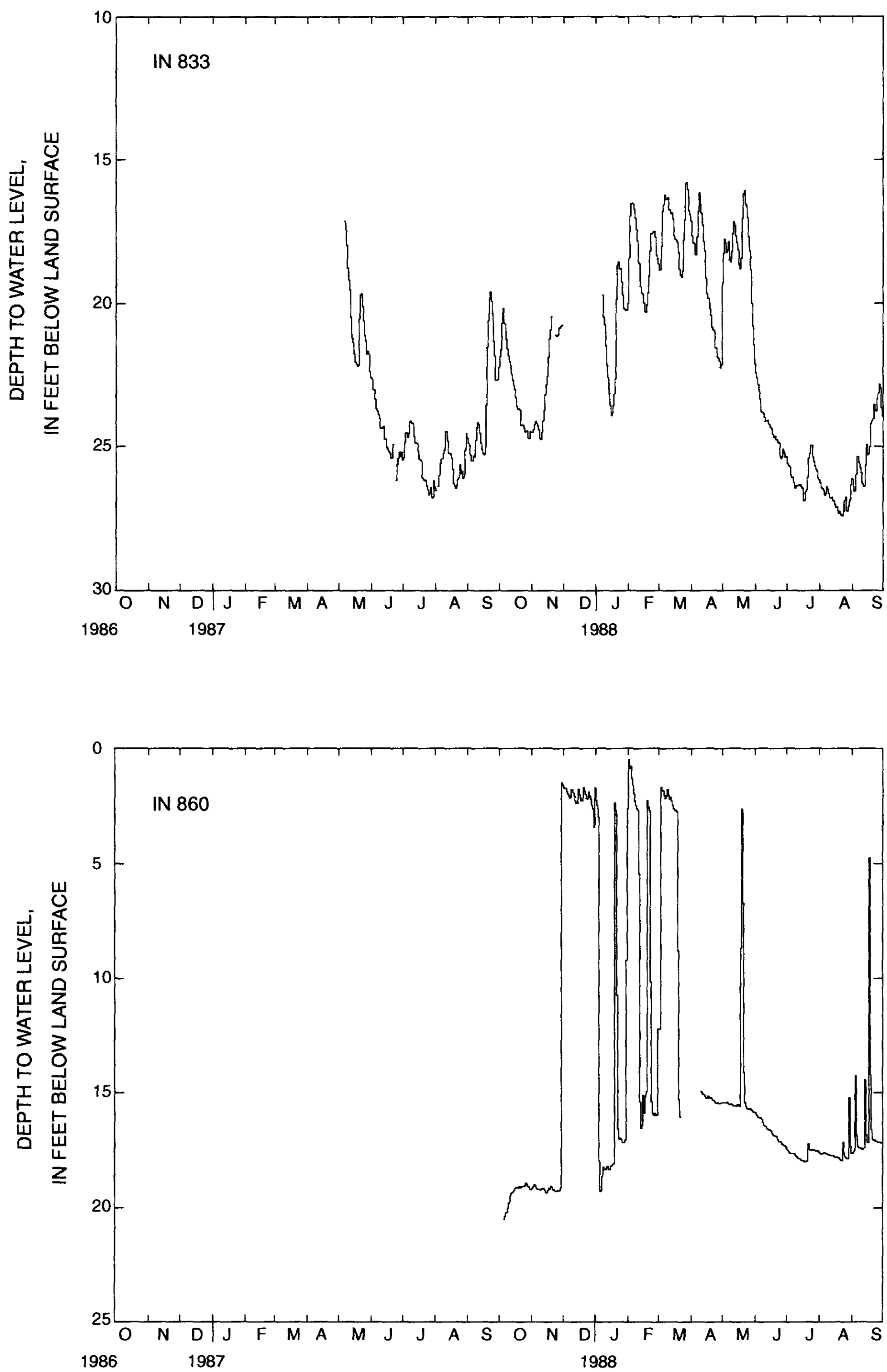


Figure 24. Maximum daily depth to water level in flat-topography wells IN 833 and IN 860, Indiana County, Pennsylvania, water years 1987-88.

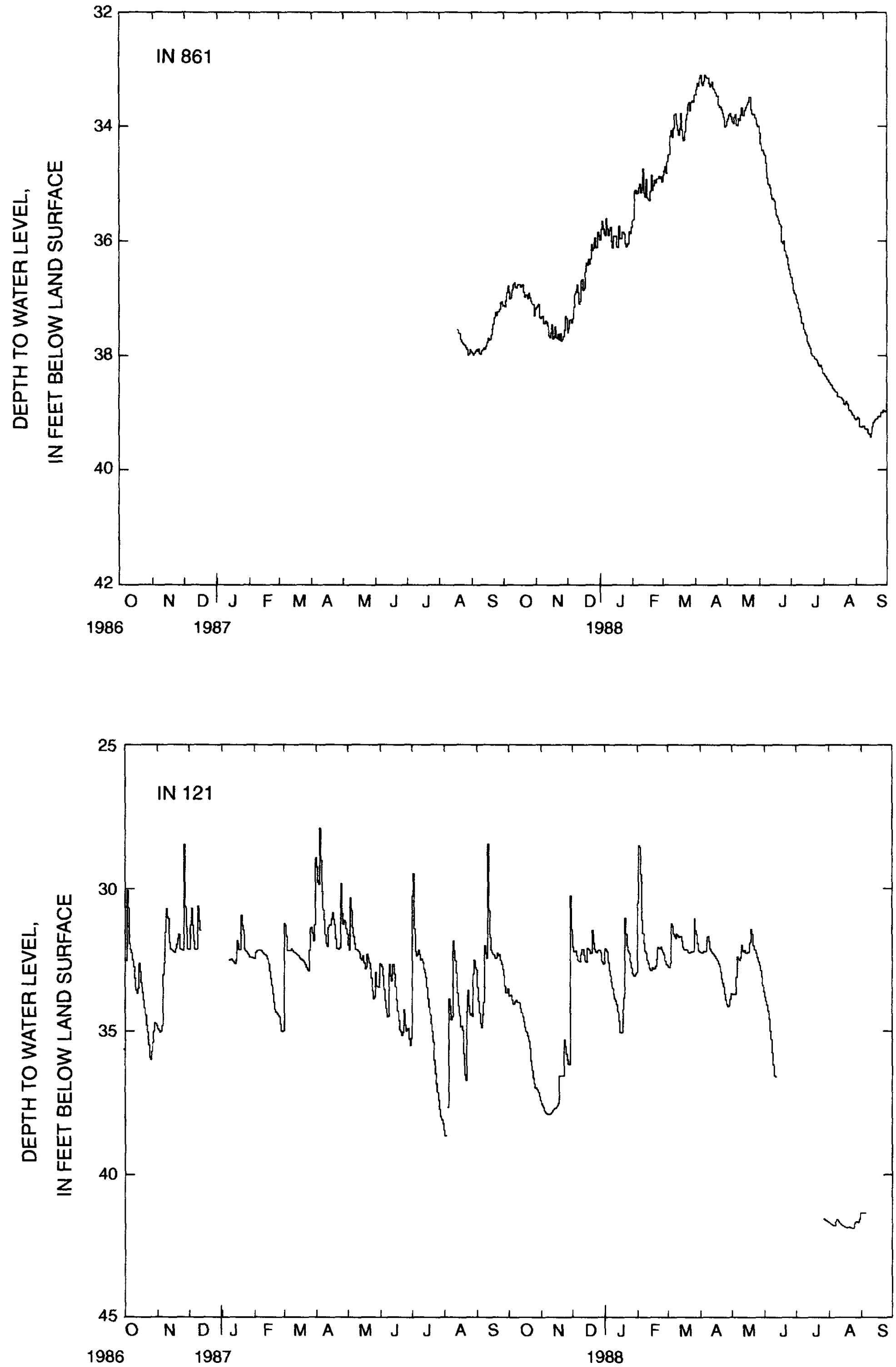


Figure 25. Maximum daily depth to water level in flat-topography well IN 861 and hillside well IN 121, Indiana County, Pennsylvania, water years 1987-88.

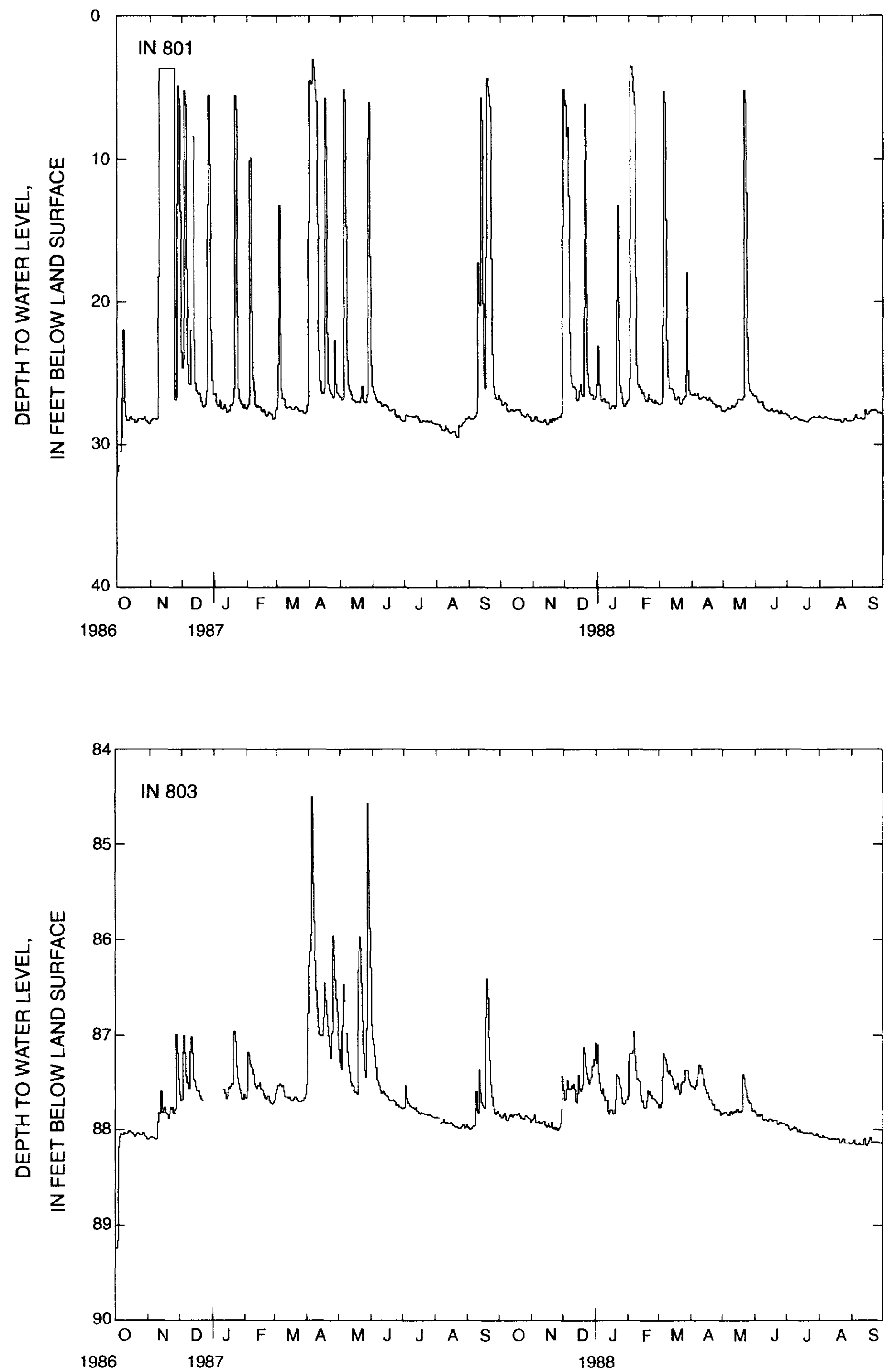
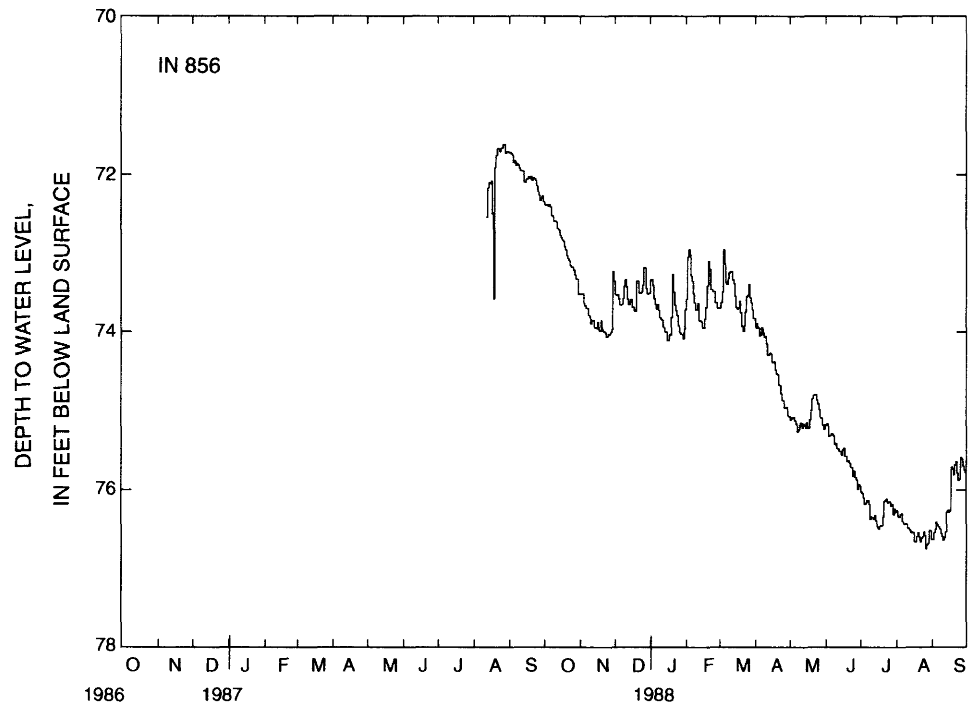


Figure 26. Maximum daily depth to water level in hillside wells IN 801 and IN 803, Indiana County, Pennsylvania, water years 1987-88.



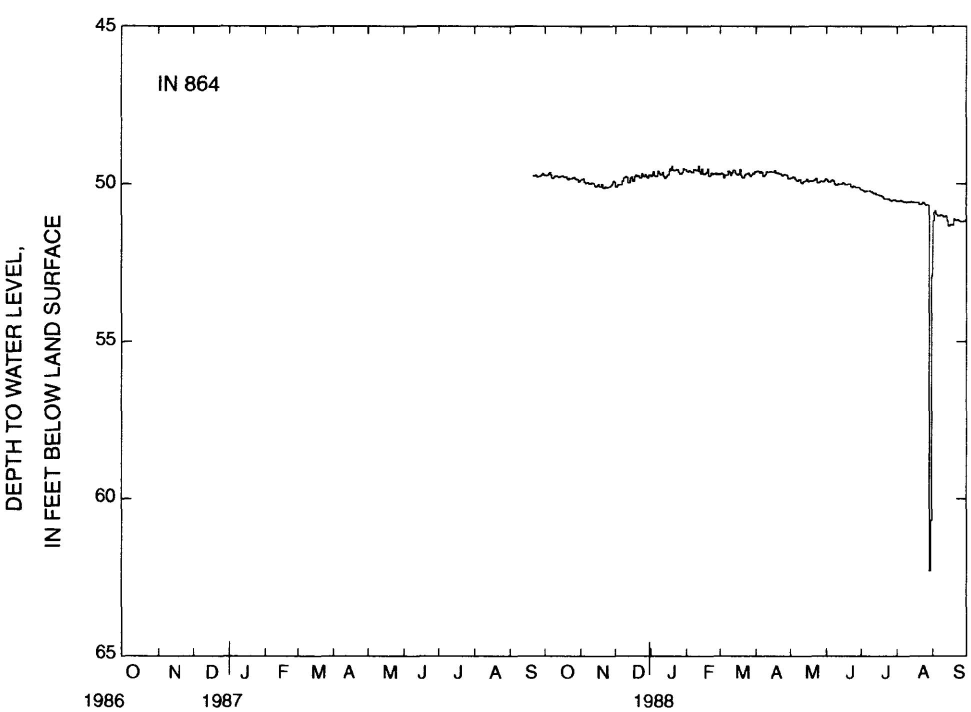


Figure 27. Maximum daily depth to water level in hillside wells IN 856 and IN 864, Indiana County, Pennsylvania, water years 1987-88.

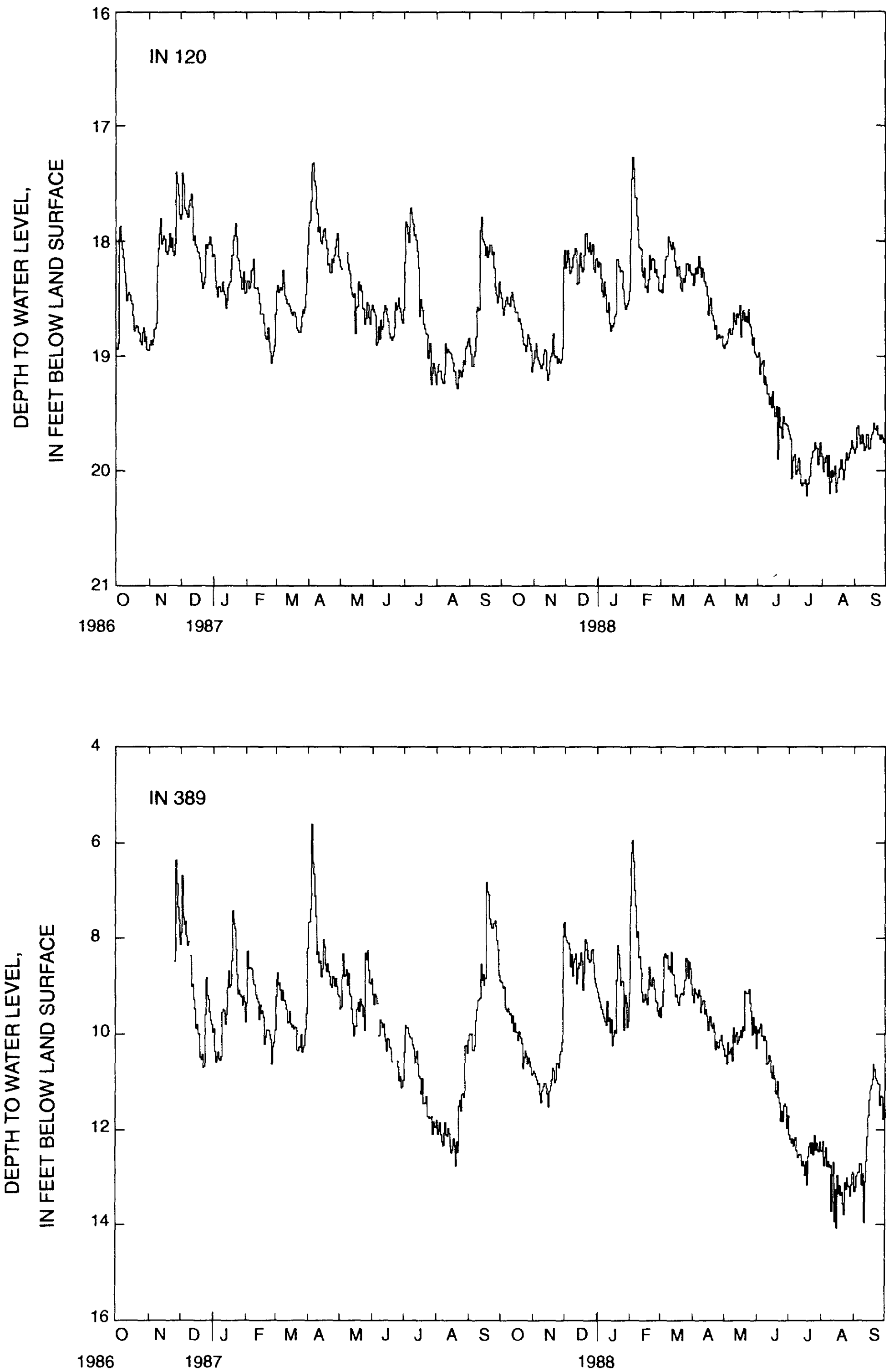


Figure 28. Maximum daily depth to water level in valley wells IN 120 and IN 389, Indiana County, Pennsylvania, water years 1987-88.

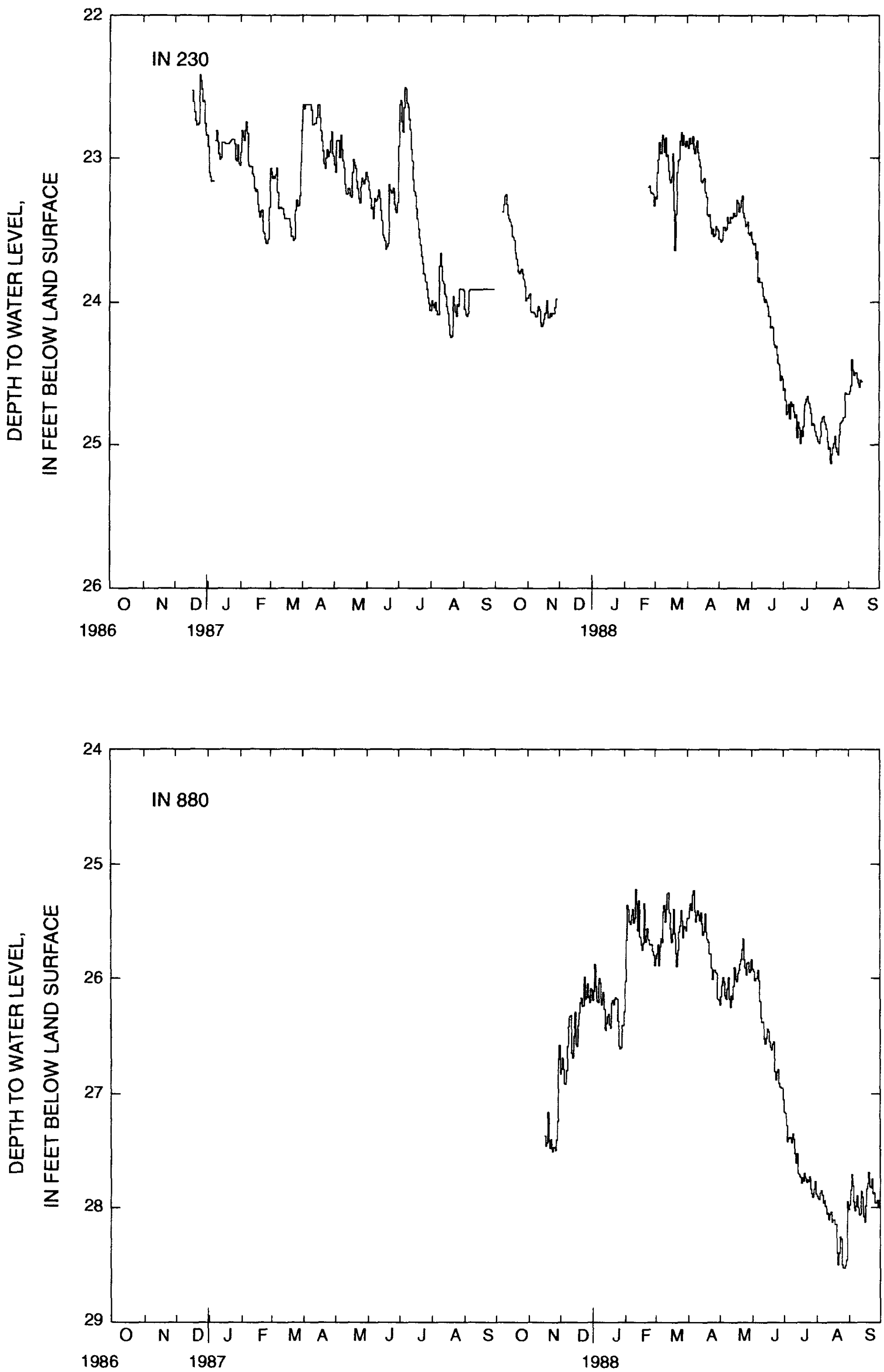


Figure 29. Maximum daily depth to water level in valley wells IN 230 and IN 880, Indiana County, Pennsylvania, water years 1987-88.

High-Yield Wells

Few wells in Indiana County can be described as high-yield wells. Of 403 reported yields, only 19 are 40 gal/min or more. Of the 19 high-yield wells, 16 are in valleys of sufficient size to have mappable alluvial deposits. Alluvial deposits are shown on plates 1 and 2.

Alluvial deposits are not the source of water for these high-yield wells; the presence of mappable alluvial deposits, however, indicates that the valley is large enough to be an area of concentrated fracturing. A concentration of fractures can weaken the rock, making it more susceptible to erosion than surrounding, less fractured rock. The accelerated erosion makes the valley larger than adjacent valleys. The greater the density of fractures, the more ground water the rock will yield. Moreover, if the valley is underlain by a sandstone, high yields are more likely than in areas underlain by plastic rocks (claystones), because sandstone is brittle and fractures are more likely to stay open. About 75 percent of the high-yield wells predominantly tap sandstone or sandstone and siltstone. Because a combination of lithologic and structural factors control fracture density, drilling into a valley containing alluvial deposits does not guarantee a high-yield well. Of 47 wells reportedly drilled in alluvial valleys in Indiana County, only 34 percent produce high yields. The only current way to determine lithology accurately is by drilling.

SURFACE-WATER RESOURCES

The surface-water characteristics of Indiana County streams were analyzed by use of data from the 31 sites established throughout the county. The quantity and distribution of streamflow are described through the analysis of low-flow frequencies, flow durations, and runoff. All sites are listed in table 1, and their locations are shown in figure 1. Long-term streamflow records were used to estimate the magnitude and distribution of future streamflow. Measurements of streamflow at partial-record sites were correlated with long-term streamflow records to estimate low-flow frequencies at the partial-record sites. The seven long-term streamflow-gaging stations in Indiana County are Little Mahoning Creek at McCormick (site 8), Little Yellow Creek near Strongstown (site 17), Yellow Creek near Homer City (site 20), Conemaugh River at Tunnelton (site 24), Two Lick Creek at Graceton (site 27), Blacklick Creek at Josephine (site 28), and Conemaugh River at Seward (site 31). Only long-term sites 8 and 17 were used for correlation purposes because the flow at the other sites was regulated. The short-term streamflow-gaging stations established specifically for this study were South Branch Plum Creek near Home (site 9) and Cherry Run near Homer City (site 26). Little Yellow Creek near Strongstown (site 17), previously in operation from 1960 through 1978, was reactivated for this study. Base-flow measurements were made at 22 additional surface-water sites throughout the county and were used for streamflow analyses.

Precipitation

Daily precipitation was measured at four sites throughout the county. Two sites were operated by the USGS and two by NOAA. The average annual precipitation for 40 years of record (1949-88) at the NOAA precipitation site in Indiana, Pa., was 44.73 in. This site is in central Indiana County and represents average precipitation conditions for the county. The cumulative departure of annual precipitation from the average shows long-term trends in climate (fig. 30). From 1949 through 1959, the cumulative departure from the average was equally distributed above and below the average precipitation for the period of record. The steady decline in cumulative precipitation from 1960 through 1969 indicates a period of drought. Deficiencies for that period (1960-69) ranged from 3.0 to 25.8 percent below the average.

July was the month of highest average monthly precipitation for the period of record. Intense thunderstorms of short duration are responsible for much of the July precipitation.

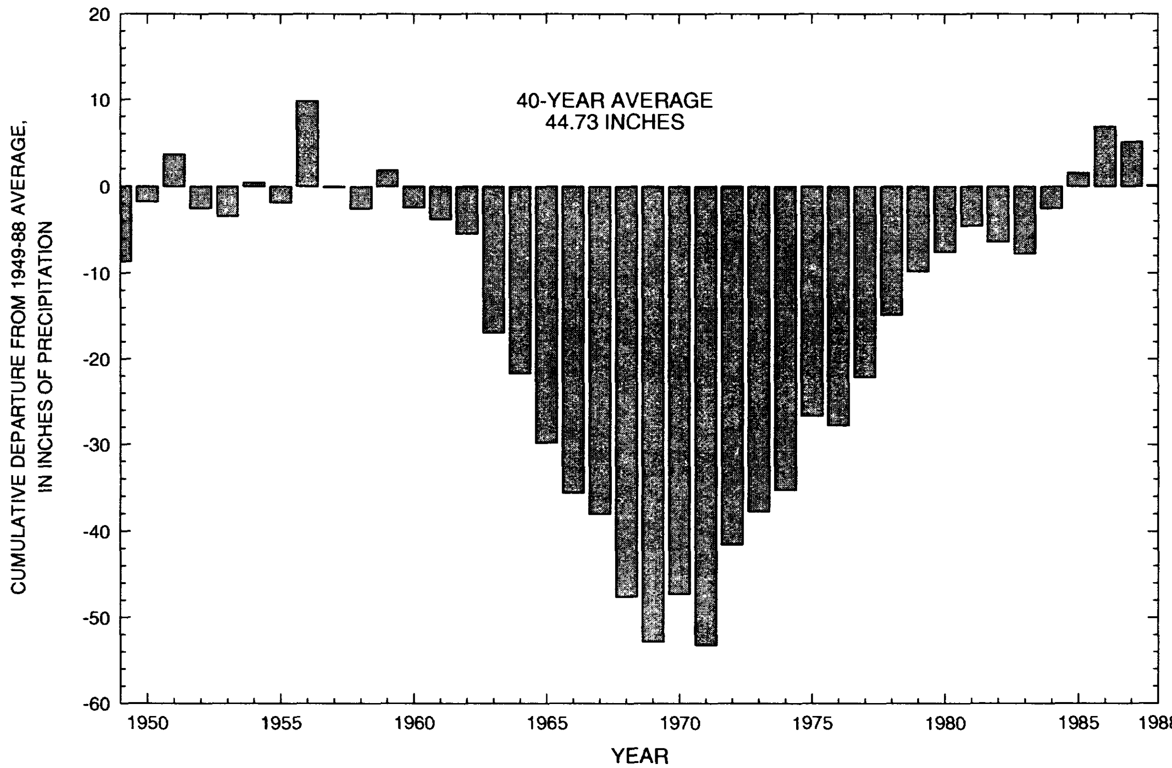


Figure 30. Cumulative departure of annual precipitation from the average annual precipitation at Indiana, Pennsylvania, 1949-88.

Total monthly precipitation recorded at all four sites is shown in figure 31. Precipitation patterns at all sites were generally similar for the 2-year period, but the magnitude of precipitation for a given month differed among the sites.

Annual precipitation recorded at each site for water years 1987-88 is listed in table 11. Precipitation was substantially lower in 1988 than in 1987. The decreases from 1987 to 1988 at Blairsville, Indiana, Cherry Run, and South Branch Plum Creek were 24, 28, 27, and 48 percent, respectively. The 1988 precipitation at the Indiana site (35.65 in.) was 20.3 percent below the 40-year average of 44.73 in.

Streamflow

Low-Flow Frequencies

The suitability of streams for water supply generally is determined by the magnitude of low flows. An understanding of low-flow characteristics of streams is essential in determining the adequacy of streamflow for particular uses and for use during periods of little or no rainfall. Low-flow-frequency data can be used to (1) design industrial and domestic water-supply systems, (2) classify streams as to their potential for waste dilution, and (3) establish criteria to maintain channel flows as required by agreement or by law. The low-flow characteristic of a stream is also an indicator of the amount of ground-water discharge to the stream because almost all streamflow during low flow is ground-water discharge. Low flows in areas of similar geology, climate, and basin size usually are about the same order of magnitude.

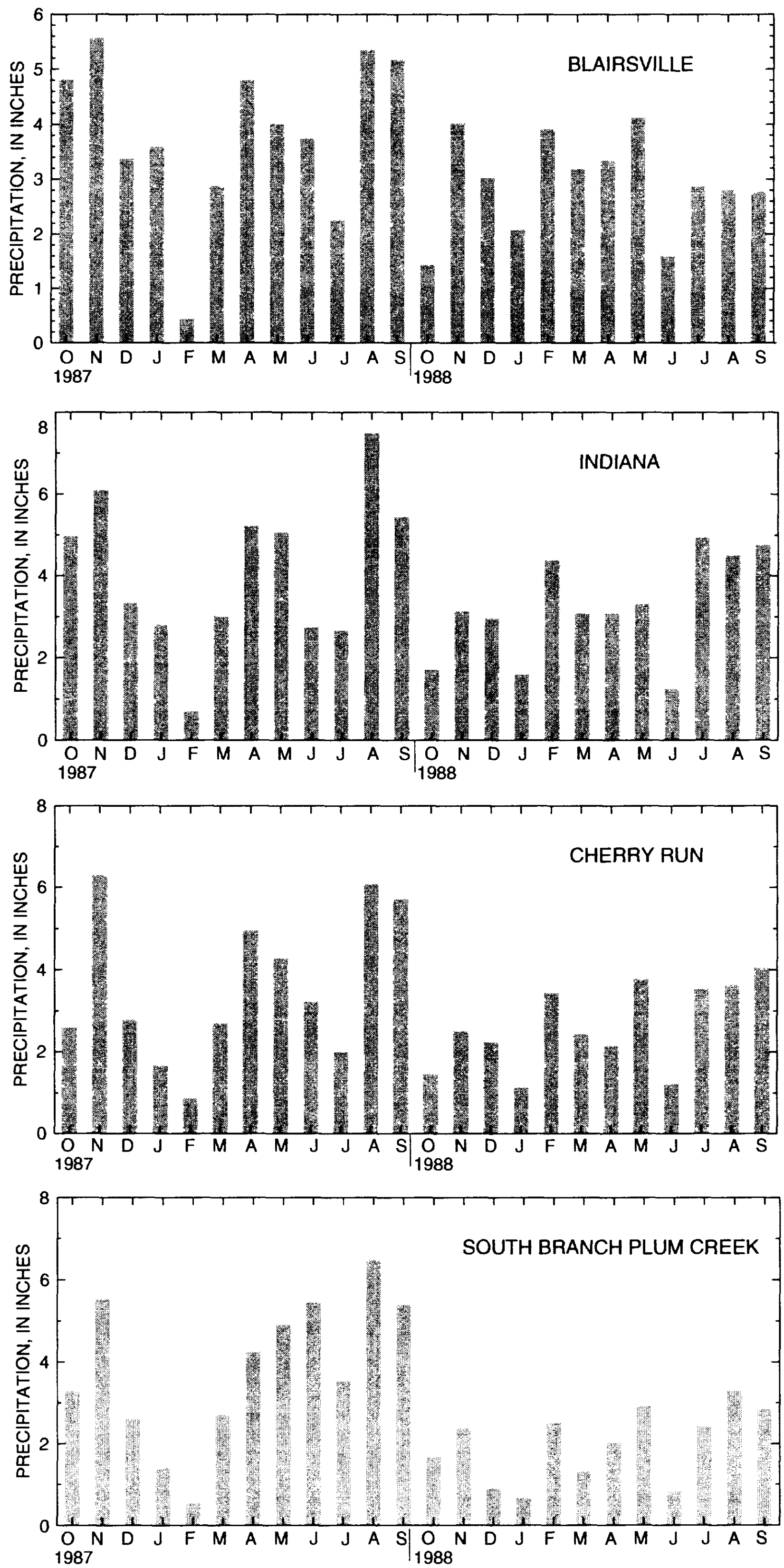


Figure 31. Monthly precipitation at four sites in Indiana County, Pennsylvania. (Locations shown in fig. 1.)

Table 11. Annual precipitation at four Indiana County sites, water years 1987-88

Site	Precipitation, in inches	
	1987	1988
Blairsville	46.05	35.22
Indiana	49.54	35.65
Cherry Run	43.19	31.60
South Branch Plum Creek	46.04	23.77

A low-flow frequency curve is a graph relating the magnitude and frequency of annual minimum flows for a given number of consecutive days. Figure 32 shows the family of low-flow frequency curves for 7, 10, 30, and 60 consecutive days for Little Mahoning Creek at McCormick (site 8) for water years 1939-88. Figure 33 shows the same family of low-flow frequency curves for Little Yellow Creek near Strongstown (site 17) for water years 1961-78 and 1987-88. The 7-day, 10-year low flow is the low-flow index most commonly used as a critical-flow factor and as a minimum dilution flow in the design of wastewater-treatment plants. The index represents the lowest mean flow for 7 consecutive days that on the average takes place once every 10 years, or that has a 10-percent probability of taking place in any 1 year. The reliability of a low-flow frequency curve based on natural, unregulated flows is related closely to the length of streamflow record; the longer the period of record, the more reliable the curve. Figure 32 shows that the 7-day, 10-year low flow for Little Mahoning Creek at McCormick is 1.6 ft^3/s, and figure 33 shows that the 7-day, 10-year low flow for Little Yellow Creek near Strongstown is 0.26 ft^3/s.

Regression analyses of daily mean base flows at long-term streamflow-gaging stations with concurrent base flows at short-term streamflow-gaging stations can be used to estimate low-flow characteristics at short-term stations. This procedure, however, could not be used on the two short-term stations, South Branch Plum Creek near Home (site 9) and Cherry Run near Homer City (site 26). Because of the extremely dry summer of 1988, no flow was recorded on 50 days at site 9, and 32 of those days were consecutive (June 19-July 20). Therefore, the 7-day, 10-year low flow for this site would have been zero. The flow at site 26 is continuously augmented by deep-mine discharge just upstream from the streamflow-gaging station. Upstream from site 26 and above the mine discharge, zero flow was observed in the main stem; therefore, the 7-day, 10-year low flow would have been zero.

One or more base-flow measurements made each year at partial-record sites can provide nearly as much low-flow information for comparison as a complete flow record of a few years (Riggs, 1972, p. 10). Base-flow measurements made at 22 partial-record sites throughout Indiana County were compared with concurrent streamflows at the two long-term unregulated sites (sites 8 and 17), and 7-day, 10-year low-flows were computed for the partial-record sites. As an example, figure 34 shows the relation of five streamflow measurements at Yellow Creek near Pikes Peak (site 19), a partial-record site, to the five concurrent streamflows recorded at Little Yellow Creek near Strongstown (site 17), a long-term streamflow-gaging station. Regression analyses that use the power curve fit ($y = ax^b$) yielded a 7-day, 10-year low flow of 0.66 ft^3/s for Yellow Creek at Pikes Peak (site 19), the partial-record site.

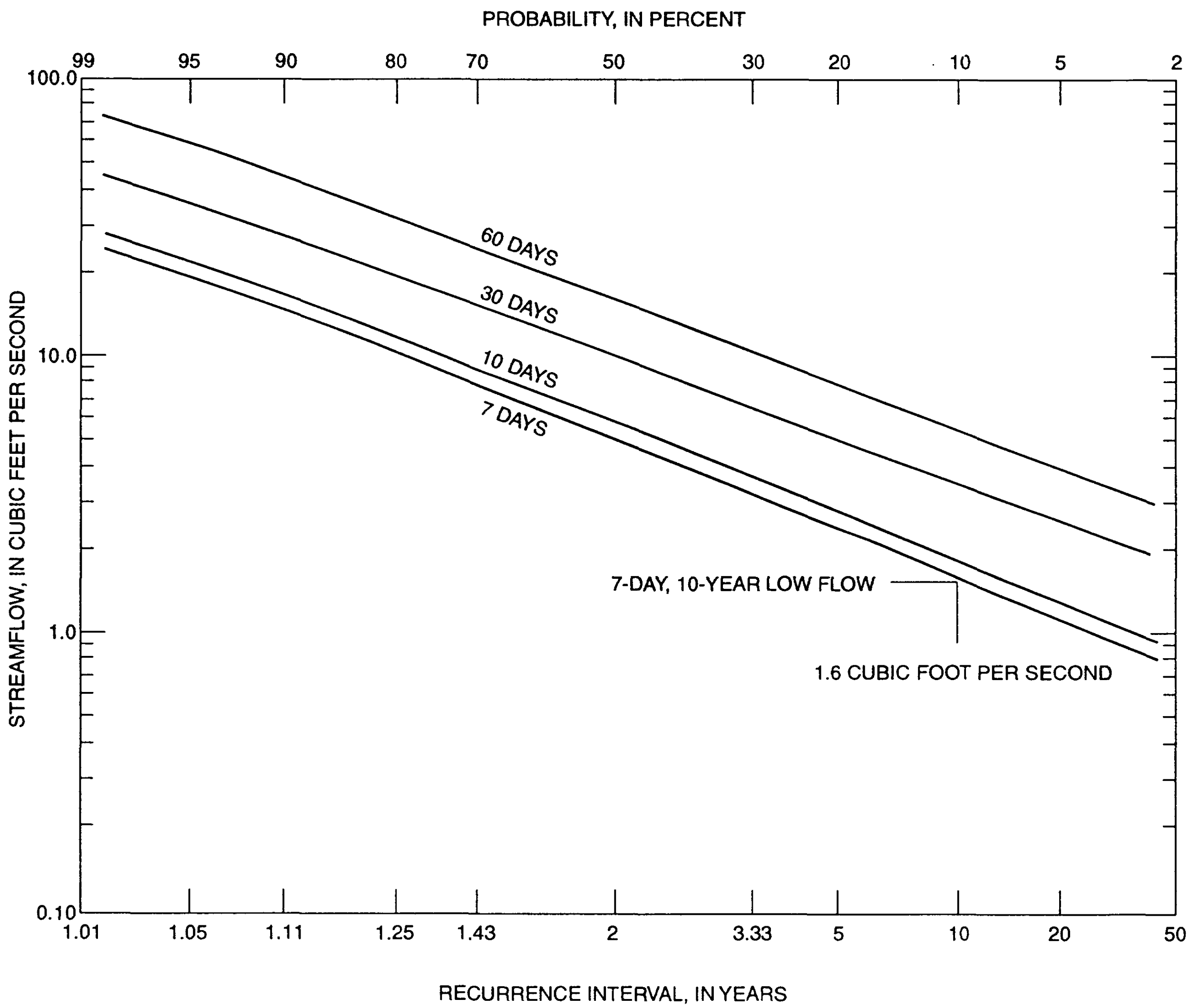


Figure 32. Low-flow frequency curves for 7, 10, 30, and 60 consecutive days for Little Mahoning Creek at McCormick (site 8), water years 1939-88.

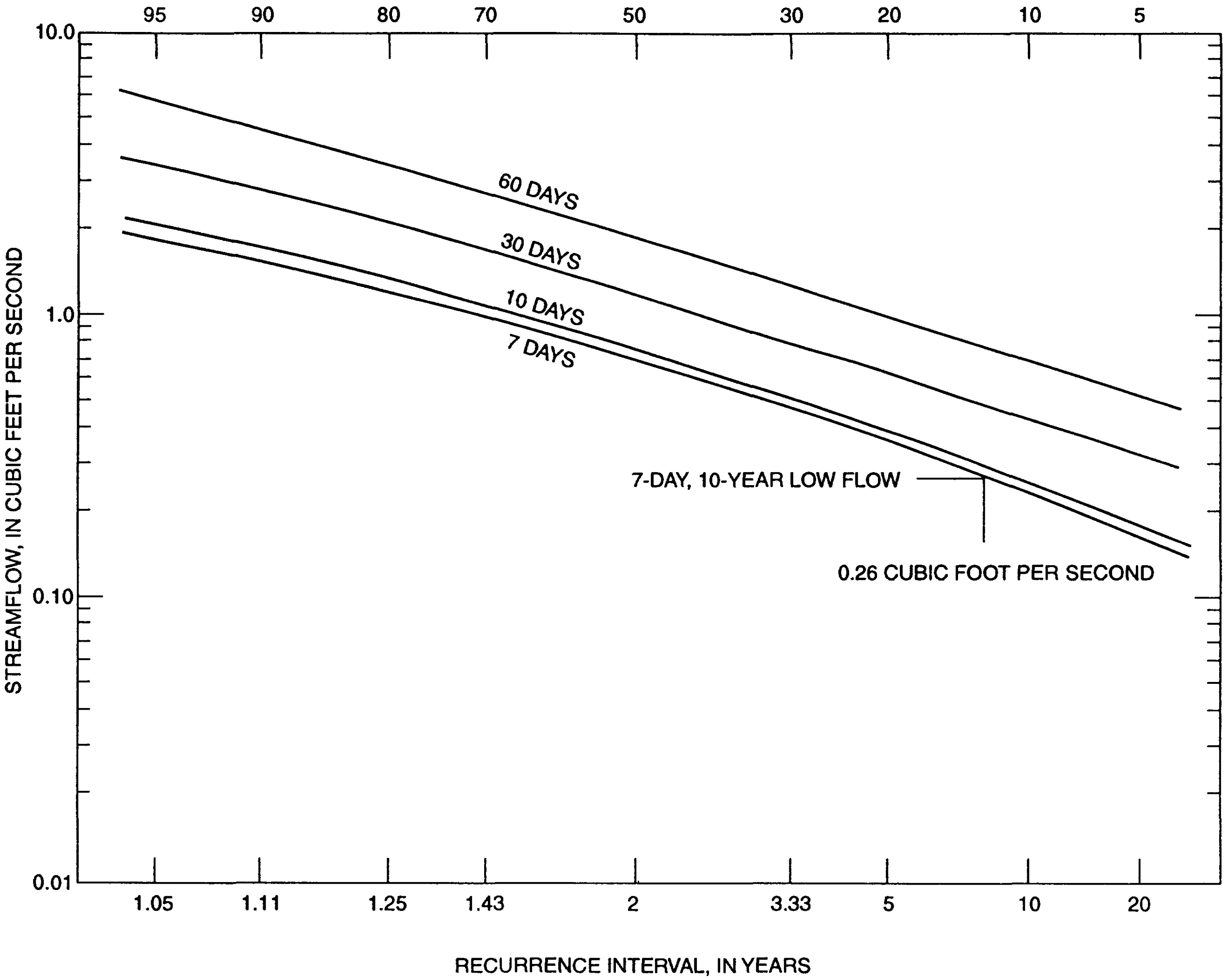


Figure 33. Low-flow frequency curves for 7, 10, 30, and 60 consecutive days for Little Yellow Creek near Strongstown (site 17), water years 1961-78 and 1987-88.

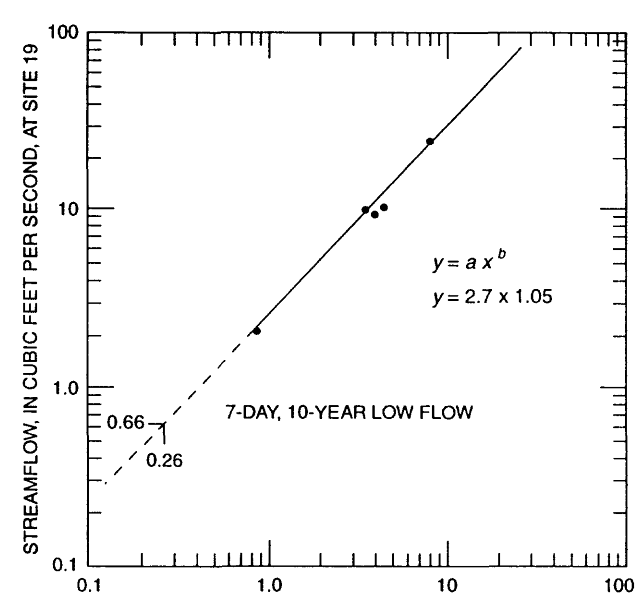


Figure 34. Relation of five concurrent base-flow discharges in Yellow Creek (site 19) and Little Yellow Creek (site 17), water years 1987-88.

The last base-flow-measurement field trip was made in August 1988 during an extended dry period, and no flow was observed at 5 of the 31 sites. The 7-day, 10-year low flows at those sites were assumed to be zero. The 7-day, 10-year low flows for all sites are shown in table 12. The low flows for the regulated sites are not indicative of natural conditions and, therefore, are not reliable low-flow indexes.

Table 12. Computed 7-day, 10-year low flows for long-term, short-term, and partial-record sites, Indiana County, Pennsylvania

[For site names, see table 1; ft^3/s, cubic foot per second; mi^2, square mile; $(ft^3/s)/mi^2$, cubic foot per second per square mile; +, long-term station; *, short-term station; (R), regulated station; stations without + or * are partial-record stations]

Site number	7-day, 10-year low flow (ft^3/s)	Drainage area (mi^2)	7-day, 10-year low flow per square mile [$(ft^3/s)/mi^2 \times 10^{-3}$]
1	0.0075	1.46	5.1
2	.98	15.8	62.0
3	.0052	2.13	2.4
4	.016	.42	38.1
5	0	12.2	0
6	.38	19.7	19.3
7	.0065	5.88	1.1
+8	1.6	87.4	18.3
*9	0	9.38	0
10	.83	53.4	15.5
11	.0050	12.0	.4
12	.021	.11	191
13	0	.39	0
14	.037	19.7	1.9
15	.22	10.7	20.6
16	1.77	51.4	34.4
+17	.26	7.36	35.3
18	.0053	5.21	1.0
19	.66	21.8	30.3
+20 (R)	4.6	57.4	80.1
21	.026	4.48	5.8
22	0	11.2	0
23	.64	21.6	29.6
+24 (R)	--	1,360	--
25	.032	19.9	1.6
*26	0	10.5	0
+27 (R)	13	171	76.0
+28 (R)	28	192	146
29	.00006	5.21	.01
30	.12	21.8	5.5
+31 (R)	179	715	250

Flow Duration

The flow distribution and variability of streams can best be shown by a flow-duration curve. The flow-duration curve is a cumulative-frequency curve that shows the percentage of time during which specified discharges were equaled or exceeded in a given period of record (Searcy, 1959). The curve shows the integrated effect of the various factors that affect runoff, such as precipitation, topography, geology, mining, urbanization, and agriculture. The curve is a means of comparing one basin response with another basin response.

The shape of the flow-duration curve is a result of the hydrologic and geologic characteristics of the drainage basin. A curve with a steep slope denotes a highly variable streamflow that is mainly derived from surface runoff. A curve with a gradual slope indicates streamflow that is mainly from surface-water or ground-water storage, such as lakes, reservoirs, or permeable rocks. The low-flow end of the duration curve characterizes the low flows of the stream. A gradual slope at the low end of the curve indicates sustained base flow, and a steep slope indicates negligible base flow. Figure 35 shows duration curves for sites 8, 17, 27, and 28 for water years 1961-78 and 1987-88, the period of record common to all four sites. All the curves have gradual slopes at the low end that indicate sustained base flow. Sites 27 and 28 are on

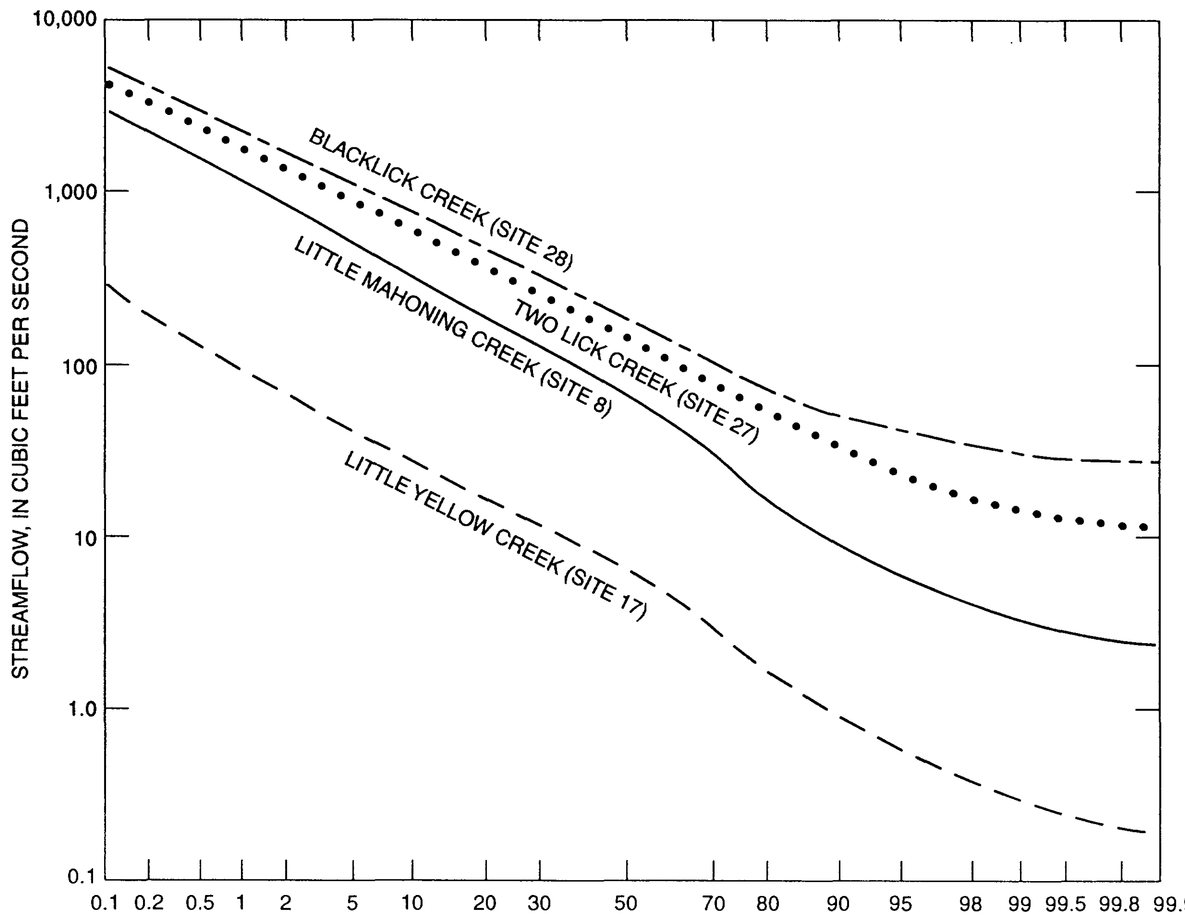


Figure 35. Flow-duration curves for Blacklick Creek (site 28), Two Lick Creek (site 27), Little Mahoning Creek (site 8), and Little Yellow Creek (site 17) Indiana County, Pennsylvania, for 1961-78 and 1987-88.

regulated streams, and the sustained base flows are possibly the result of low-flow augmentation upstream from each of the sites. The sustained base flows at sites 8 and 17 are the result of natural basin conditions. The sustained base flows per square mile for sites 8 and 17 are similar.

The duration curves for sites 9 and 26, the two short-term streamflow-gaging stations for water years 1987-88, are shown in figure 36. The steep slope at the low end of the curve for site 9 indicates negligible base flow, indicative of the drought conditions in summer 1988. The duration curve for site 26 indicates a sustained base flow with a gradual slope on the low end; however, the sustained flow was the result of a constant deep mine discharge just above the measurement site. Without the mine discharge, the curve probably would have been similar to that for site 9.

Three flow-duration curves for Blacklick Creek (site 28) for three different time periods, water years 1953-70, 1971-88, and 1953-88, are shown in figure 37. The curves indicate that the flow near the average flow range for the first 18 years of record (1953-70) was less than for the last 18 years of record (1971-88) but that low flow at the 99.9th percentile was the same for both periods. Precipitation data collected at the Indiana NOAA site shows the average yearly precipitation for 1953-70 was 42.24 in. and for 1971-88 was 47.36 in. The difference in the amounts of precipitation was probably a main factor affecting flow duration. The amount of mining and mine discharges in the Blacklick Creek Basin also could have been a factor.

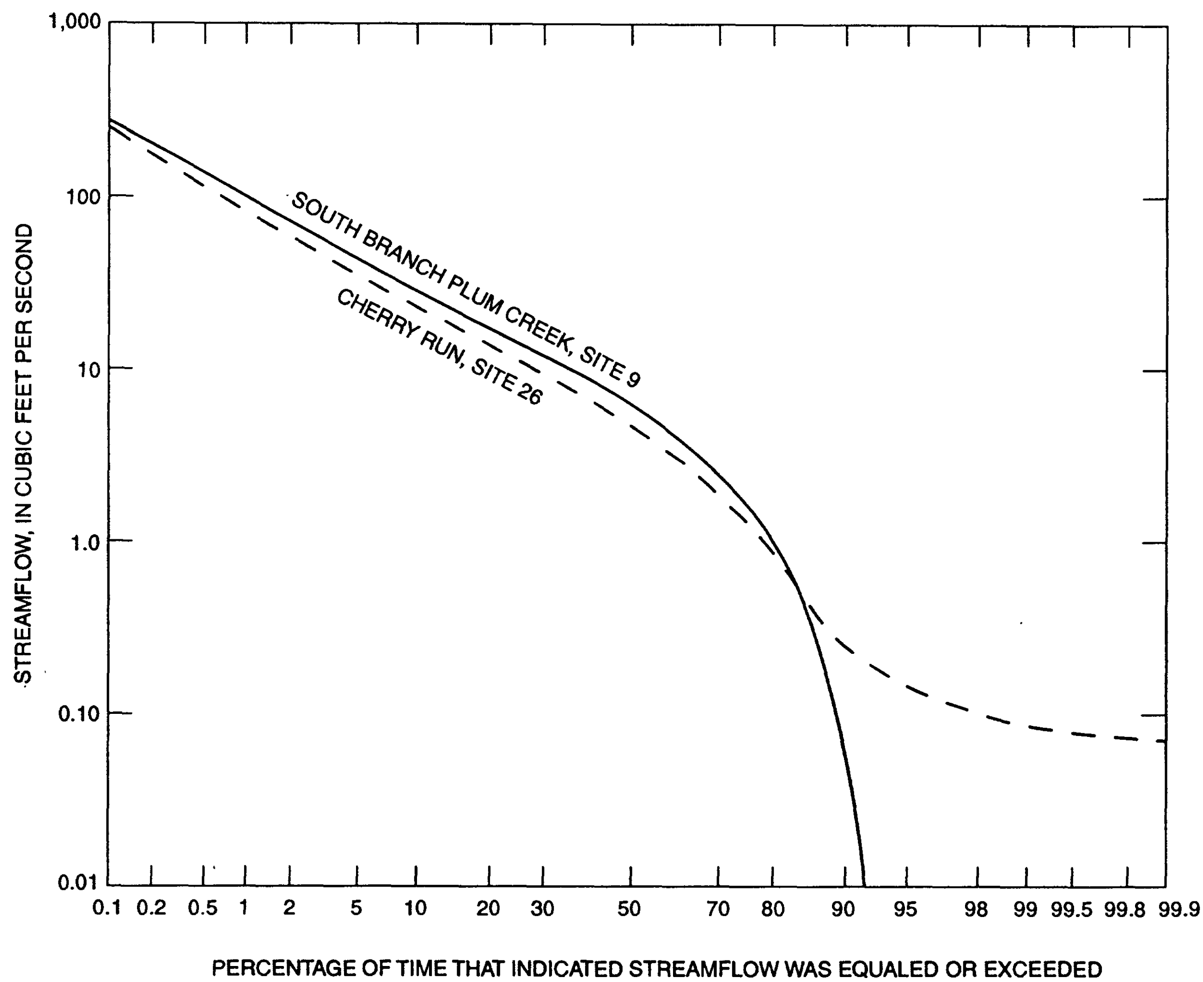


Figure 36. Flow-duration curves for South Branch Plum Creek (site 9) and Cherry Run (site 26), Indiana County, Pennsylvania, water years 1987-88.

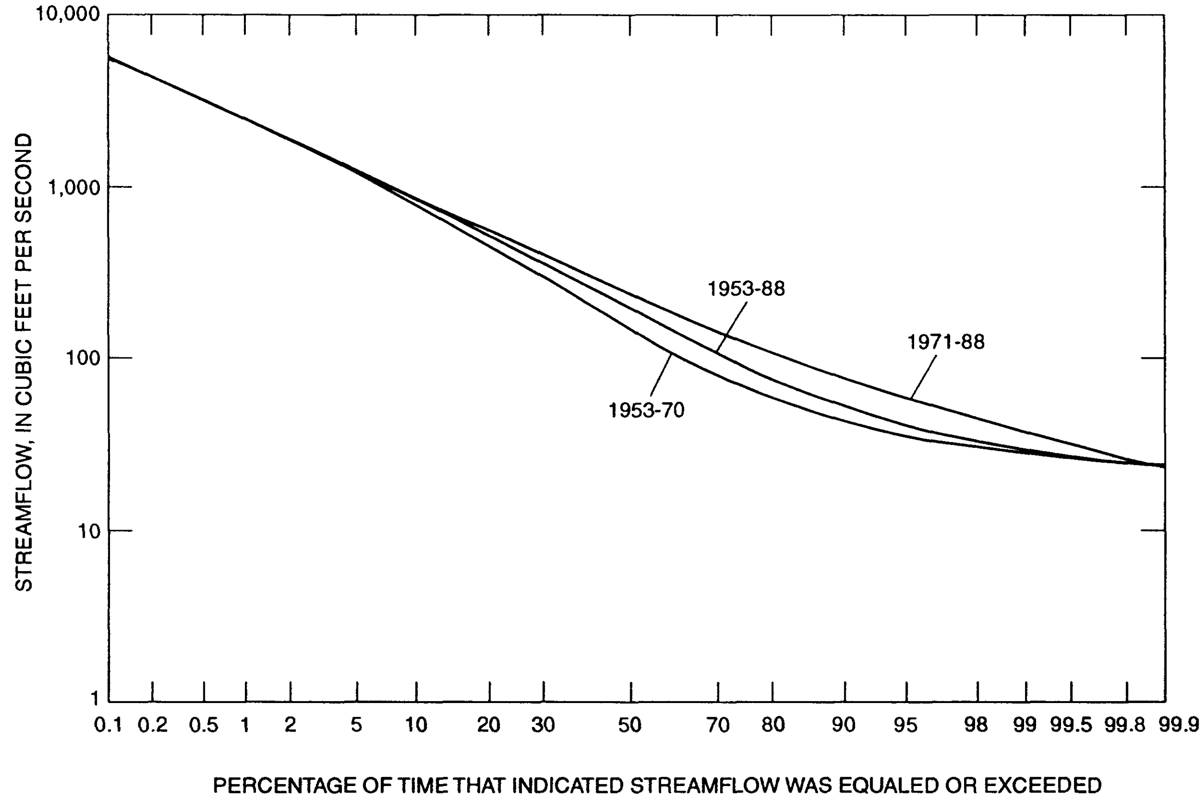


Figure 37. Flow-duration curves for Blacklick Creek (site 28), Indiana County, Pennsylvania, water years 1953-70, 1971-88, and 1953-88.

Storm Runoff

Total stream runoff consists of ground-water discharge from shallow aquifers plus surface runoff. Runoff has a distinct seasonal variability. Runoff is normally at its maximum in late winter and early spring because of ground-water discharge, icemelt, snowmelt, and high precipitation. It generally decreases with the onset of warmer weather because of increased rates of evaporation, transpiration, and soil absorption. Runoff is normally at its minimum in late summer and early fall. Runoff and precipitation measured at four Indiana County streamflow-gaging stations for water years 1987-88 are summarized in table 13. Mean runoff, in inches (table 13), refers to the equivalent amount of water throughout the upstream drainage basin that would produce the corresponding mean runoff in cubic feet per second. The value in cubic feet per second was the measured streamflow. The measured precipitation, in inches, is the actual amount of precipitation measured at a nearby rain gage. The measured precipitation at the three rain gages was from 1.5 to 2.1 times greater than the mean runoff in inches. The annual water loss (difference between measured precipitation and runoff) ranged from 35 to 53 percent. Water loss is affected by evaporation, transpiration, diversion, mines, ground-water outflow, and water consumption by animals. Annual water losses at the four streamflow-gaging stations, represented as a percentage of precipitation, are listed in table 14. Where surface water is being considered as a potential water-supply source, water losses can be used to determine the most productive areas of runoff, or those areas where the percentage of annual water loss is lowest.

Table 13. Measured runoff and precipitation at four streamflow-gaging stations, Indiana County, Pennsylvania, water years 1987-88

[mi², square mile; ft³/s, cubic foot per second; (ft³/s)/mi², cubic foot per second per square mile; in., inches]

Station	Drainage area (mi²)	1987				1988			
		Mean runoff			Measured precipitation (in.)	Mean runoff			Measured precipitation (in.)
		ft³/s	(ft³/s)/mi²	in.		ft³/s	(ft³/s)/mi²	in.	
Little Mahoning Creek at McCormick (site 8)	87.4	157	1.80	24.38	46.04	98.6	1.13	15.37	23.77
South Branch Plum Creek near Home (site 9)	9.38	16.7	1.78	24.12	46.04	9.27	.99	13.45	23.77
Little Yellow Creek near Strongstown (site 17)	7.36	12.6	1.71	23.15	49.54	9.60	1.30	17.76	35.65
Blacklick Creek at Josephine (site 28)	192	320	1.67	22.64	46.05	291	1.51	20.63	35.22

Table 14. Annual water losses at four streamflow-gaging stations, Indiana County, Pennsylvania, water years 1987-88

[Water loss expressed as percentage of precipitation]

	1987	1988	Average for both years
Little Mahoning Creek at McCormick (site 8)	47.0	35.3	41.2
South Branch Plum Creek near Home (site 9)	47.6	43.4	45.5
Little Yellow Creek near Strongstown (site 17)	53.4	50.2	51.8
Blacklick Creek at Josephine (site 28)	50.8	41.4	46.1

Water Quality

The water quality of streams in any area is affected by many natural factors and human activities. The water quality for some basins does not vary, whereas for others, water quality varies as a result of human activities and because of daily and seasonal weather conditions.

Indiana County has been affected by mining, oil and gas development, farming, logging, industry, and rural development. Because of these activities, the surface-water-quality characteristics of some perennial streams in the county are degraded. However, the surface-water quality does vary in the county as a result of local natural factors and land use. A network of 31 sampling sites was established to assess the water quality countywide (table 1 and fig. 1). The sampling sites were selected on the basis of five criteria: (1) main streams in the county (sites 8, 10, 16, 20, 24, 27, 28, and 31); (2) streams considered to have a high recreational value, such as those designated by the Pennsylvania Fish Commission as approved trout waters and other such streams inhabited by warm-water species of game fish (sites 2, 3, 4, 5, 6, 7, 8, 14, 17, 18, 19, 21, and 29); (3) inflows to public-water-supply reservoirs (sites 1, 12, 13, and 21); (4) streams where previous water-quality or -quantity data have been collected (sites 2, 8, 10, 17, 19, 20, 23, 24, 25, 27, 28, and 30); and (5) streams where acid mine drainage has affected water quality (sites 10, 15, 16, 23, 24, 25, 26, 27, 28, and 31).

All 31 sites were sampled five times during low and high base flows. Streamwater at base flow generally contains higher concentrations of dissolved constituents than does streamwater at medium to high flows because base flow is least affected by dilution from surface runoff. Low base-flow samples were collected in November 1986, October 1987, and August 1988. High base-flow samples were collected in May 1987 and May 1988. Most samples for each individual sampling run were collected on the same day at similar climatic and streamflow conditions.

All water-quality data collected are listed in Williams and McElroy (1991). Previous water-quality data were collected at sites 10, 14, 15, 19, 23, and 30 as part of the USGS Coal Hydrology network; these data were published by the USGS (1980-82) in annual water-resources data reports.

Criteria used to categorize surface-water quality were based on USEPA MCL's and SMCL's (1983). The time of lowest base flow coincides with the lowest ground-water levels, usually during the late spring, summer, and early fall when ground-water evapotranspiration and soil-moisture evapotranspiration is at a maximum and recharge is at a minimum. The time of highest base flow coincides with the highest ground-water levels, usually during the late fall, winter, and early spring when ground-water evapotranspiration and soil moisture evapotranspiration is at a minimum and recharge is at a maximum.

Dissolved-solids concentrations are used in evaluating and in comparing overall water quality of streams. Individual ions, pairs of ions, and complexes comprised of several ions contribute to the dissolved-solids concentration. The principal inorganic anions in surface water include carbonates, chloride, and sulfate. Principal cations include calcium, magnesium, sodium, and potassium. In coal-mined areas, the weathering and oxidation of pyrite and other minerals can produce elevated concentrations of iron, manganese, aluminum, and zinc, which can contribute to unusually high dissolved-solids concentrations. The SMCL for dissolved solids in drinking water is 500 mg/L. Water becomes unsuitable for many purposes when concentrations of dissolved solids exceed 1,000 mg/L. The sites where the average concentration of dissolved solids was less than 150 mg/L, 150 to 300 mg/L, 301 to 500 mg/L, and greater than 500 mg/L are shown in figure 38.

All streams were measured during base-flow conditions. The highest dissolved-solids concentrations generally were measured on the large streams in the southern half of the county. The four sites where average concentrations were greater than 500 mg/L (sites 23, 25, 26, and 28) were on streams known to be greatly affected by acid mine drainage.

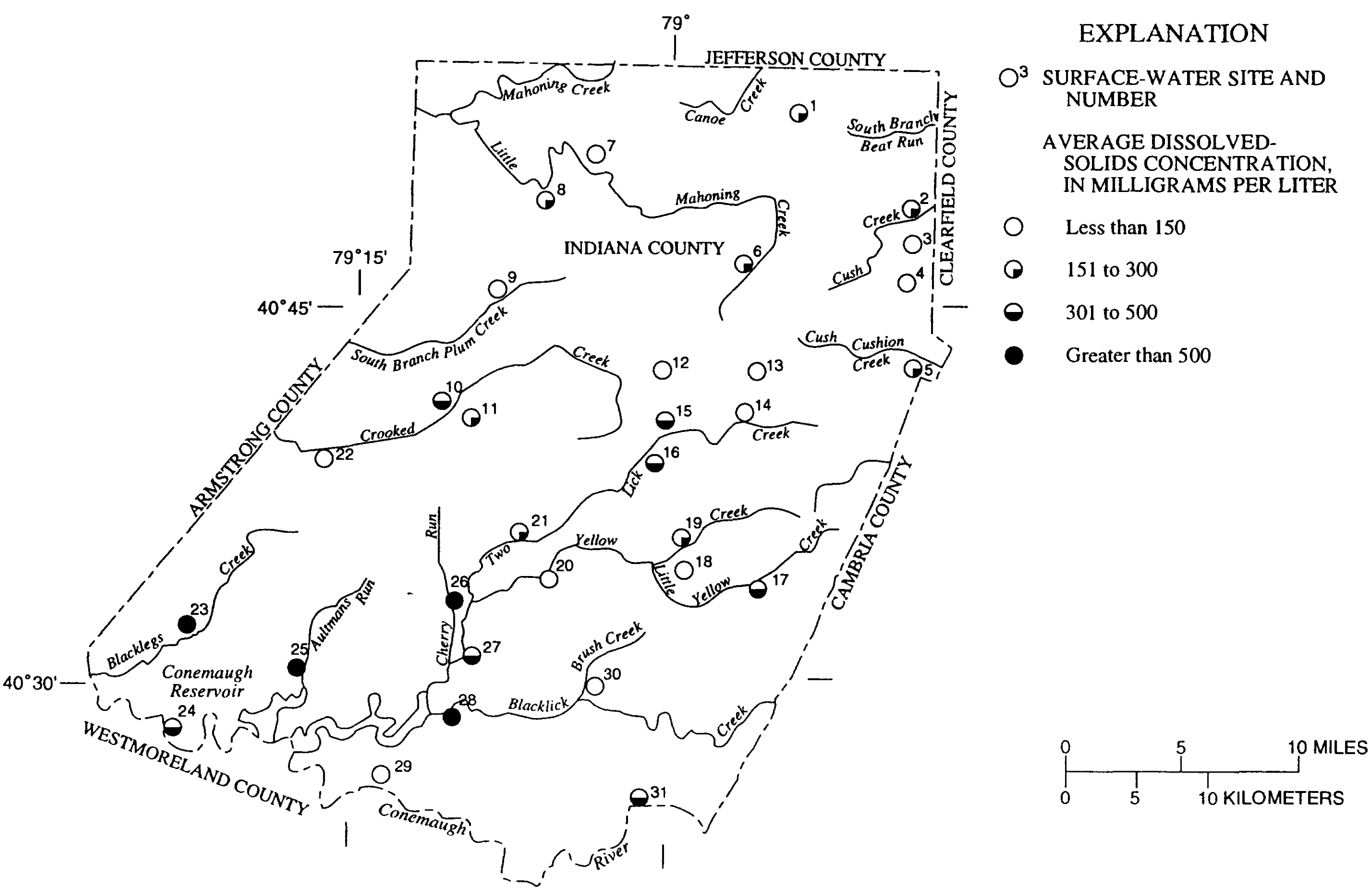


Figure 38. Average dissolved-solids concentrations measured in base-flow samples from selected streams, Indiana County, Pennsylvania, water years 1987-88.

The pH of streamwater normally ranges from 6.5 to 8.5, and pH of most streamwater samples fell within that range. Sites where pH was outside the normal range were in areas where mining had created a considerable amount of acid mine drainage. In coal-mine areas, a pH less than 6.5 commonly indicates acid mine drainage, and a pH less than 4.5 commonly indicates untreated acid mine drainage. Exceptions can be found, such as at site 23 on Blacklegs Creek in the southwestern corner of Indiana County and at site 26 in the south-central part of the county. Acid mine drainage affects both streams, but the pH range was from 7.1 to 8.0 at site 23 and from 6.5 and 7.6 at site 26. The water at these sites was sufficiently buffered (either naturally or artificially) to neutralize the acid mine drainage. At sites 24, 25, 27, 28, and 31, the pH was well below 6.5, and on occasions, below 4.5, indicating unbuffered acid mine drainage. Secondary reactions with the low-pH water can bring many other constituents into solution, particularly those associated with coal and pyrite such as iron, manganese, aluminum, and zinc. All these elements, with the exception of zinc, are at high concentrations at the five sites.

The alkalinity of streamwater is a measure of the stream's capacity to neutralize an acid. In this report, alkalinity is expressed as an equivalent concentration of calcium carbonate ($CaCO_3$), in milligrams per liter. According to Biesecker and George (1966), alkalinities of less than 50 mg/L are incapable of neutralizing large quantities of acid mine drainage. The average alkalinity exceeded 50 mg/L at only six sites (sites 10, 11, 17, 21, 23, and 26); thus, most streams could not effectively neutralize acidic mine inflows.

Hardness is reported in terms of an equivalent concentration of calcium carbonate ($CaCO_3$) or as total hardness. The average hardness measured at the 31 surface-water sites according to the classification in table 7 is shown in figure 39.

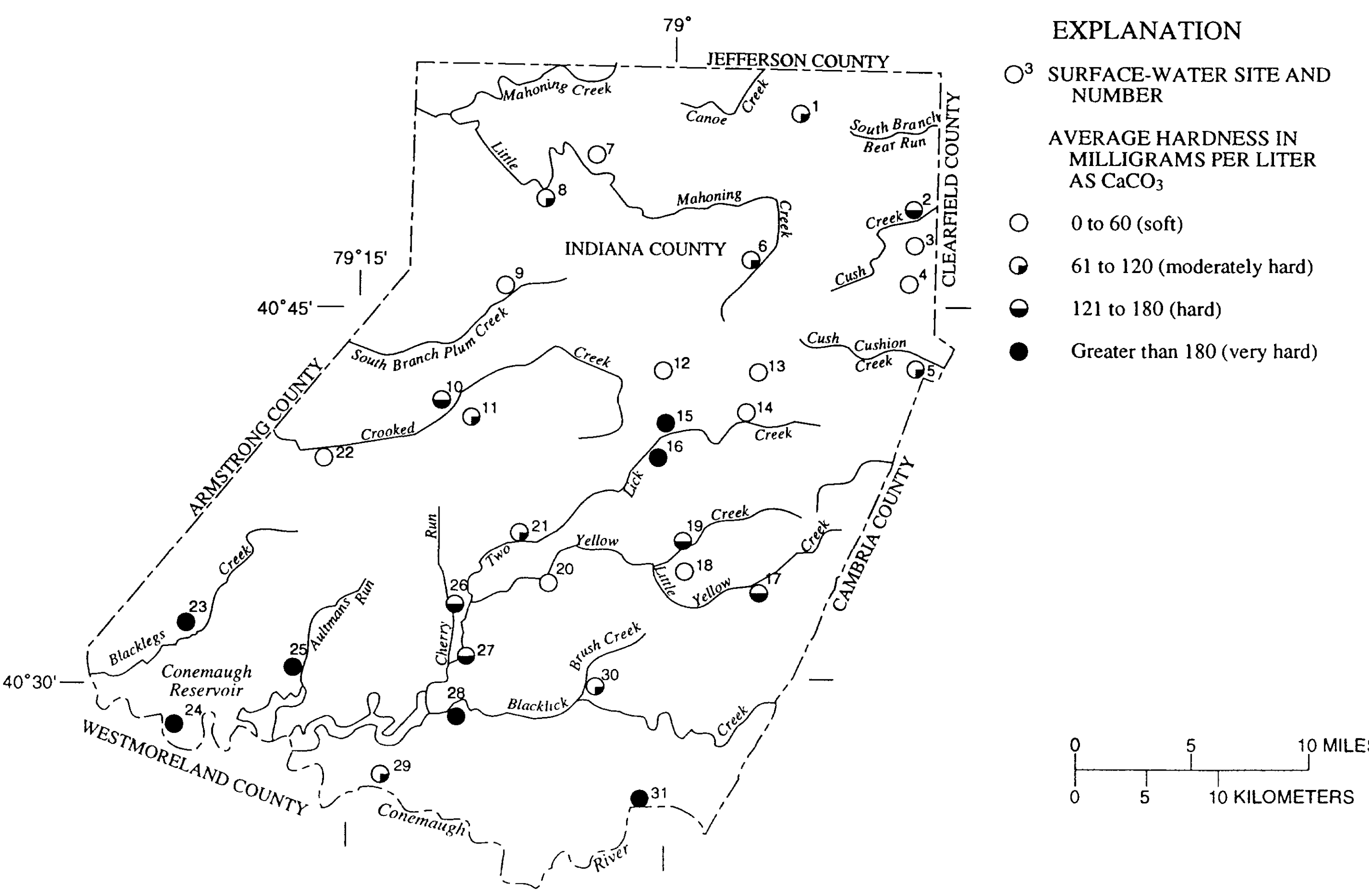


Figure 39. Average hardness concentrations measured in base-flow samples from selected streams, Indiana County, Pennsylvania, water years 1987-88.

Sulfate, iron, and manganese are three constituents associated with acid mine drainage. Acid mine drainage is produced by the oxidation of pyrite (FeS_2), commonly present in coal and rock strata. When coal is mined, pyrite is exposed to water and air, and oxidation is accelerated; this, in turn, accelerates the production of sulfate, iron, and hydrogen ions.

The oxidation of pyrite usually is described by the following reaction in which pyrite, oxygen, and water form sulfuric acid and ferrous sulfate:

$$2FeS_2 + 7O_2 + 2H_2O \leftrightarrow 4H^+ + 2Fe^{+2} + 4SO_4^{-2} \ . \qquad (2)$$

Oxidation of ferrous iron (Fe^{+2}) produces ferric ions (Fe^{+3}) by the following reaction:

$$8Fe^{+2} + O_2 + 4H^+ \leftrightarrow 8Fe^{+3} + 2H_2O. \qquad (3)$$

Reaction 3 is believed to be accelerated by the bacteria *Thiobacillus ferrooxidans.* This species of bacteria thrives in water having a pH less than 4, a common condition when sulfuric acid is formed in reaction 2. Reaction of ferric ions with water produces an insoluble ferric hydroxide [$Fe(OH)_3$], and more acid:

$$Fe^{+3} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+. \qquad (4)$$

Ferric ions can also oxidize more ferrous sulfate, producing additional acid and sulfate:

$$FeS_2 + 14Fe^{+3} + 8H_2O \leftrightarrow 15Fe^{+2} + 16H^+ + 2SO_4^{-2} \ . \qquad (5)$$

The above reactions produce elevated concentrations of ferric hydroxide [$Fe(OH)_3$], sulfate (SO_4^{-2}) and acid (H^+). The acidic water dissolves many other constituents such as manganese, aluminum, and zinc. The acidic, mineralized water collects in mine impoundments and spoil, where it eventually evaporates, percolates downward into underlying aquifers, or runs off into streams. If the receiving stream is sufficiently alkaline, the acidic water may be neutralized quickly. However, natural neutralization or deliberate neutralization (treatment with an alkaline agent) does not change the concentration of sulfate; therefore, sulfate persists as an indicator of mine drainage. According to Toler (1982), sulfate concentrations in excess of 100 mg/L in base-flow samples can be attributed to drainage from coal-mined areas. Because all five sampling trips were done during base flow, the average sulfate concentration could be used as an indicator of mine drainage. As figure 40 shows, most of the sites where the average dissolved-sulfate concentration exceeded 100 mg/L were in the southern half of the county.

As indicated earlier, elevated concentrations of iron, manganese, aluminum, and zinc commonly are associated with elevated concentrations of sulfate and acid mine drainage, although increased alkalinity in the stream causes these metals to precipitate. Ferric hydroxide, which coats the stream bottoms with a yellow-orange precipitate, is noticeable in many streams, particularly in southern Indiana County where acid mine drainage is most common. Sites where the average dissolved-iron concentration in water was less than 300 μg/L, 301 to 1,000 μg/L, and greater than 1,000 μg/L are shown in figure 41. The laboratory detection limit for dissolved iron was 100 μg/L. The USEPA SMCL for drinking water for iron is 300 μg/L.

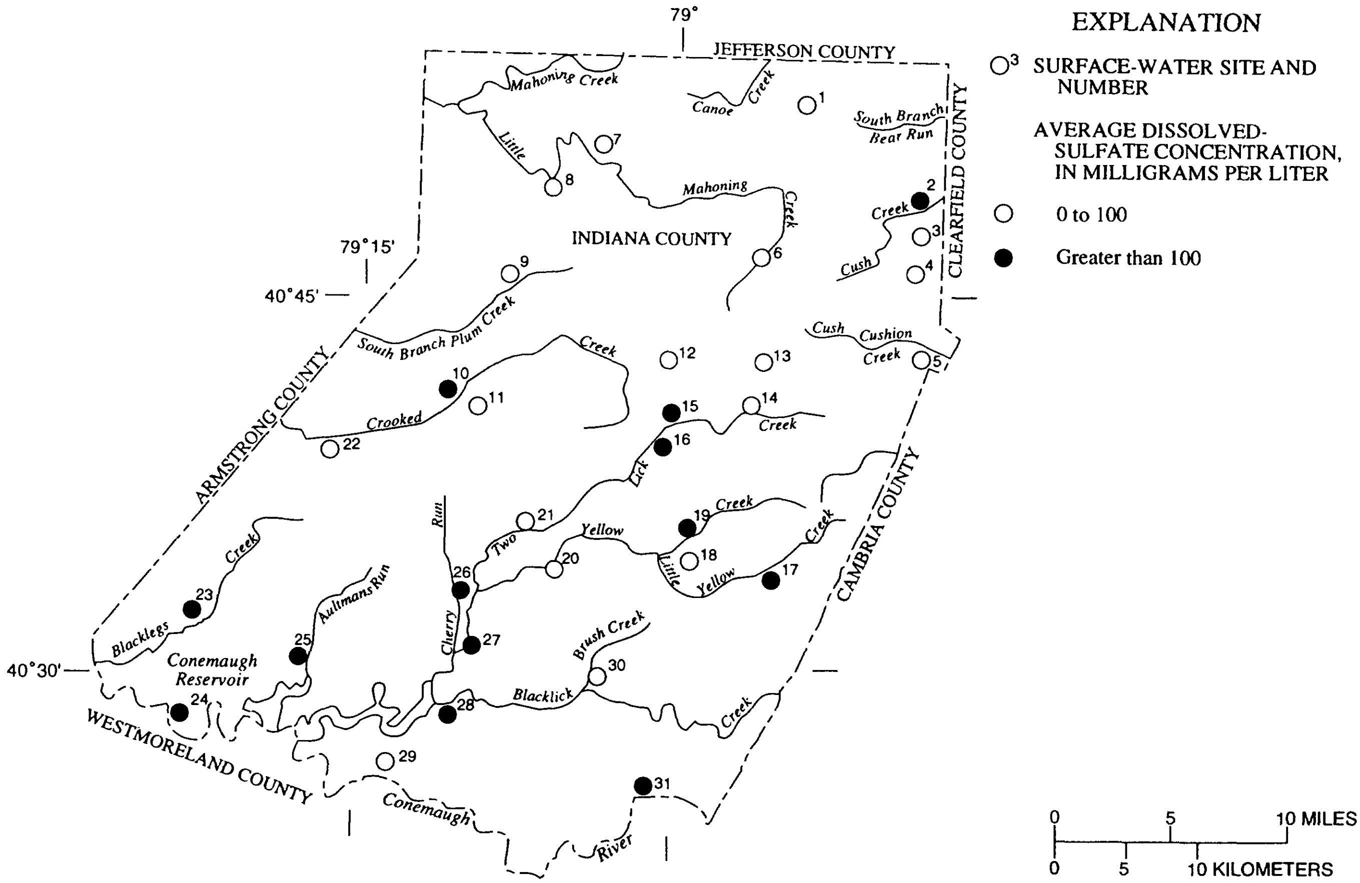


Figure 40. Average dissolved-sulfate concentrations measured in base-flow samples from selected streams, Indiana County, Pennsylvania, water years 1987-88.

Manganese is found in various salts and minerals, commonly in association with iron compounds. Most stream sites where dissolved-iron concentrations are higher than the SMCL are also sites where dissolved-manganese concentrations are higher than the USEPA SMCL of 50 µg/L. Similarly, concentrations of dissolved aluminum and zinc were elevated at sites where iron and manganese concentrations were elevated.

Samples were also collected for nitrate, fluoride, and trace metals. The trace metals included arsenic, barium, cadmium, chromium, lead, mercury, and selenium. Laboratory analyses indicated that the sample concentrations of the trace metals, nitrate, and fluoride were less than the MCL's at all sites.

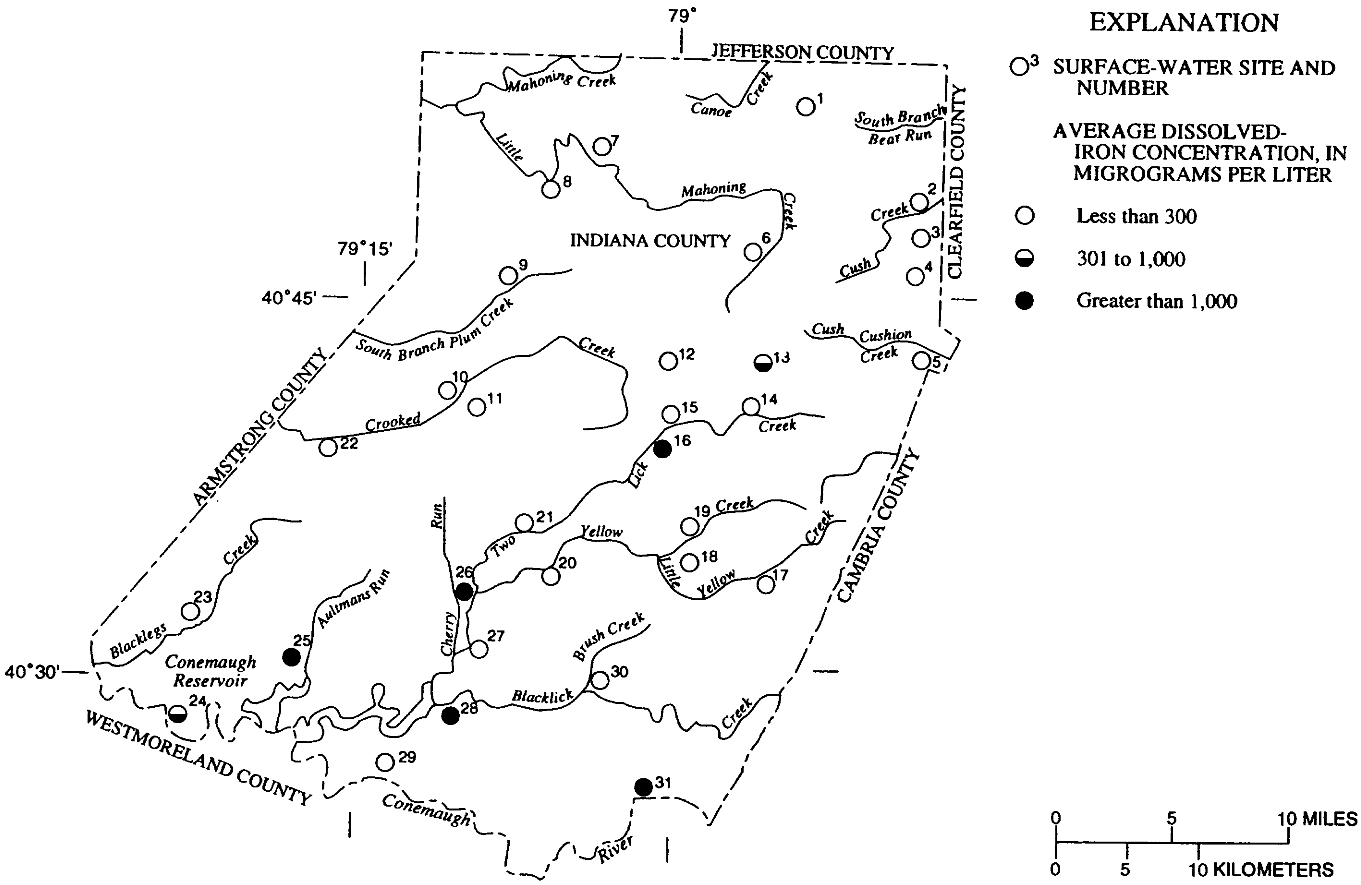


Figure 41. Average dissolved-iron concentrations measured in base-flow samples from selected streams, Indiana County, Pennsylvania, water years 1987-88.

HYDROLOGIC EFFECTS OF COAL MINING

Ground Water

Availability

Dewatering of aquifers by drainage to underground mines can have a significant effect on ground-water availability. Ground water intercepted by the deep mine is typically degraded by acidity and iron before being released to the surface. Air shafts and fractures caused by blasting or subsidence provided additional pathways for ground water to enter the mines.

Cherry Run has been deep mined extensively, and streamflow data indicate that water that would normally flow into the stream may have been intercepted by the underlying mine complex. Seepage runs in May and October 1987 and June 1988 revealed reaches where flow decreased downstream (table 15). Fractures concealed by alluvium may drain the streamwater. Moreover, the water budget indicates significantly lower percentages of surface runoff and ground-water discharge than in the South Branch Plum Creek Basin, which has not been deep mined. If evapotranspiration is about equal in the two basins, then approximately one-third of total base flow is intercepted by the mine. On May 3, 1987, both basins received 1 in. of rainfall during a soaking storm. Hydrographs for the two basins before, during, and after the storm are shown in figure 42. Total flow was divided by basin drainage area for construction of the hydrographs. They show that, except at peak flow, the South Branch Plum Creek has the consistently greater flow of the two streams, indicating that water is draining into the mine and out of the basin.

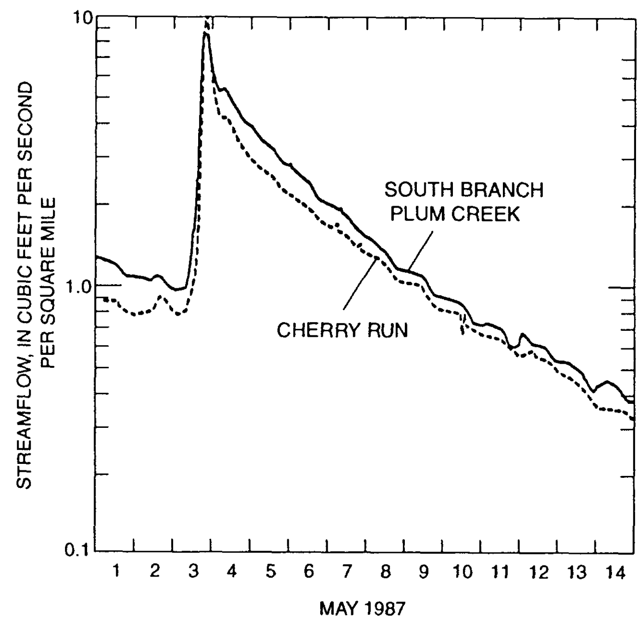


Figure 42. Hydrographs of Cherry Run and South Branch Plum Creek, Indiana County, Pennsylvania, May 1-14, 1987.

Water Quality

Wells

Of the 301 sampled wells, 22 (7.3 percent) yielded water whose sulfate concentration was greater than 100 mg/L, an indication of contamination by acid mine drainage. Elevated concentrations of dissolved solids, hardness, calcium, magnesium, iron, manganese, and strontium also are indicative of acid mine drainage influence on the ground-water system. All these wells, except for well IN 152, are near surface or deep mines. The source of the contamination in well IN 152 is uncertain. However, the well penetrates two coal seams, at 105 and 186 ft. One mechanism for generating acid mine drainage is contact of atmospheric oxygen with iron sulfides; water-level fluctuation in the well may have caused wetting and drying of iron sulfides. (The wellhead is buried, so depth to water could not be measured.)

Springs

Of the 121 sampled springs, 8 (6.6 percent) produced water whose sulfate concentration was greater than 100 mg/L. All of these springs are near surface mines. Dissolved solids, hardness, calcium, magnesium, and alkalinity in the springwater also were at greater concentrations than in water from other springs. Iron concentrations exceeded the SMCL of 300 μg/L only in water from spring IN SP 292, which also had manganese concentrations that were greater than the 50 μg/L SMCL. Springs IN SP 268 and IN SP 334 also produced ground water with large manganese concentrations.

Surface Water

Streamflow, stream-water quality, and hydrologic budgets of two small basins for the period 1987-88 were compared in order to understand the hydrologic effects of coal mining on surface water. The South Branch Plum Creek Basin (site 9) in northwestern Indiana County is in an unmined area of the county, and the Cherry Run Basin (site 26) in south-central Indiana County is in a deep-mined area of the county. The drainage areas of the South Branch Plum Creek and Cherry Run Basins are 9.38 and 10.5 mi^2, respectively. The topography, geology, and geography of both basins are similar. Land use in the South Branch Plum Creek Basin is primarily agriculture and secondarily forest. Land use in the Cherry Run Basin is primarily agriculture; however, the northern part of the basin is now being developed into a residential area.

Streamflow

Continuous streamflow data were collected at a streamflow-gaging station in each of the two small basins. The data were published in a basic data report (Williams and McElroy, 1991). High and low base-flow seepage-run data were collected throughout both basins on four occasions (tables 15 and 16). The basins were divided into the subbasins shown in figures 43 and 44. Streamflow data were collected on the same day during all four seepage runs at least 3 days after any significant rainfall. Therefore, ground water was assumed to be the source of flow.

Data collected on October 16, 1987, and June 7, 1988, best represent low base-flow conditions. Streamflows at the South Branch Plum Creek main-stem sites progressively increased downstream to sites 9 and 19 (fig. 43). The sum of the flows at sites 9, 19, and 20 should approximately equal the flow at site 21. However, during both seepage runs, a 21 percent decrease in streamflow was noted at site 21, an indication of water loss in the main stem between sites 9 and 19 and site 21. During the high-base flow seepage run on May 14, 1987, streamflow increased as expected at site 21.

Streamflows at the Cherry Run main-stem sites did not always increase progressively downstream, as would be expected. Seepage-run dates and main-stem sites where discharges decreased instead of increased downstream are listed in table 17. The loss of water at these main-stem sites could be attributed to evaporation, subsurface flow, water withdrawals, or loss to subsurface mines. No fracturing or subsidence as a result of mine collapse was indicated in the basin, although that was a possibility. As shown in figure 44, all of the Cherry Run Basin was completely undermined except for the northwestern corner. The Upper Freeport coal, the seam mined, is 100 to 200 ft below the main stem of Cherry Run. Hilltops throughout the basin range from 150 to 300 ft above the main stem; thus, depending on the specific location in the basin, the depth from land surface to coal or mine ranged from 100 to 500 ft. Room and pillar mining was used throughout the basin, but mining has been inactive since 1964. The specific causes for the water losses at the main-stem sites were not determined.

Table 15. Streamflow, water-temperature, and specific-conductance data for seepage runs in the subbasins of South Branch Plum Creek, Indiana County, Pennsylvania

[mi^2, square miles; ft^3/s, cubic foot per second; (ft^3/s)/mi^2, cubic foot per second per square mile; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; --, no data available]

Subbasin number	Drainage area (mi^2)	May 14, 1987				October 16, 1987			
		Streamflow (ft^3/s)	Streamflow per square mile [(ft^{3}s)/ mi^2] × 10	Water temperature (°C)	Specific conductance (µS/cm)	Streamflow (ft^3/s)	Streamflow per square mile [(ft^{3}s)/ mi^2] × 10	Water temperature (°C)	Specific conductance (µS/cm)
1	0.69	0.298	43.2	12.0	175	0.252	36.5	10.5	160
2	.20	.106	53.0	12.5	175	.451	226	10.5	160
3	.19	.067	35.3	13.0	190	.171	90.0	10.0	195
4	.12	.061	50.8	14.0	198	.233	194.2	8.5	185
[1]5	1.83	.803	43.9	15.0	175	.635	34.7	9.0	170
6	.45	.155	34.4	16.5	195	.254	56.4	9.0	190
[1]7	2.57	1.05	40.9	22.5	180	2.04	79.4	8.0	180
[1]8	2.93	1.36	46.4	19.0	167	1.39	47.4	7.0	160
[1]9	5.54	2.41	43.5	--	--	3.43	61.9	7.0	170
10	.99	.428	43.2	15.5	155	.490	49.5	8.5	170
11	.32	.104	32.5	16.5	145	.110	34.4	9.0	155
[1]12	.94	.300	31.9	21.0	163	.336	35.7	10.5	182
[1]13	1.54	.629	40.8	21.0	153	.757	49.2	12.0	170
14	.39	.130	33.3	12.0	88	.171	43.8	8.5	125
15	.95	.320	33.7	13.0	102	.413	43.5	8.0	135
[1]16	.72	.320	44.4	14.0	100	.250	34.7	6.5	127
[1]17	2.06	.780	37.9	16.0	112	.899	43.6	6.5	140
18	.35	.120	34.3	16.0	112	.122	34.8	5.5	145
[1]19	2.75	1.08	39.3	15.5	112	1.17	42.5	6.5	145
20	.36	.200	55.6	20.5	135	.169	46.9	7.0	190
[1]21	9.38	4.10	43.7	19.0	142	3.94	42.0	7.5	170

Subbasin number	Drainage area (mi^2)	June 7, 1988				July 6, 1988			
		Streamflow (ft^3/s)	Streamflow per square mile [(ft^{3}s)/mi^2] × 10	Water temperature (°C)	Specific conductance (µS/cm)	Streamflow (ft^3/s)	Streamflow per square mile [(ft^{3}s)/mi^2] × 10	Water temperature (°C)	Specific conductance (µS/cm)
1	0.69	0.051	7.4	24.0	147	0.020	2.9	23.0	180
2	.20	.044	22.0	23.0	162	.002	1.0	20.0	200
3	.19	.052	27.4	24.5	190	<.001	.59	21.0	285
4	.12	.013	10.8	28.0	212	.004	3.7	19.0	265
[1]5	1.83	.265	14.5	28.5	187	.008	.44	20.0	380
6	.45	.036	8.0	20.0	180	0	--	--	--
[1]7	2.57	.350	13.6	23.5	188	0	--	--	--
[1]8	2.93	.318	10.9	20.0	183	0	--	--	--
[1]9	5.54	.668	12.1	--	--	0	--	--	--
10	.99	.071	7.2	25.0	161	0	--	--	--
11	.32	.007	2.2	23.0	150	0	--	--	--
[1]12	.94	.036	3.8	29.5	161	0	--	--	--
[1]13	1.54	.068	4.4	31.0	156	0	--	--	--
14	.39	--	--	--	--	0	--	--	--
15	.95	.024	2.5	14.5	123	0	--	--	--
[1]16	.72	.058	8.1	15.0	123	0	--	--	--
[1]17	2.06	.171	8.3	18.0	186	0	--	--	--
18	.35	.027	7.7	16.0	130	0	--	--	--
[1]19	2.75	.351	12.7	17.0	133	0	--	--	--
20	.36	.041	11.4	17.5	175	0	--	--	--
[1]21	9.38	.877	9.4	26.0	161	0	--	--	--

[1] Mainstream sites—drainage areas at the main-stem sites include all subbasins upstream from the site.

Table 16. Streamflow, water-temperature, and specific-conductance data for seepage runs in the subbasins of Cherry Run, Indiana County, Pennsylvania

[mi^2, square miles; ft^3, cubic foot per second; $(ft^3/s)/mi^2$, cubic foot per second per square mile; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; --, no data available]

Subbasin number	Drainage area (mi^2)	May 14, 1987				October 16, 1987			
		Streamflow (ft^3/s)	Streamflow per square mile $[(ft^3s)/mi^2] \times 10$	Water temperature (°C)	Specific conductance (µS/cm)	Streamflow (ft^3/s)	Streamflow per square mile $[(ft^3s)/mi^2] \times 10$	Water temperature (°C)	Specific conductance (µS/cm)
1	0.31	0.089	28.7	24.5	235	0.041	13.2	6.0	240
2	.32	.100	31.2	23.0	165	.047	14.7	6.0	150
3	.14	.044	31.5	20.5	235	.018	12.8	8.0	360
4	.15	--	--	26.0	225	.020	13.3	7.0	200
5	.43	.183	42.5	21.5	180	.075	17.4	5.5	180
[1] 6	1.82	.550	30.2	21.0	190	.317	17.4	6.5	190
7	.36	.075	20.8	20.5	165	.064	17.8	8.0	160
8	.27	.188	69.6	20.0	300	.032	11.8	10.5	250
[1] 9	2.61	.809	31.0	19.5	237	.410	15.7	7.5	220
[1] 10	3.18	.794	25.0	20.5	205	.517	16.3	12.0	200
11	.57	.018	3.2	21.5	210	.010	1.8	12.5	480
[1] 12	1.33	.212	15.9	22.0	175	.077	5.8	6.5	190
13	.84	.376	44.8	21.0	152	.161	19.2	5.5	220
14	.56	.189	33.8	22.0	205	.113	20.2	6.0	250
[1] 15	1.95	.555	28.5	20.0	180	.288	14.8	6.0	215
16	.80	.109	13.6	21.0	160	.045	5.6	6.5	183
[1] 17	3.70	.852	23.0	21.0	200	.241	6.5	6.0	227
[1] 18	8.32	1.86	22.4	--	--	1.26	15.1	9.0	225
19	.34	.080	23.5	19.0	235	.050	14.7	9.0	235
20	.17	.054	31.8	19.0	165	.064	37.6	11.5	170
21	9.12	--	--	--	--	1.22	13.4	9.0	223
22	.97	.356	36.7	20.5	173	.152	15.7	13.0	235
23	[2]	.017	--	12.5	4,000	.047	--	12.5	4,100
[1] 24	10.5	2.95	28.1	20.5	315	1.73	16.5	14.0	520

Table 16. Streamflow, water-temperature, and specific-conductance data for seepage runs in the subbasins of Cherry Run, Indiana County, Pennsylvania—Continued

Subbasin number	Drainage area (mi^2)	June 7, 1988				July 6, 1988			
		Streamflow (ft^3/s)	Streamflow per square mile [(ft^3s)/ mi^2] × 10	Water temperature (°C)	Specific conductance (µS/cm)	Streamflow (ft^3/s)	Streamflow per square mile [(ft^3s)/ mi^2] × 10	Water temperature (°C)	Specific conductance (µS/cm)
1	0.31	0.049	15.8	25.0	295	0	--	--	--
2	.32	.040	12.5	23.0	255	0	--	--	--
3	.14	.040	28.5	23.0	310	0	--	--	--
4	.15	.003	2.0	24.0	235	0	--	--	--
5	.43	.052	12.1	22.5	190	0	--	--	--
[1]6	1.82	.198	10.9	21.0	235	0	--	--	--
7	.36	.035	9.7	20.0	170	0	--	--	--
8	.27	.010	3.7	19.0	380	0	--	--	--
[1]9	2.61	.183	7.0	19.0	253	0	--	--	--
[1]10	3.18	.222	7.0	21.5	225	0	--	--	--
11	.57	0	--	--	--	0	--	--	--
[1]12	1.33	.056	4.2	18.5	190	0	--	--	--
13	.84	.168	20.0	18.0	195	0	--	--	--
14	.56	.054	9.6	18.0	250	0	--	--	--
[1]15	1.95	.253	13.0	17.0	230	0	--	--	--
16	.80	.001	.125	17.0	165	0	--	--	--
[1]17	3.70	.230	6.2	17.5	225	0	--	--	--
[1]18	8.32	0	--	--	--	0	--	--	--
19	.34	.026	7.6	27.5	275	0	--	--	--
20	.17	.018	10.6	25.0	190	0	--	--	--
21	9.12	.679	7.4	23.0	225	<.002	--	28.0	245
22	.97	.130	13.4	28.5	195	0	--	--	--
23	[2]	.044	--	14.0	4,000	.044	--	14.0	4,200
[1]24	10.5	.973	9.3	27.5	685	.18	--	26.5	2,750

[1] Main-stem sites—drainage areas at the main stem include all subbasins upstream of the site.
[2] Mine discharge.

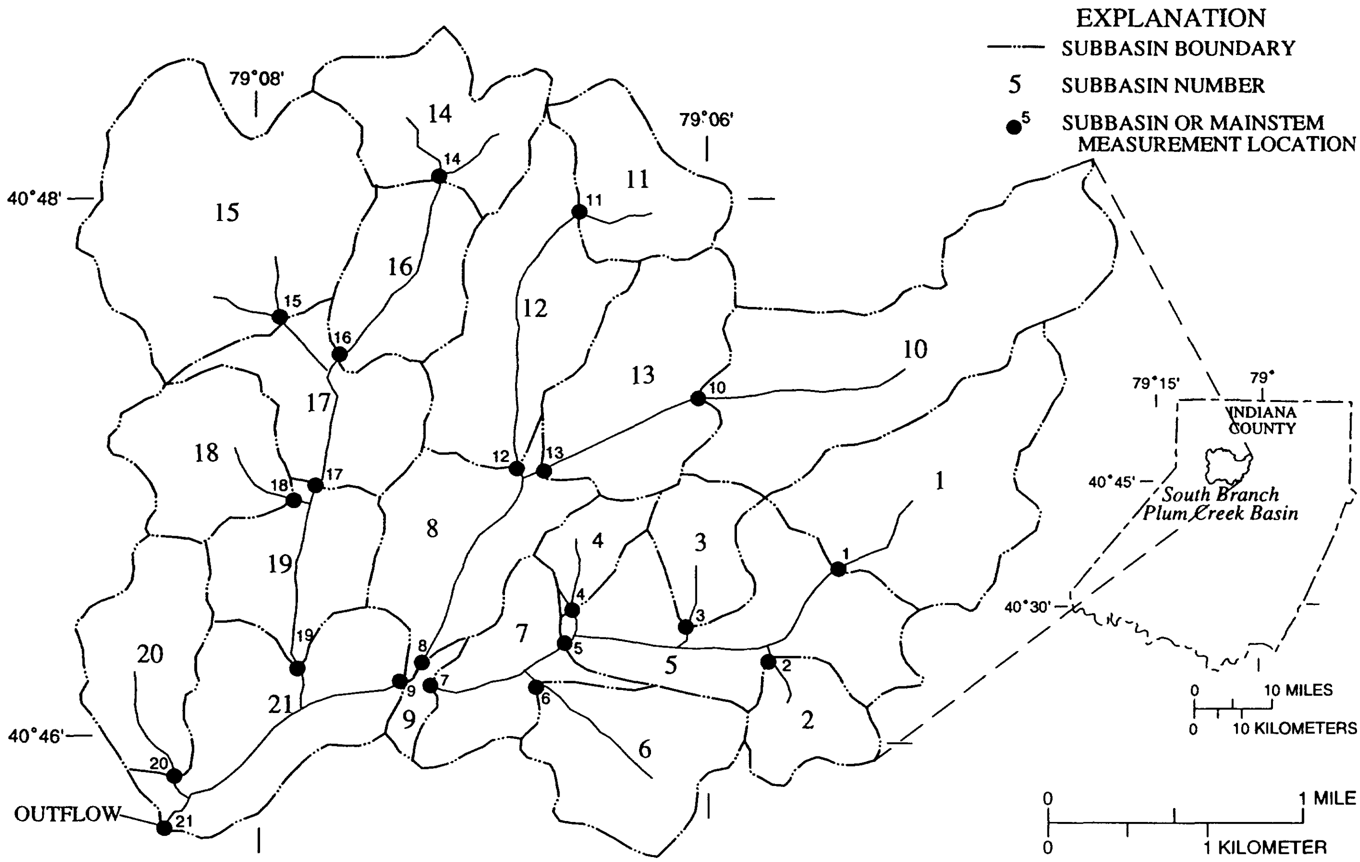


Figure 43. Subbasins and measurement locations, South Branch Plum Creek, Indiana County, Pennsylvania.

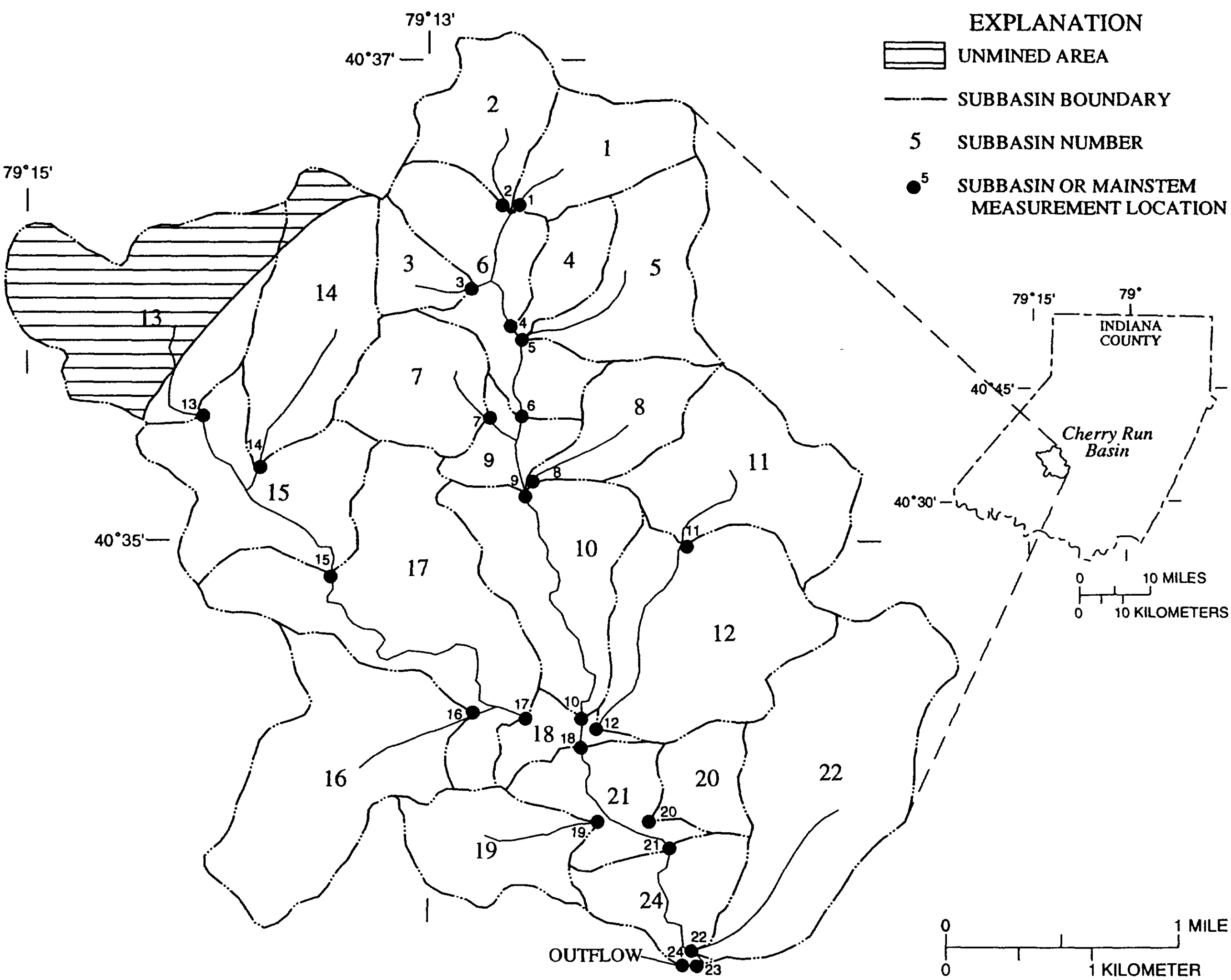


Figure 44. Subbasins and measurement locations, Cherry Run Basin, Indiana County, Pennsylvania.

Table 17. Sites on Cherry Run, Indiana County, Pennsylvania, where streamflows decreased instead of increased downstream

[Streamflow is in cubic feet per second; --, not applicable]

	May 14, 1987		October 16, 1987		June 7, 1988	
	Site number	Streamflow	Site number	Streamflow	Site number	Streamflow
Upstream site	9	0.809	15	0.288	6	0.198
Downstream site	10	.794	17	.241	9	.183
Upstream site	--	--	18	1.26	15	.253
Downstream site	--	--	21	1.22	17	.230

The streamflows per square mile were fairly consistent in each basin during the high base-flow run on May 14, 1987, but were much less consistent during the low base-flow run of June 7, 1988. The seepage run of July 6, 1988, was done in the middle of a drought, when most tributaries in both basins were completely dry. In the South Branch Plum Creek Basin, all sites were dry except for sites 1 through 5. Although the flow at each of these sites was minute, streamflow was measurable in the tributaries (sites 1-4) and the main stem at site 5, an indication of a persistent ground-water-discharge source. From site 5 to site 7, the flow either evaporated or infiltrated the channel because the stream was dry at site 7.

The Cherry Run Basin was completely dry on July 6, 1988, except at sites 21, 23, and 24. At site 21, the flow was less than 0.002 ft^3/s (estimated). Some ground-water discharge was observed at this site, and the streamflow gradually increased downstream to site 24. Site 23 is a deep-mine discharge that flowed continuously at a fairly constant rate and discharged into the main stem just above site 24. The mine discharge and the ground-water discharge from site 21 are the main contributors to streamflow at site 24 (streamflow-gaging station).

Water Quality

Six water-quality samples were collected at site 24 on Cherry Run, and five samples were collected at site 21 on South Branch Plum Creek (Williams and McElroy, 1991). The samples were collected during base flow at the outflow site of each basin. Maximum, minimum, and mean concentrations of selected constituents, most of which are indicators of mine drainage, are shown in figure 45.

The pH of the outflow water in both basins was 6.5 to 7.7. The median pH on Cherry Run was 6.9, which is slightly acidic, and on South Branch Plum Creek was 7.4, which is slightly alkaline.

The mean alkalinity of water in South Branch Plum Creek was 36 mg/L, and the maximum measured alkalinity did not exceed 50 mg/L, an indication that this stream is not well buffered. Alkalinity of water from Cherry Run was higher; the mean concentration was 75 mg/L. The higher alkalinity could be either the result of chemical neutralization of the acid mine drainage at site 23 or natural stream alkalinity.

The mean and range of dissolved-solids concentrations differed significantly between streams. In water from South Branch Plum Creek, the mean concentration was 140 mg/L and the range was from 84 to 202 mg/L. In water from Cherry Run, the mean was 750 mg/L and the range was from 180 to 2,580 mg/L. The higher dissolved-solids concentrations in water from Cherry Run are attributed to the mine discharge at site 23. Laboratory analyses of water from site 24 indicate that the sulfate ion was the main contributor to the dissolved-solids concentration, but calcium, magnesium, sodium, chloride, and iron concentrations also had a significant effect on the dissolved-solids concentration.

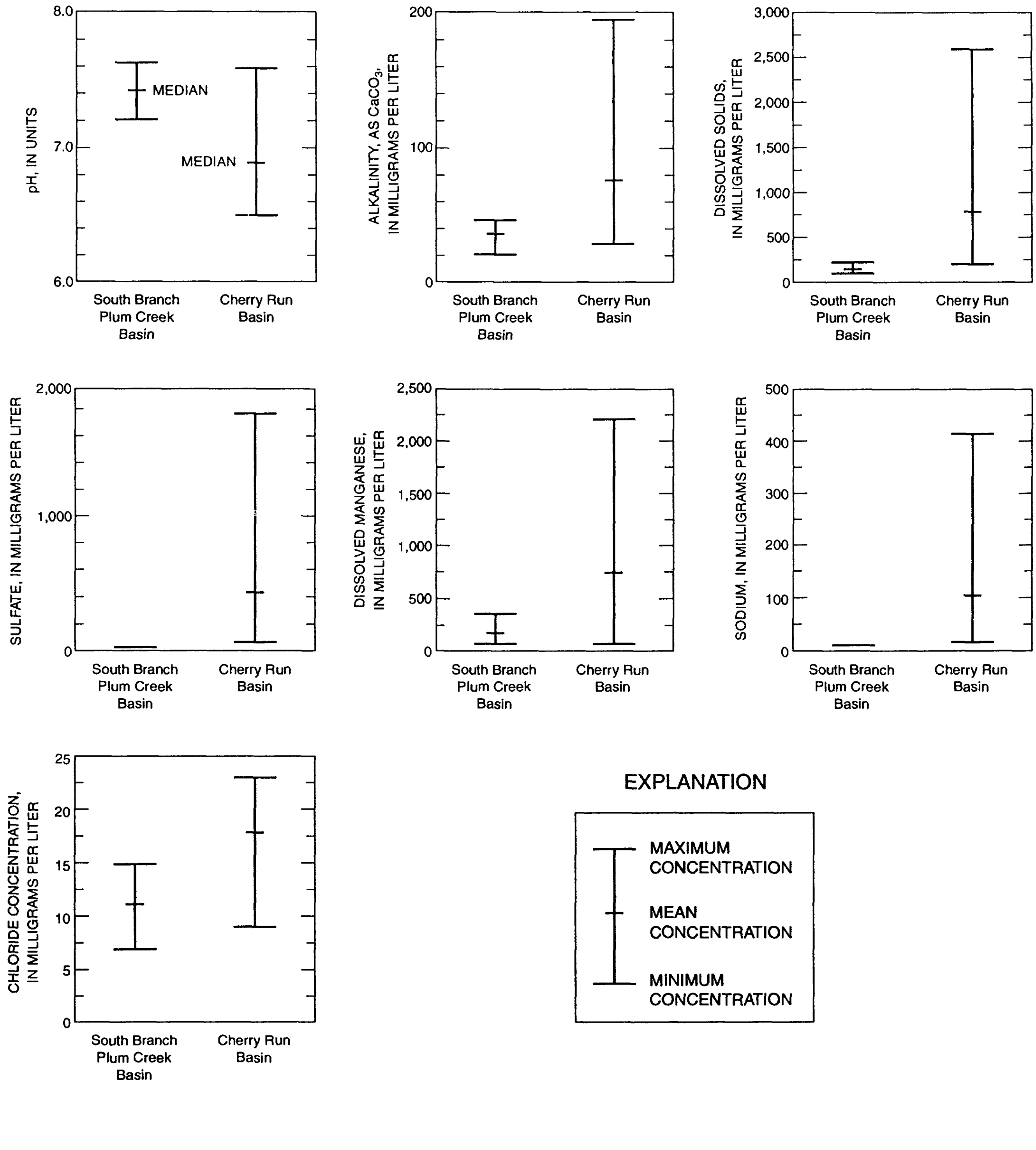


Figure 45. Maximum, minimum, and mean concentrations of selected constituents measured at the outflow sites of the South Branch Plum Creek and Cherry Run Basins, Indiana County, Pennsylvania, water years 1987-88.

Sulfate concentrations were substantially different between streams. In water from South Branch Plum Creek, sulfate concentrations ranged from 21 to 31 mg/L; the mean was 25 mg/L. In water from Cherry Run, sulfate concentrations ranged from 68 to 1,800 mg/L; the mean was 441 mg/L. The source of the high sulfates in Cherry Run samples was primarily the mine discharge at seepage-run site 23.

Concentrations of dissolved iron in water from Cherry Run ranged from 590 to 87,000 µg/L; the mean was 5,160 µg/L. Ferric hydroxide precipitate coated much of the stream bottom from the mine discharge (site 23) to well below the streamflow-gaging station at site 24. Concentrations of dissolved iron in water from South Branch Plum Creek ranged from 150 to 360 µg/L; the mean was 270 µg/L.

Concentrations of dissolved manganese in Cherry Run were higher than those in South Branch Plum Creek, but the differences were not as great as for the iron concentrations. In Cherry Run, concentrations ranged from 80 to 2,200 µg/L; the mean was 750 µg/L. In South Branch Plum Creek, concentrations ranged from 80 to 350 µg/L; the mean was 210 µg/L.

Sodium and chloride ions are present in all natural waters, but concentrations generally are low except when streams receive inflow from sources such as saline ground water or industrial wastes. The elevated concentrations of chloride, and particularly sodium, in water from Cherry Run are attributed to the mine discharge from site 23.

Concentrations of other constituents, such as potassium, fluoride, silica, and nitrate, differed little between the two streams.

Concentrations of most of the trace elements were below the detection levels in both streams; however, concentrations of dissolved aluminum and zinc were above the detection levels in Cherry Run on the last three seepage runs. All concentrations of dissolved strontium were above the detection level of 100 µg/L in Cherry Run.

The specific conductances in the subbasins of Cherry Run were higher (mean of 221 µS/cm) than those in South Branch Plum Creek (mean of 165 µS/cm).

CONTAMINATION OF WATER BY BRINE AND NATURAL GAS

The drilling of, and production from, natural gas wells throughout Indiana County has increased dramatically since about 1980, mainly because of an increase in the demand for domestic natural gas. During 1979-82, Indiana County was the leading county in Pennsylvania for the number of gas wells (Upper Devonian) drilled annually (Pennsylvania Department of Environmental Resources, Bureau of Topographic and Geologic Survey, Oil and Gas Geology Division, written commun., 1989). As of August 1989, 6,868 permitted gas wells were in operation throughout the county, which represent 11 percent of the total permitted gas wells in Pennsylvania. Wells are most concentrated in the western and northern parts of the county (fig. 46).

The increased development of natural gas creates a potential for increased ground-water and surface-water contamination. Possible sources for the contamination of freshwater aquifers and surface water include (1) brine, which is a byproduct of water that was trapped in the sediments at the time of their deposition (Poth, 1962) and is a byproduct of most gas-production activities, (2) chemicals used in drilling muds, fracturing operations, and well servicing, and (3) the natural gas itself.

Two approaches were used to study potential contamination by natural gas wells. The first was to examine available ground-water data for high concentrations of the major constituents of brine (chloride, sodium, calcium, and magnesium). Only ground water was studied, because no known streams in Pennsylvania are substantially affected by gas-well drilling or gas-production procedures (Alan Eichler, Pennsylvania Department of Environmental Resources, Bureau of Oil an Gas Management, oral commun., 1989). The second approach involved investigating sites where the PaDEP, Bureau of Oil and Gas Management, identified possible contamination by gas wells.

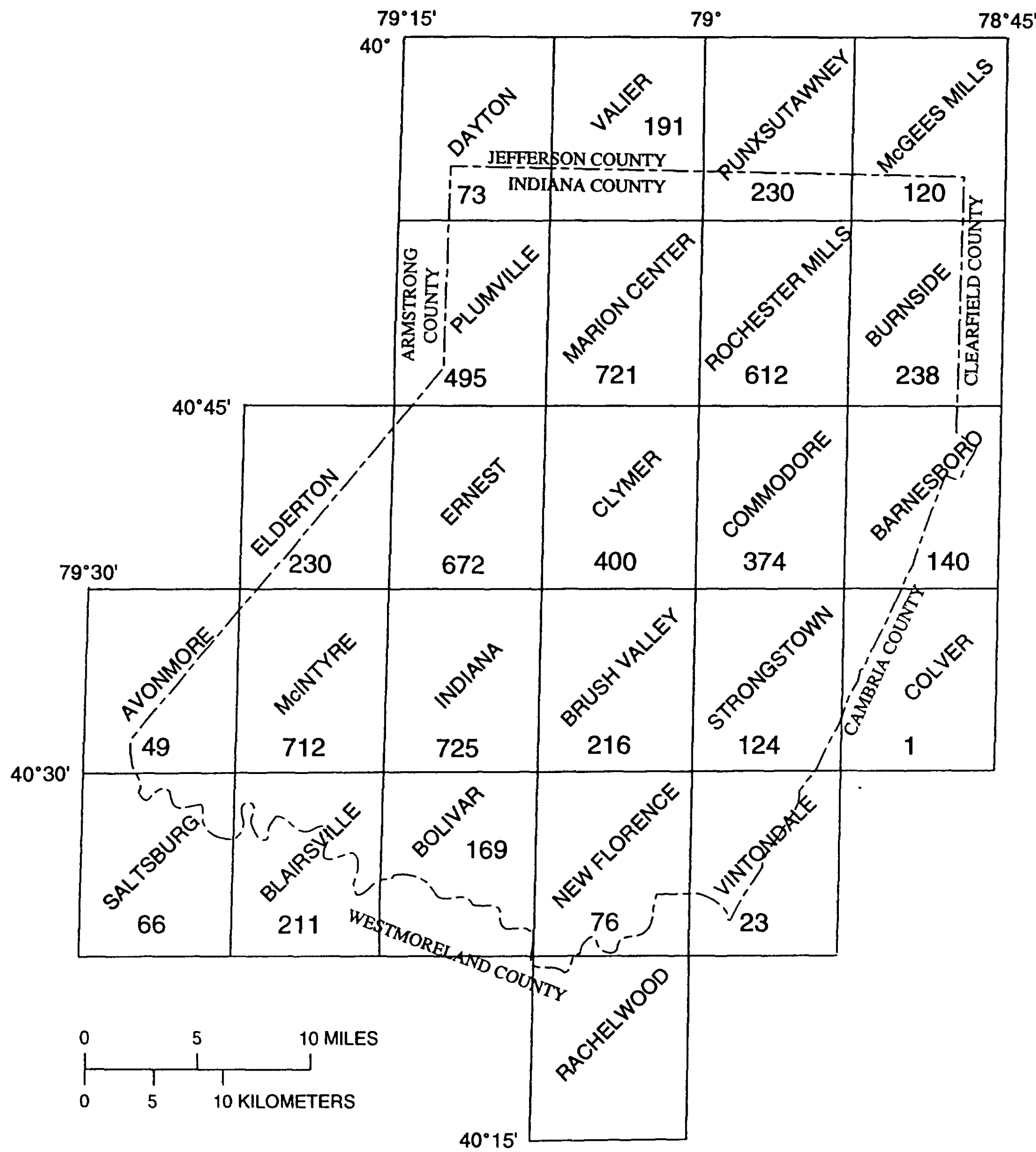


Figure 46. U.S. Geological Survey 7 1/2-minute quadrangles showing the total number of permitted gas wells within the Indiana County boundary as of August 1989.

Brine

Two pathways for contaminants to enter shallow aquifer systems are (1) downward leaching from the land surface and (2) upward migration from the subsurface. Contaminants are leached from improperly sealed holding ponds or brine disposal on roads. Subsurface migration of contaminants may be by (1) movement along a fracture zone, (2) an improperly abandoned gas well, or (3) an improperly seated casing of a gas well.

A total of 302 domestic water wells were routinely sampled throughout the county. Comparisons of the concentrations of constituents in the water of some wells with those commonly found in brine indicate the possibility of contamination from gas-well drilling or gas production. In water from seven wells, chloride concentrations were greater than 100 mg/L, and the concentrations of other constituents commonly associated with brine also were elevated. All these wells are near gas fields. However, water-quality data alone cannot establish that the drilling was responsible for the elevated concentrations. Three of the seven wells—IN 451, IN 452, and IN 454—are close to one another and are 150, 250, and 210 ft deep, respectively. Well IN 453, which is 123 ft deep, is also in the same area, but the constituents of interest are not at elevated concentrations in water from this well. This water-quality pattern indicates that water having elevated constituent concentrations such as produced from wells IN 451, IN 452, and IN 453 is not present at shallow depths.

A domestic water well (IN 508) in northeastern Indiana County was sampled in June 1987 as part of the countywide well-inventory coverage. The depth of the water well is 56.6 ft below land surface. In January 1988, a gas well was drilled about 720 ft from the domestic water well and upgradient from the water well. Well IN 508 was resampled periodically between May and September 1988. All samples were collected after the well was pumped at a rate between 9.7 and 36.0 gal/min for 15 minutes to 1 hour. A major change in the concentration of several constituents was evident over the sampling period (table 18). Specific conductance and dissolved-solids concentration increased. Concentrations of calcium, magnesium, sodium, potassium, chloride, sulfate, and hardness increased. Concentrations of iron, manganese, zinc, and cobalt increased substantially.

A spring (IN SP 340) about 150 ft downgradient from the water well also was sampled five times beginning May 2, 1988 (table 18). Laboratory analyses show a similarity in water quality between the springwater and the well water. On the basis of water-quality changes in the well water, it appears that the quality of the shallow aquifer may be related to the nearby gas well. Because of the large number of gas wells within the county, there could be a potential for other ground-water supplies to be affected in the same manner.

Table 18. Water-quality analyses, well IN 508 and spring IN SP 340, Indiana County, Pennsylvania

[All values in milligrams per liter except where noted; °C, degrees Celsius; µg/L, micrograms per liter; <, less than; --, no data]

Date	Time	Water temperature (°C)	pH (units)	Acidity (as H^+)	Alkalinity (as $CaCO_3$)	Specific conductance (microsiemens per centimeter)	Dissolved solids, residue, dissolved at 105°C	Calcium	Magnesium	Sodium	Potassium	Fluoride	Chloride	Sulfate	Silica	Hardness	Nitrate	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Aluminum, dissolved (µg/L)	Zinc, dissolved (µg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Cobalt, dissolved (µg/L)	Copper, dissolved (µg/L)	Lead, dissolved (µg/L)	Nickel, dissolved (µg/L)	Strontium, dissolved (µg/L)	Selenium, dissolved (µg/L)	Mercury, dissolved (µg/L)
Well IN 508																																
6-3-87	1740	13.0	5.6	16	6	95	66	5.3	2.6	4.7	1.4	<0.1	10	10	5.7	31	1.4	<100	150	<135	14	<4	<500	0.5	<50	<25	<10	7	<25	<100	<6	<1
5-2-88	1220	10.5	6.1	36	12	190	360	9.8	4.5	13.5	2.8	<.1	78	25	4.6	57	.08	1,070	4,880	<135	94	<4	<500	.6	<50	234	14	<4	<25	<100	<6	<1
5-2-88	1255	9.5	6.1	32	10	185	188	9.7	4.4	13.9	2.9	<.1	50	23	4.5	54	.19	580	4,990	<135	63	<4	<500	.7	<50	260	11	<4	<25	<100	<6	<1
5-2-88	1315	9.5	6.1	34	10	190	--	9.5	4.3	13.8	2.9	<.1	53	22	4.6	53	.21	530	4,780	<135	62	<4	<500	.7	<50	251	11	<4	<25	<100	<6	<1
6-16-88	1100	--	5.9	24	8	136	252	9.1	3.9	10.2	2.4	<.1	28	15	6.6	44	.46	280	2,390	161	68	<4	<500	1.0	<50	148	<10	<4	47	<100	<6	<1
8-3-88	1025	11.0	6.1	12	12	160	152	9.5	4.5	10.6	2.3	<.1	30	10	6.4	43	.88	160	2,210	<135	85	<10	<500	1.3	<50	84	17	<4	<10	<100	<6	<1
8-3-88	1055	11.0	6.0	18	10	156	204	9.8	4.4	10.0	6.8	<.1	33	17	7.6	44	.75	650	2,400	137	91	<4	<500	1.4	<50	89	<10	<4	<25	<100	<6	<1
8-30-88	1015	11.5	6.0	14	10	160	136	8.7	4.1	11.0	2.2	<.1	38	18	6.8	47	.35	400	2,100	183	106	<4	<500	1.2	<50	67	12	<4	40	<100	<6	<1
9-21-88	1435	12.0	6.0	12	8	156	--	10.2	4.4	13.8	2.0	<.1	30	16	6.4	45	2.3	620	1,800	163	81	<4	<500	1.0	<50	51	<10	<4	<25	<100	<6	<1
Spring IN SP 340																																
5-2-88	1445	10.0	6.1	32	8	195	--	11.7	5.0	16.5	2.5	<.1	53	20	6	53	.04	830	5,800	190	40	<4	<500	.3	<50	216	<10	<4	33	<100	<6	<1
6-23-88	1000	--	5.8	14	8	137	200	8.7	3.6	10.7	3.3	<.1	29	32	5	49	.42	720	2,600	211	80	<4	<500	2.2	<50	130	63	<4	37	<100	<6	<1
7-28-88	1545	24.0	6.2	18	12	161	132	8.0	3.7	10.3	2.5	<.1	32	24	5	54	.21	230	2,400	169	65	<4	<500	.8	<50	124	16	<4	77	<100	<6	<1
8-30-88	1045	16.0	6.2	8	16	149	144	9.2	4.0	11.6	2.6	<.1	31	16	5	39	.57	300	2,360	136	53	<4	<500	.5	<50	96	25	<4	40	<100	<6	<1
9-21-88	1530	16.0	6.2	6	14	160	84	9.3	4.1	16.7	2.4	<.1	31	18	3	43	.67	<100	1,580	<135	57	<4	<500	.5	<50	85	<10	<4	<25	<100	<6	<1

Natural Gas

Natural gas is present in some water wells in Indiana County. A photo of ignited gas emerging from the vent pipe of a water well in White Township is shown in figure 47. The locations of all the sites discussed in the following paragraphs were obtained from personnel in the PaDEP, Bureau of Oil and Gas Management. In none of the cases has it been shown that contamination has been caused by drilling.

Figure 47. Burning natural gas from a water well, Indiana County, Pennsylvania.

Well IN 222 produces small quantities of natural gas. Gases emerging from the borehole of well IN 887 were about 20 percent natural gas. When the well was pumped, the loss of hydrostatic head caused the natural gas percentage to increase to 88 percent (fig. 48).

In an area in Rayne Township, on LR 32071 between Dixonville and Tanoma, water wells also produce natural gas. This area is on the axis of the Dixonville Syncline, which plunges to the southwest (pl. 1). Topography of the area, well locations, and a mined-out area are shown in figure 49. The coal seam mined (the Lower Freeport) lies approximately 35 ft below the surface of the area and was mined from 1914 through 1962 (A.E. Glover, Pennsylvania Department of Environmental Resources, Bureau of Topographic and Geologic Survey, oral commun., 1990). The coal under the area of interest was probably not mined because of water inflow from the two unnamed streams in the area. Seismic lines show that bedrock is 20 ft below the surface.

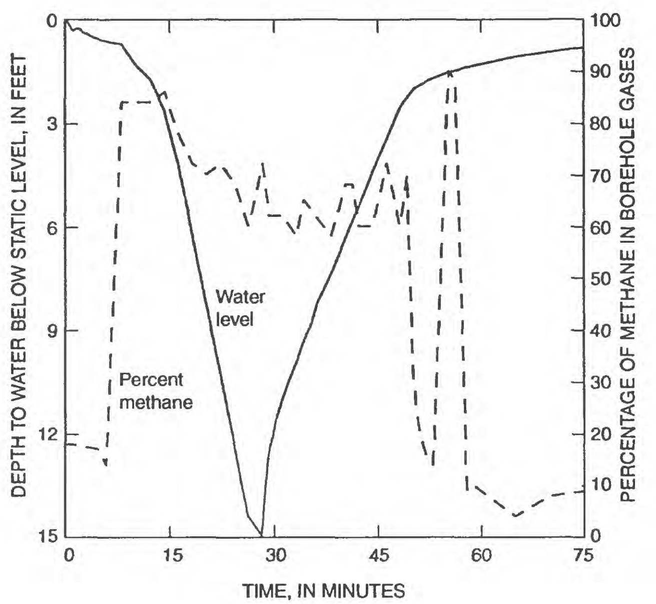
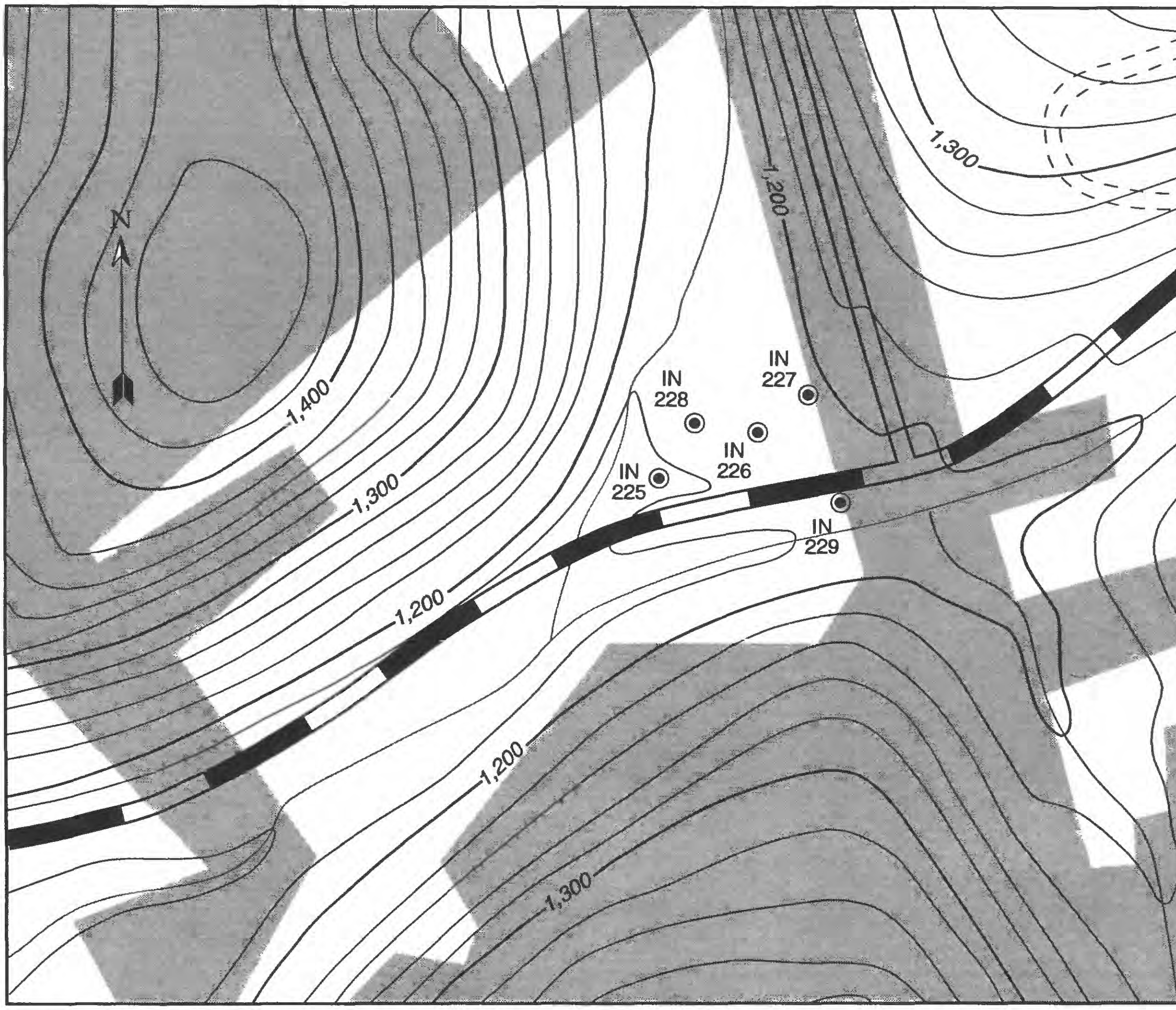


Figure 48. Drawdown, recovery, and methane percentage, well IN 887, Indiana County, Pennsylvania.

Two of the area wells, IN 227 and IN 228, do not produce natural gas. They are both used for domestic supply. Well IN 227 is 64 ft deep, and the measured water level in July 1988 was 30 ft below land surface. Well IN 228 is 64 ft deep, according to the owners. (The wellhead is buried, so depth to water could not be measured.)

Wells IN 225, IN 226, and IN 229 all produce natural gas. The owner of well IN 225 reported that if the gas is set on fire, it burns with a steady, 6-ft-high flame. The well is 81.0 ft deep, and was dry in July 1988. A temperature log indicated that the gas may be entering at 50 ft. Well IN 226 is 85.8 ft deep. In July 1988, depth to water was 80.0 ft. Temperature and caliper logs indicate gas entry into the borehole at 64 ft. Well IN 229 is 102 ft deep. (The well is buried, so depth to water could not be measured.) The well is used as a domestic supply. Natural gas is vented to the atmosphere through a small tube.

The source of the natural gas is not known. It is not from the Lower Freeport coal, because the gas enters the wells below the coal. Wells IN 228 and IN 227 are apparently tapping a perched water source or sources, because water levels in wells IN 225 and IN 226 are below the bottoms of wells IN 227 and IN 228.



Base from U.S. Geological Survey
Clymer 1963, 1:24,000

0 — 1,000 FEET
0 — 300 METERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

MINED-OUT AREA

WELL LOCATION

Figure 49. Well sites, topography, and mined out area near gas-contamination study area, Indiana County, Pennsylvania.

Water pressure in the wells may be sufficient to inhibit natural gas from entering the wells, or as in well IN 222, the wells may be too shallow to intercept fractures through which the natural gas passes. If wells IN 225 and IN 226 initially penetrated perched water such as that supplying wells IN 227 and IN 228, they drained off the water. Because the nearby wells IN 227 and IN 228 were not dewatered, a hydrologic connection between the wells does not seem possible. Well IN 229 is apparently tapping a different aquifer than wells IN 227 and IN 228 are, as indicated by greater mineralization of water from well IN 229 (fig. 50).

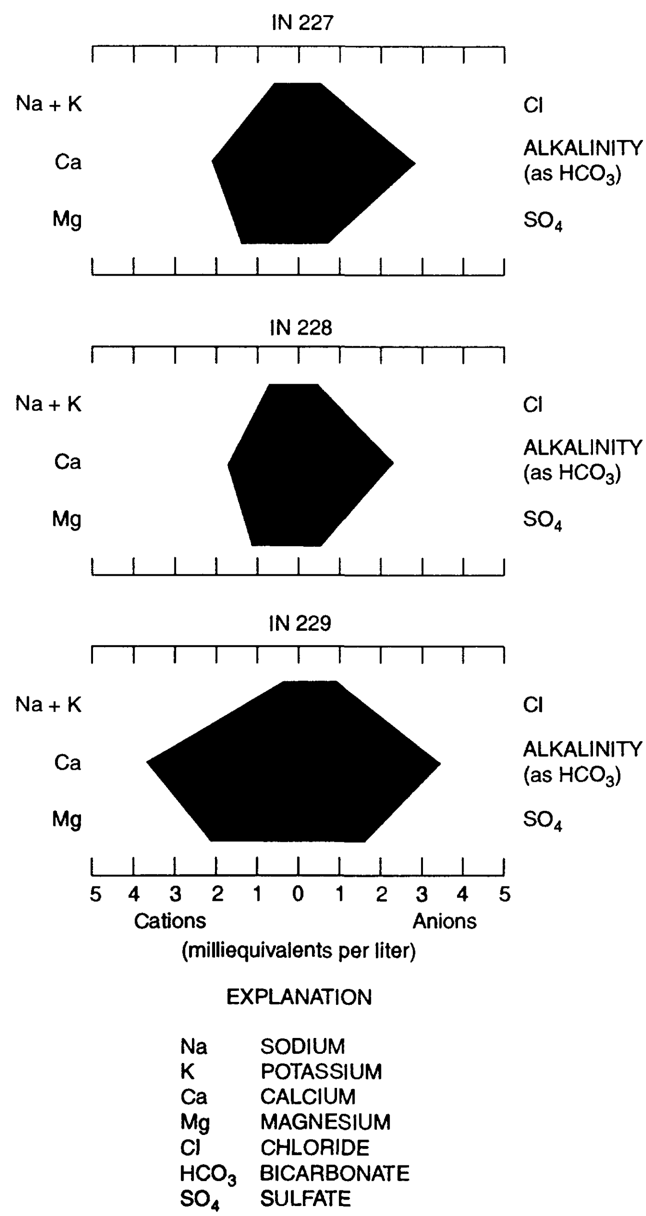


Figure 50. Stiff diagrams showing water from wells IN 227, IN 228, and IN 229, Indiana County, Pennsylvania.

CONCLUSIONS

Ground water in Indiana County flows through fractures in the rock. The size and extent of the fractures, which are controlled by lithology, topography, and structure, determine the sustained yield of a well. Topography has the greatest effect on well yield. Data indicate that sandstones underlying valleys are the most productive aquifers in the county, but the extent of valley sandstones cannot be mapped except by drilling. Because the lithology of the rocks is generally in homogeneous vertically and laterally, hydraulic conductivity is anisotropic.

Valleys where alluvial deposits are extensive enough to be mappable are the most likely sites for developing large yield wells. Wells in this setting are likely to be most productive if they are in sandstone.

Rocks of Middle to Upper Pennsylvanian age underlie most of the county. They consist of shale, sandstone, siltstone, and claystone, and minor amounts of limestone and coal. The remainder of the rocks, except for an igneous dike of Jurassic age, are Lower Pennsylvanian to Devonian and consist of sandstone, shale, and limestone. From oldest to youngest, the rock units are the Rockwell Formation, the Burgoon Sandstone, the Loyalhanna Formation, the Mauch Chunk Formation, the Pottsville Group, the Allegheny Group, the Glenshaw Formation, the Casselman Formation, the Monongahela Group, and the Dixonville dike. Structure is characterized by open folds that generally strike N. 30° E. Topography has a significant control over yields of wells tapping the Allegheny Group. Hilltop well yields may be marginal for even low-use domestic supplies, but valley wells may yield sufficient amounts for large-volume users. Yields of properly sited valley wells in the Glenshaw Formation may be adequate for nondomestic uses. Few wells produce water at depths greater than 150 ft. The Casselman Formation yields adequate amounts of water for large volume users. Productivity of the Monongahela Group is meager, and water quality may be unsuitable for many uses. Optimal well depth depends on topography. Ground water from the Casselman Formation, Glenshaw Formation, and Allegheny Group tends be hard and may have concentrations of iron and manganese greater than the USEPA SMCL's. Data on the remaining rock units are too sparse to enable their characterization as aquifers.

Short-term water-level fluctuations are highly variable from well to well, even among wells that are close together. Long-term water levels fluctuate in response to season and the amount of precipitation. The drought of summer 1988 lowered the water level more than usual in almost all of the wells measured.

Water from nearly half the springs is low in pH and dissolved solids. Ground water from wells in the Glenshaw Formation is less mineralized than ground water from the Allegheny Group. Dissolved-solids concentrations of water from the Casselman Formation are between those in water from the Glenshaw Formation and the Allegheny Group. Water from wells on hilltops has lower concentrations of dissolved solids than water from wells on hillsides. Water from wells in valleys is the most mineralized. Approximately 7 percent of the wells and springs sampled yielded water that seems to have been degraded by acid mine drainage.

Contamination of some water wells by gas-well development is possible but cannot be confirmed, owing to insufficient background data. Natural gas is produced by some water wells. It is not known whether the natural gas enters water wells through preexisting fracture systems or through fractures resulting from gas production.

Many streams in mined areas have high concentrations of sulfate, iron, manganese, aluminum, zinc, and dissolved solids. Sulfate concentrations of more than 100 mg/L, an indication of acid mine drainage, were measured in streams at many sites in the southern half of the county. Mean dissolved-solids concentrations in streams known to be affected by acid mine drainage were greater than 500 mg/L at sites 23, 25, 26, and 28 (fig. 38); however, many smaller streams draining unmined areas had mean dissolved-solids concentrations less than 150 mg/L. The pH at sites 24, 25, 27, 28, and 31 was much lower than 6.5, and on many occasions lower than 4.5; pH in this range indicates acid mine drainage. Water quality in Cherry Run at the outflow site (site 24) was significantly different than the water quality at the South Branch Plum Creek outflow site (site 9). The water-quality degradation in Cherry Run was primarily the result of mine discharge at site 23 into Cherry Run just upstream from site 24.

Precipitation for 1988 at the Indiana NOAA site (35.65 in.) was 20 percent below the 40-year average (44.73 in.). Precipitation for 1988 in the Cherry Run Basin (31.60 in.) and the South Branch Plum Creek Basin (23.77 in.) were 29 and 47 percent, respectively, below the 40-year average at Indiana.

The 7-day, 10-year low flows at unregulated surface-water sites ranged from 0 to 0.19 $(ft^3/s)/mi^2$. The 7-day, 10-year low flows were zero at five unregulated sites because of the drought of 1988. The flow-duration curves for sites 8 and 17, located on natural, unregulated streams, indicate a smaller sustained base flow than for sites 27 and 28, located on regulated streams. The sustained base flow in the regulated streams was the result of low-flow augmentation above the sites. Annual water loss at four surface-water sites (sites 8, 9, 17, and 28) for 1987 and 1988 ranged from 35 to 53 percent. Annual water loss was greatest in the Little Yellow Creek Basin (site 17) and averaged about 53 percent for 1987-88.

Streamflow data collected during base flow throughout two similar-sized basins, one that was almost completely subsurfaced mined (Cherry Run Basin) and one unmined (South Branch Plum Creek Basin), indicated a consistent water loss in Cherry Run at main-stem sites. Data indicate that deep mines near the land surface can intercept ground water and reduce ground-water availability. The water loss could have been through existing rock fractures or fractures induced by subsidence above the mine, although subsidence was not confirmed. The depth from land surface to the top of the deep mine ranged from 100 to 500 ft throughout the Cherry Run Basin.

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SOURCES OF INFORMATION ABOUT WATER

A variety of information on water supplies is available from the sources listed below. When requesting information, it is important to give an accurate location of the site for which information is requested.

- The **Bureau of Topographic and Geologic Survey, PaDCNR,** Harrisburg, Pa., has information on the geology of Indiana County and published reports that describe in detail the rocks that underlie the area. Well drillers' logs and reports on new wells that have been drilled also are available.
- The **Bureau of Water Supply and Community Health, PaDEP,** Harrisburg, Pa., can supply information on well-construction requirements, biological reports on well water, and data on the chemical quality of ground water. The Bureau, through several regional offices, tests water samples for bacterial contamination, and can also advise on effective corrective measures when contamination is reported. The Bureau also has information on streamflow, floods, reservoir requirements, and powerplant discharges.
- The **Bureau of Mining and Reclamation, Ebensburg District Office, PaDCNR,** has jurisdiction over mining in Indiana County, including mine permitting and inspection. The Bureau can also provide information on mining-related effects on ground water and water supplies.
- The **Public Utility Commission, Bureau of Rates and Research,** has information on some municipal water supplies, including source, average daily use, total annual use, and estimated future needs.
- The **U.S. Geological Survey,** Lemoyne, Pa., has data on wells, springs, and streams, and on the chemical quality of ground water and surface water.
- **Local well drillers and pump installers** can usually provide prices and suggest the type of equipment needed to develop a water supply. They also can suggest the proper well diameter for the necessary pumping equipment. Pump installers can supply information concerning the size of the pump, depth of the pump setting, and pressure-tank capacity.
- **Commercial water-treatment companies** can provide the necessary information and equipment if chemical analysis of the well water indicates that treatment is necessary. Equipment for water treatment can be purchased or rented; generally, the supplier will also service the equipment.

GLOSSARY

Acidity—The capacity of a water for neutralizing a basic solution. Acidity, as used in this report, is primarily caused by the presence of hydrogen ions produced by hydrolysis of the salts of strong acids and weak bases.

Alkalinity—The capacity of a water for neutralizing an acidic solution. Alkalinity in natural water is caused primarily by the presence of carbonate and bicarbonate.

Alluvium—Sand, gravel, or other similar particulate material deposited by running water.

Anisotropic—Not having the same properties in all directions.

Anticline—An upfold or arch of stratified rock in which the beds dip in opposite directions from the crest.

Aquifer—A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield usable quantities of water to wells and springs.

Aquifer test—A test or controlled field experiment involving either the withdrawal of measured quantities of water from, or addition of water to, a well (or wells) and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition.

Base flow—Discharge entering stream channels as effluent from the ground-water reservoir; the dry-weather flow of streams.

Bedrock—A general term for the rock, generally solid, that underlies soil or other unconsolidated or semiconsolidated surficial material.

Confined aquifer—An aquifer that is bounded above and below by rocks of significantly lower permeability than that of the aquifer itself.

Cubic foot per second (ft^3/s)—The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second (equivalent to 7.48 gallons per second or 448.8 gallons per minute).

Cubic feet per second per square mile [$(ft^3/s)/mi^2$]—The average number of cubic feet of water per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly, in time and area.

Dip—The angle or rate of drop at which a layer of rock is inclined from the horizontal.

Dissolved—Refers to that material in a representative water sample that passes through a 0.45-micrometer membrane filter. This is an operational definition used by Federal agencies that collect water data. Determinations of "dissolved" constituents are made on subsamples of the filtrate.

Dissolved solids—The dissolved mineral constituents in water; they form the residue after evaporation and drying at a temperature of 180 degrees Celsius; they also can be calculated by adding concentrations of anions and cations.

Drawdown—The lowering of the water table or potentiometric surface caused by pumping (or artesian flow) of a well.

Evapotranspiration—A collective term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration.

Flow-duration curve—A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Fold—A bend or flexure produced in rock strata by forces operating after deposition of the rock.

Formation—The fundamental unit in rock-stratigraphic classification. It is a body of internal homogeneous rock; it is prevailingly but not necessarily tabular and is mappable at the Earth's surface or traceable in the subsurface.

Fracture—A break in the rock.

Ground water—That part of the subsurface water in the zone of saturation.

Ground-water discharge—Release of water in springs, seeps, or wells from the ground-water reservoir.

Ground-water recharge—Addition of water to the ground-water reservoir by infiltrating precipitation or seepage from a streambed.

Group—A stratigraphic unit consisting of two or more formations.

Hardness—A physical-chemical characteristic that commonly is recognized by the increased quantity of soap required to produce lather. It is attributable to the presence of alkaline earths (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$).

Head (static)—The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. In this report, head is synonymous to water level.

Lineament—A natural linear feature greater than 1 mile in length.

Joint—A fracture in a rock, generally more or less vertical, along which no differential movement has taken place.

Lingula—A brachiopod (marine invertebrate) dating from the Cambrian and persisting practically without change to the present.

Lithology—The physical characteristics of a rock, generally as determined by examination with the naked eye or with the aid of low-power magnifier.

Mean—Arithmetic average calculated by dividing the sum of a set of numerical values by the number of values.

Median—The value midway in the frequency distribution. Half the values are lower than the median, and half are higher.

Micrograms per liter (µg/L)—A unit expressing the concentration of chemical constituents in solution as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter.

Milligrams per liter (mg/L)—A unit for expressing the concentration of chemical constituents in solution. Milligrams per liter represent the mass of solute per unit volume (liter) of water.

Ostracode—A small crustacean.

pH—A measure of the acidity or alkalinity of water. Mathematically, the pH is the negative logarithm of the hydrogen ion activity, pH = -log10[H^+], where [H^+] is the hydrogen-ion concentration in moles per liter. A pH of 7.0 indicates a neutral condition. An acid solution has a pH less then 7.0, and a basic or alkaline solution has a pH greater than 7.0.

Permeability—The capacity of a porous rock, sediment, or soil to transmit a fluid under a hydraulic head; it is a measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Potentiometric surface—A surface that represents the static head of an aquifer.

Primary permeability—The permeability of a material caused by its soil or rock matrix.

Runoff—That part of the precipitation that appears in streams. It is the same as streamflow unaffected by diversions, storage, or other artificial influences in or on the stream channels.

Secondary permeability—The increase or decrease in permeability in the soil or rock caused by fracturing, solution, or cementation.

Specific capacity—The well yield divided by the drawdown (pumping water level minus static water level) necessary to produce this yield. It is usually expressed as gallons per minute per foot [(gal/min)/ft].

Specific conductance—A measure of the ability of a water to conduct an electrical current. It is expressed in microsiemens per centimeter at 25°Celsius. Specific conductance is related to the type and concentration of ions in the solution and can be used for approximating the dissolved-solids concentration of the water. Commonly, the concentration of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance (in microsiemens). This relation is not constant from stream to stream, and it may vary in the same source with changes in the composition of the water.

Spirorbis—The fossilized shell of a small coiled worm.

Streamflow—The discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff," because streamflow can be applied to discharge whether or not it is affected by diversion or regulation.

Syncline—A downfold or depression of stratified rock in which the beds dip inward toward the axis of the fold.

Transmissivity—Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It can be expressed in cubic feet per day per foot, or feet squared per day (ft^2/d).

Unconfined aquifer—An aquifer that contains the water table.

Water table—The upper surface of the zone of saturation.

Water year—October 1 through September 30 of the designated year. For example, water year 1989 begins October 1, 1988, and ends September 30, 1989.

APPENDIX

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania

[mg/L, milligram per liter; µg/L, microgram per liter; <, less than. For some data sets, medians and standard deviations could not be computed because too many values were less than the detection limit; general information is substituted for those data sets in place of medians and standard deviations]

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Casselman Formation, all wells					
Acidity (mg/L)	12 = zero		0	6	13
Alkalinity (mg/L)	142	67	42	246	13
Aluminum (µg/L)	12<detection limit		<135	205	13
Arsenic (µg/L)	12<detection limit		<4	6	13
Barium (µg/L)	12<detection limit		<1	28	13
Calcium (mg/L)	35.0	19.0	4.06	73.1	13
Chloride (mg/L)	9	22	1	78	13
Fluoride (mg/L)	5<detection limit		<.1	.5	13
Hardness (mg/L)	122	72	28	258	13
Iron (µg/L)	180	1,246	43	5,150	44
pH	7.2	--	6.1	8.2	44
Magnesium (mg/L)	9.20	5.80	3.03	20.5	44
Manganese (µg/L)	50	153	<10	830	43
Sodium (mg/L)	5.54	17.62	.396	83.8	44
Nickel (µg/L)	12<detection limit		<25	49	13
Nitrate (mg/L)	.58	1.21	<.04	3.74	13
Potassium (mg/L)	1.16	.60	.31	2.33	13
Selenium (µg/L)	All<detection limit				13
Silica (mg/L)	12.1	4.3	3.8	20.2	13
Strontium (µg/L)	465	255	<100	2,190	48
Sulfate (mg/L)	28	30	<10	127	13
Dissolved solids (mg/L)	212	89	68	378	11
Zinc (µg/L)	10	2,286	<10	8,320	13
Copper (µg/L)	7<detection limit		<10	228	13
Chromium (µg/L)	All<detection limit				13
Cadmium (µg/L)	7<detection limit		<.20	108.5	13
Cobalt (µg/L)	All<detection limit				13
Lead (µg/L)	5<detection limit		<4.0	19.7	13

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Glenshaw Formation, all wells					
Acidity (mg/L)	0	--	0	30	202
Alkalinity (mg/L)	97	56	0	258	202
Aluminum (µg/L)	170<detection limit		85	2,650	201
Arsenic (µg/L)	198<detection limit		<4	29	202
Barium (µg/L)	189<detection limit		1	1,970	213
Calcium (mg/L)	30.4	35.0	1.71	341	202
Chloride (mg/L)	7	35	1	343	199
Fluoride (mg/L)	.2	.1	.04	1.4	202
Hardness (mg/L)	103	128	15	1,288	202
Iron (µg/L)	270	12,656	41	172,000	201
pH	7.0	--	4.2	9.5	202
Magnesium (mg/L)	7.32	9.39	<.01	105	202
Manganese (µg/L)	100	700	<10	8,200	201
Sodium (mg/L)	4.83	19.66	.349	150	213
Nickel (µg/L)	77<detection limit		<25	384	213
Nitrate (mg/L)	.06	1.00	<.04	9.02	201
Potassium (mg/L)	1.08	.72	.07	4.88	213
Selenium (µg/L)	All<detection limit				213
Silica (mg/L)	11.2	3.9	2.2	38.1	212
Strontium (µg/L)	240	470	<100	4,400	213
Sulfate (mg/L)	19	125	<10	1,367	214
Dissolved solids (mg/L)	180	229	16	2,260	184
Zinc (µg/L)	22	354	<10	4,130	214
Copper (µg/L)	95<detection limit		<10	6,480	214
Chromium (µg/L)	207<detection limit				214
Cadmium (µg/L)	143<detection limit		.02	5.8	214
Cobalt (µg/L)	195<detection limit		<25	71	214
Lead (µg/L)	142<detection limit		<4	137	214

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
		Allegheny Group, all wells			
Acidity (mg/L)	0	--	0	26	54
Alkalinity (mg/L)	108	66	2	338	54
Aluminum (µg/L)	36<detection limit		122	1,140	54
Arsenic (µg/L)	53<detection limit				54
Barium (µg/L)	56<detection limit				62
Calcium (mg/L)	38.95	51.44	3.42	306.	54
Chloride (mg/L)	9.	20	1	85	54
Fluoride (mg/L)	.1	.1	<1	.6	54
Hardness (mg/L)	143.	206	23	1,250	54
Iron (µg/L)	670	5,276	<100	32,400	54
pH	7.0	4.8	8.2	54	
Magnesium (mg/L)	9.77	12.94	1.64	80.6	54
Manganese (µg/L)	170	823	<50	4,000	54
Sodium (mg/L)	2.26	11.7	.376	54.5	62
Nickel (µg/L)	46<detection limit		<25.	73	63
Nitrate (mg/L)	.05	.58	<.04	2.42	54
Potassium (mg/L)	1.41	1.10	.72	7.80	62
Selenium (µg/L)	All<detection limit				62
Silica (mg/L)	8.4	2.2	4.5	18.0	63
Strontium (µg/L)	220	470	61	2,360	62
Sulfate (mg/L)	29	190	<10	1,176	64
Dissolved solids (mg/L)	232	454	48	2,488	33
Zinc (µg/L)	38.0	487	<10	2,830	62
Copper (µg/L)	55<detection limit		<10	5,170	62
Chromium (µg/L)	60<detection limit		<4.	50	62
Cadmium (µg/L)	34<detection limit		<.2	4.55	62
Cobalt (µg/L)	56<detection limit		<25	41	63
Lead (µg/L)	39<detection limit		<4	25.1	63

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Glenshaw Formation, hillside wells					
Acidity (mg/L)	0	--	0	22	77
Alkalinity (mg/L)	112	57	4	250	77
Aluminum (μg/L)	65<detection limit		85	2,650	77
Arsenic (μg/L)	75<detection limit				77
Barium (μg/L)	72<detection limit		<1	960	81
Calcium (mg/L)	31.90	37.37	1.71	326.	77
Chloride (mg/L)	6	17	1	109	76
Fluoride (mg/L)	.2	.2	<.04	1.4	77
Hardness (mg/L)	104	136	16	1,200	77
Iron (μg/L)	170	3,860	43	31,800	76
pH	7.1	--	5.7	9.5	77
Magnesium (mg/L)	7.66	11.88	<.05	105	77
Manganese (μg/L)	55	943	<10	8,200	76
Sodium (mg/L)	4.90	20.40	.396	137	81
Nickel (μg/L)	59<detection limit		<25.	250	81
Nitrate (mg/L)	.10	.86	<.04	6.16	76
Potassium (mg/L)	1.15	.726	.26	4.07	81
Selenium (μg/L)	All<detection limit				81
Silica (mg/L)	11.0	4.0	2.2	27.8	80
Strontium (μg/L)	310	477	<100	2,350	80
Sulfate (mg/L)	20	157	<10	1,367	81
Dissolved solids (mg/L)	176	270	44	2,260	69
Zinc (μg/L)	21	303	<10	2,610	81
Copper (μg/L)	47<detection limit		<10	439	81
Chromium (μg/L)	76<detection limit		<4.	21	81
Cadmium (μg/L)	57<detection limit		<.10	2.00	81
Cobalt (μg/L)	71<detection limit		<25	71	81
Lead (μg/L)	58<detection limit		<4	137	81

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Allegheny Group, hillside wells					
Acidity (mg/L)	0	--	0	26	27
Alkalinity (mg/L)	108	74	2	338	27
Aluminum (µg/L)	18<detection limit		122	1,140	27
Arsenic (µg/L)	All<detection limit				27
Barium (µg/L)	27<detection limit		<1.	600	29
Calcium (mg/L)	43.2	65.9	3.42	306.	27
Chloride (mg/L)	8	17	1	85	27
Fluoride (mg/L)	.1	.1	<.1	.6	27
Hardness (mg/L)	143	278	23	1,250	27
Iron (µg/L)	790	6,985	<100	32,400	27
pH	7.0	--	4.8	8.2	27
Magnesium (mg/L)	9.16	17.39	1.64	80.60	27
Manganese (µg/L)	280	950	<50	4,000	27
Sodium (mg/L)	1.16	12.17	.51	49.8	29
Nickel (µg/L)	18<detection limit		<25.	73	28
Nitrate (mg/L)	14<detection limit		<.04	2.00	27
Potassium (mg/L)	1.42	1.05	.72	6.00	29
Selenium (µg/L)	All<detection limit				29
Silica (mg/L)	8.0	2.5	5.7	18.0	29
Strontium (µg/L)	180	404	<100	1,860	29
Sulfate (mg/L)	30	267	<10	1,176	30
Dissolved solids (mg/L)	232	582	48	2,488	19
Zinc (µg/L)	47	697	<10	2,830	29
Copper (µg/L)	11<detection limits		<10	222	29
Chromium (µg/L)	All<detection limit				29
Cadmium (µg/L)	24<detection limits		<.2	4.55	29
Cobalt (µg/L)	24<detection limits		<25	41	29
Lead (µg/L)	19<detection limits		<4	25.1	29

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Glenshaw Formation, valley wells					
Acidity (mg/L)	All zero				29
Alkalinity (mg/L)	134	45	56	258	29
Aluminum (µg/L)	25<detection limit		<135	396	29
Arsenic (µg/L)	28<detection limit				29
Barium (µg/L)	25<detection limit		<1	1,970	30
Calcium (mg/L)	33.5	58.0	22.7	341	29
Chloride (mg/L)	9	26	2	97	29
Fluoride (mg/L)	.2	.1	.1	.3	29
Hardness (mg/L)	115.	220	73	1,288	29
Iron (µg/L)	750	6,470	<100	35,100	29
pH	6.9	--	6.3	8.0	29
Magnesium (mg/L)	8.67	12.05	4.20	68.7	29
Manganese (µg/L)	130	345	<50	1,500	29
Sodium (mg/L)	12.55	17.59	1.95	68.5	30
Nickel (µg/L)	21<detection limit		<25.	384	30
Nitrate (mg/L)	16<detection limit		<.04	1.74	29
Potassium (mg/L)	1.24	.85	.44	4.88	30
Selenium (µg/L)	All<detection limit				30
Silica (mg/L)	10.5	3.6	7.3	21.9	30
Strontium (µg/L)	470	746	130	4,400	30
Sulfate (mg/L)	22	205	<10	1,139	30
Dissolved solids (mg/L)	212	331	150	1,940	28
Zinc (µg/L)	27	749	<10	4,130	30
Copper (µg/L)	18<detection limit		<10	401	30
Chromium (µg/L)	29<detection limit		<4.	51	30
Cadmium (µg/L)	18<detection limit		<.2	5.8	30
Cobalt (µg/L)	29<detection limit		<25	50	30
Lead (µg/L)	16<detection limit		<4	136	30

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Allegheny Group, valley wells					
Acidity (mg/L)	0	--	0	4	15
Alkalinity (mg/L)	100	54	10	208	15
Aluminum (µg/L	9<detection limit		<135	304	15
Arsenic (µg/L)	All<detection limit				15
Barium (µg/L)	17<detection limit		<1.	<500	19
Calcium (mg/L)	40.3	30.5	6.42	117.	15
Chloride (mg/L)	12	21	3	70	15
Fluoride (mg/L)	.1	.1	<.1	.3	15
Hardness (mg/L)	157	69	38	301	15
Iron (µg/L)	1,390	2,640	140	8,900	15
pH	6.9	--	6.0	8.2	15
Magnesium (mg/L)	12.5	5.7	3.44	23.0	15
Manganese (µg/L)	230	856	<50	3,500	15
Sodium (mg/L)	6.12	13.18	.68	54.5	19
Nickel (µg/L)	16<detection limit		<25.	67	19
Nitrate (mg/L)	11<detection limit		<.04	1.64	15
Potassium (mg/L)	1.41	1.49	.85	7.80	19
Selenium (µg/L)	All<detection limit				19
Silica (mg/L)	8.7	1.3	6.9	11.7	19
Strontium (µg/L)	260	581	<100	2,360	19
Sulfate (mg/L)	28	51	<10	176	19
Dissolved solids (mg/L)	289	101	150	400	6
Zinc (µg/L)	58	181	<10	659	19
Copper (µg/L)	9<detection limit		<10	482	19
Chromium (µg/L)	18<detection limit		34	<50	19
Cadmium (µg/L)	16<detection limit		<.2	1.32	19
Cobalt (µg/L)	18<detection limit		<25.	30	19
Lead (µg/L)	10<detection limit		<4	16.1	19

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Glenshaw Formation, hilltop wells					
Acidity (mg/L)	0	--	0	30	74
Alkalinity (mg/L)	76	50	0	222	74
Aluminum (µg/L)	61<detection limit		<135	606	73
Arsenic (µg/L)	All<detection limit				74
Barium (µg/L)	68<detection limit		<1	900	78
Calcium (mg/L)	25.5	19.0	1.8	92.7	74
Chloride (mg/L)	8.	51	1	343	72
Fluoride (mg/L)	.2	.1	<.1	.4	74
Hardness (mg/L)	87	60	18	296	74
Iron (µg/L)	330	19,820	44	172,000	74
pH	7.0	--	4.2	8.1	75
Magnesium (mg/L)	6.29	4.95	1.89	28.4	75
Manganese (µg/L)	100	410	<10	2,030	75
Sodium (mg/L)	3.84	21.0	.349	150	79
Nickel (µg/L)	64<detection limit		22	126	79
Nitrate (mg/L)	.06	1.52	<.04	9.02	75
Potassium (mg/L)	.90	.62	.13	3.47	79
Selenium (µg/L)	All<detection limit				79
Silica (mg/L)	11.5	4.1	5.3	28.1	78
Strontium (µg/L)	30<detection limit		<100	2,080	79
Sulfate (mg/L)	16	13	<10	104	79
Dissolved solids (mg/L)	172	133	50	812	69
Zinc (µg/L)	22	167	<10	1,390	79
Copper (µg/L)	30<detection limit		<10	1,050	79
Chromium (µg/L)	78<detection limit				79
Cadmium (µg/L)	49<detection limit		<.2	5.6	79
Cobalt (µg/L)	75<detection limit		<20	47	79
Lead (µg/L)	50<detection limit		<4	37.6	79

Appendix. Means, standard deviations, range, and number of wells sampled for Mann-Whitney U-tests on ground-water-quality data, Indiana County, Pennsylvania—Continued

Property or constituent	Median	Standard deviation	Range		Number of samples
			Minimum	Maximum	
Glenshaw Formation, flat-topography wells					
Acidity (mg/L)	0	--	0	16	22
Alkalinity (mg/L)	81	53	8	168	22
Aluminum (µg/L)	21<detection limit				22
Arsenic (µg/L)	All<detection limit				22
Barium (µg/L)	All<detection limit				24
Calcium (mg/L)	27.6	23.6	2.46	95.4	22
Chloride (mg/L)	7	9	2	38	22
Fluoride (mg/L)	.1	.1	<.1	2.8	22
Hardness (mg/L)	93	81	15	338	22
Iron (µg/L)	350	4,410	<100	18,600	22
pH	7.2	--	5.5	8.1	22
Magnesium (mg/L)	7.19	5.65	1.45	22.4	22
Manganese (µg/L)	240	821	<50	3,400	22
Sodium (mg/L)	2.38	5.40	.36	22.8	24
Nickel (µg/L)	16<detection limit		<25	147	24
Nitrate (mg/L)	11<detection limit		0	.16	22
Potassium (mg/L)	.87	.68	.07	3.35	24
Selenium (µg/L)	All<detection limit				24
Silica (mg/L)	11.8	3.4	5.3	18.0	24
Strontium (µg/L)	10<detection limit		<100	1,470	24
Sulfate (mg/L)	20	44	<10	210	24
Dissolved solids (mg/L)	182	125	16	496	18
Zinc (µg/L)	20	144	<10	614	24
Copper (µg/L)	13<detection limit		<10	6,480	24
Chromium (µg/L)	All<detection limit				24
Cadmium (µg/L)	17<detection limit		<.02	1.09	24
Cobalt (µg/L)	21<detection limit		<25	53	24
Lead (µg/L)	18<detection limit		<4	30.3	24