# Effects of Underground Mining and Mine Collapse on the Hydrology of Selected Basins in West Virginia

United States Geological Survey Water-Supply Paper 2384

Prepared in cooperation with the West Virginia Geological and Economic Survey

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

## METRIC CONVERSION FACTORS AND VERTICAL DATUM

| *Multiply* | *By* | *To obtain* |
|---|---|---|
| | *Length* | |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | *Area* | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| acre | 0.4047 | hectare (ha) |
| | *Volume* | |
| gallon (gal) | 3.785 | liter (L) |
| | $3.785 \times 10^{-3}$ | cubic meter ($m^3$) |
| million gallons ($10^6$ gal) | 3,785 | cubic meters ($m^3$) |
| | $3.785 \times 10^{-3}$ | cubic hectometers ($hm^3$) |
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| | *Flow* | |
| cubic foot per second ($ft^3/s$) | 28.32 | liter per second (L/s) |
| | 0.02832 | cubic meters per second ($m^3/s$) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| | $6.309 \times 10^{-5}$ | cubic meters per second ($m^3/s$) |
| million gallons per day (Mgal/d) | .04381 | cubic meters per second ($m^3/s$) |

*Sea level*: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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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By W.A. HOBBA, Jr.

Prepared in cooperation with the West Virginia
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U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2384

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BRUCE BABBITT, Secretary

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# CONTENTS

## GLOSSARY

The hydrologic and mining terms pertinent to this report are defined as follows:

**Anticline**—an upward fold in the rocks.

**Aquifer**—rock formation that contains sufficient saturated permeable material to yield significant amounts of water to wells or springs.

**Aquifer, confined (or artesian)**—the water level in a well tapping a confined aquifer will rise above the top of the aquifer because of hydrostatic pressure.

**Aquifer, unconfined**—the water level in a well tapping an unconfined aquifer will not rise above the water table.

**Base flow**—a stream is at base flow when all of its flow is derived from ground-water inflow.

**Bedding plane**—any plane in sedimentary rock, along which sediment was deposited simultaneously.

**Coefficient of storage**—the volume of water an aquifer releases, or takes into storage, per unit surface area of the aquifer, per unit change in head.

**Depression, cone of**—the depression in the water table or other potentiometric surface caused by the withdrawal of water from a well.

**Dip of rock strata**—the angle between the horizontal and the bedding plane; dip is measured in a vertical plane at right angles to the strike of the bedding. (See strike of rock strata.)

**Drawdown in a well**—the vertical drop in water level caused by pumping.

**Drift mine**—a horizontal or nearly horizontal mine passage underground that follows a mineral deposit (such as a coal bed) and is entered from the surface.

**Evapotranspiration**—evaporation from water surfaces, plus transpiration from plants.

**Fault**—a fracture in the Earth's crust accompanied by displacement of one side of the fracture with respect to the other.

**Fracture**—a break in rock that may be caused by compressional or tensional forces.

**Gaining stream**—a stream, or segment of a stream, that receives water from an aquifer. (See losing stream.)

**Gob or spoil**—the refuse or waste rock material displaced by mining.

**Gradient, hydraulic**—the change of head per unit distance from one point to another in an aquifer.

**Ground water**—water contained in the zone of saturation in the rock. (See surface water.)

**Head**—the height above a datum plane of a column of water.

**High wall**—the exposed vertical or near-vertical rock wall associated with a strip mine or surface mine.

**Hydraulic conductivity**—a medium has a hydraulic conductivity of unit length per unit time, if it will transmit in unit time a unit volume of water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through unit length of flow.

**Imagery, satellite or thermal**—photographiclike images prepared by use of special electronic transmitters, sensors, and computers.

**Joints**—system of fractures in rocks along which there has been no movement parallel to the fracture surface. In coal, joints and fractures may be termed "cleats."

**Lineaments**—linear features on aerial photographs or imagery formed by the alignment of stream channels or tonal features in soil, vegetation, or topography.

**Losing stream**—a stream, or segment of a stream, that is contributing water to an underlying aquifer. (See gaining stream.)

**Microsiemens**—the unit used in reporting specific conductance of water per centimeter at 25 °C.

**Overburden**—rock and soil overlying a minable coal bed.

**Perched water table**—a saturated zone of rock separated from an underlying unconfined aquifer by unsaturated zone. Perched water tables sometimes are associated with a zone of relatively low hydraulic conductivity inside the unsaturated zone overlying an unconfined aquifer.

**Permeability, intrinsic**—a measure of the relative ease with which a porous medium can transmit a liquid under a hydraulic gradient.

**pH**—the negative logarithm of the hydrogen-ion concentration in the water.

**Porosity, primary**—interstices that were created at the time the rocks were formed.

**Potentiometric surface**—an imaginary surface that everywhere coincides with the static level of water in an aquifer.

**Precipitation, atmospheric**—water in the form of hail, mist, rain, sleet, or snow that falls to the Earth's surface.

**Recovery of pumped well**—when pumping from a well ceases, the water level rises (or recovers) toward the level existing (static level) before pumping.

**Seepage measurements**—flow measurements made at various points along a stream to determine if the stream is losing or gaining water.

**Slug test**—a well-testing method whereby a known volume or "slug" of water is suddenly injected into or removed from a well, and the decline or recovery of the water level is repeatedly measured at closely spaced intervals to determine hydraulic characteristics of the rocks penetrated by the well.

**Specific capacity**—the rate of discharge of a well, divided by the drawdown of the water level in the well.

**Specific conductance**—the measured electrical conductance of a unit length and cross section of water, reported in microsiemens (μS/cm) per centimeter at 25 °C. Often referred to as "conductivity."

**Storage coefficient**—the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer, per unit change in head.

**Strike of rock strata**—the direction of a line formed by the intersection of the bedding and a horizontal plane. (See dip of rock strata.)

**Strip mining**—removal of mineral from beneath the Earth's surface by excavation of surface soil and rock, generally in a "strip" parallel to the mineral outcrop.

**Subsidence**—a sinking of part of the Earth's surface, such as may result from soil compaction, collapse of underground mines, or removal of ground water, oil, or gas.

**Subsidence crack**—a crack or joint in the rock formed or widened as a result of subsidence.

**Surface water**—water on the surface of the Earth, including snow and ice. (See ground water.)

**Syncline**—a downward fold in the rocks.

**Table, water**—that surface in an unconfined water body at which pressure is atmospheric; generally the top of the saturated zone.

**Transmissivity**—the rate at which water of a prevailing viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

**Underground mining**—removal of mineral from beneath the Earth's surface, with little removal of surface rocks.

**Water year**—a 1-year period from October 1 through September 30 of next calendar year.

# EFFECTS OF UNDERGROUND MINING AND MINE COLLAPSE ON THE HYDROLOGY OF SELECTED BASINS IN WEST VIRGINIA

By W.A. Hobba, Jr.

## ABSTRACT

The effects of underground mining and mine collapse on areal hydrology were determined at one site where the mined bed of coal lies above major streams and at two sites where the bed of coal lies below major streams. Subsidence cracks observed at land surface generally run parallel to predominant joint sets in the rocks. The mining and subsidence cracks increase hydraulic conductivity and interconnection of water-bearing rock units, which in turn cause increased infiltration of precipitation and surface water, decreased evapotranspiration, and higher base flows in some small streams. Water levels in observation wells in mined areas fluctuate as much as 100 ft annually. Both gaining and losing streams are found in mined areas. Mine pumpage and drainage can cause diversion of water underground from one basin to another. Areal and single-well aquifer tests indicated that near-surface rocks have higher transmissivity in a mine-subsided basin than in unmined basins. Increased infiltration and circulation through shallow subsurface rocks increase dissolved mineral loads in streams, as do treated and untreated contributions from mine pumpage and drainage. Abandoned and flooded underground mines make good reservoirs because of their increased transmissivity and storage. Subsidence cracks were not detectable by thermal imagery, but springs and seeps were detectable.

## ACKNOWLEDGMENTS

This investigation was done with the cooperation of many landowners, mining companies, and officials of local, State, and Federal agencies. Engineers of Eastern Associated, Bethlehem, and Consolidation Coal Companies were helpful in providing data on water pumpage from their mines.

The following provided well data, water data, or helpful discussions: Wade Ferguson, U.S. Soil Conservation Service; Frank Fonner, West Virginia Geological and Economic Survey; Kirk McCabe and John Jansky, U.S. Department of Labor (MSHA); Henry Rauch, West Virginia University; H.G. Custer, Farmington Water Department; J. Payone, U.S. Bureau of Mines; and F. Wolle, U.S. Environmental Protection Agency. Special thanks are given the land owners who permitted access to observe and measure wells, streams, and subsidence features.

# Effects of Underground Mining and Mine Collapse on Water

Underground coal mining generally affects the land surface, ground water, and surface water. The purpose of this study was to investigate the effects on water.

Underground mining alters the Earth's crust, and many parts of West Virginia have been undermined. As mining continues to completion, mine roofs may fall, clay floors may heave, and coal pillars may collapse or push into the soft clay floors. In some areas, mining and subsidence have lowered ground-water levels, causing some wells and streams to go dry, changes in water quality, and structural damage to buildings, roads, pipelines, and reservoirs. In other places, abandoned water-filled mines act as ground-water reservoirs, providing water to wells for public supply.

Because of the increasing importance of coal as a source of energy, it is likely that much of the coal in West Virginia will be mined. The main purpose of this study was to investigate the effects of deep mining and subsequent mine collapse on ground water and surface water. For this study, two types of areas were chosen: one where the main bed of mined coal lies above the major streams, the other where the main bed of mined coal lies below the major streams. The overall effect of coal mining on the hydrologic budget was determined by measuring streamflow, mine pumpage, ground-water levels, and precipitation, and by mapping mine-collapse features.

The map in figure 1.1A shows the three basins included in this study. The mined coal bed lies below major streams in the Buffalo and Indian Creek basins, and above major streams in the Roaring Creek–Grassy Run basins near Norton, W. Va. Work was concentrated in Buffalo Creek basin because of the measurable and visible subsidence near Farmington, W. Va. Minimal work was done in Indian Creek basin because little or no subsidence or effect on ground-water levels was observed or reported. Also, minimal work was done in Roaring Creek–Grassy Run basins because data had already been collected, largely by J.T. Gallaher (written commun.), and by Industrial Environmental Research Laboratory (1977). An attempt is made in this report to describe the hydrologic effects where mining is deep and below the level of major streams, and compare these effects to those where mining is shallow and above the level of major streams.

The geology is relatively simple; however, the hydrology becomes quite complex once mining starts. In order to understand the complexity of the system after mining, it is necessary to understand the system before mining, the basic principles of ground-water and surface-water hydrology, and some methods of mining.

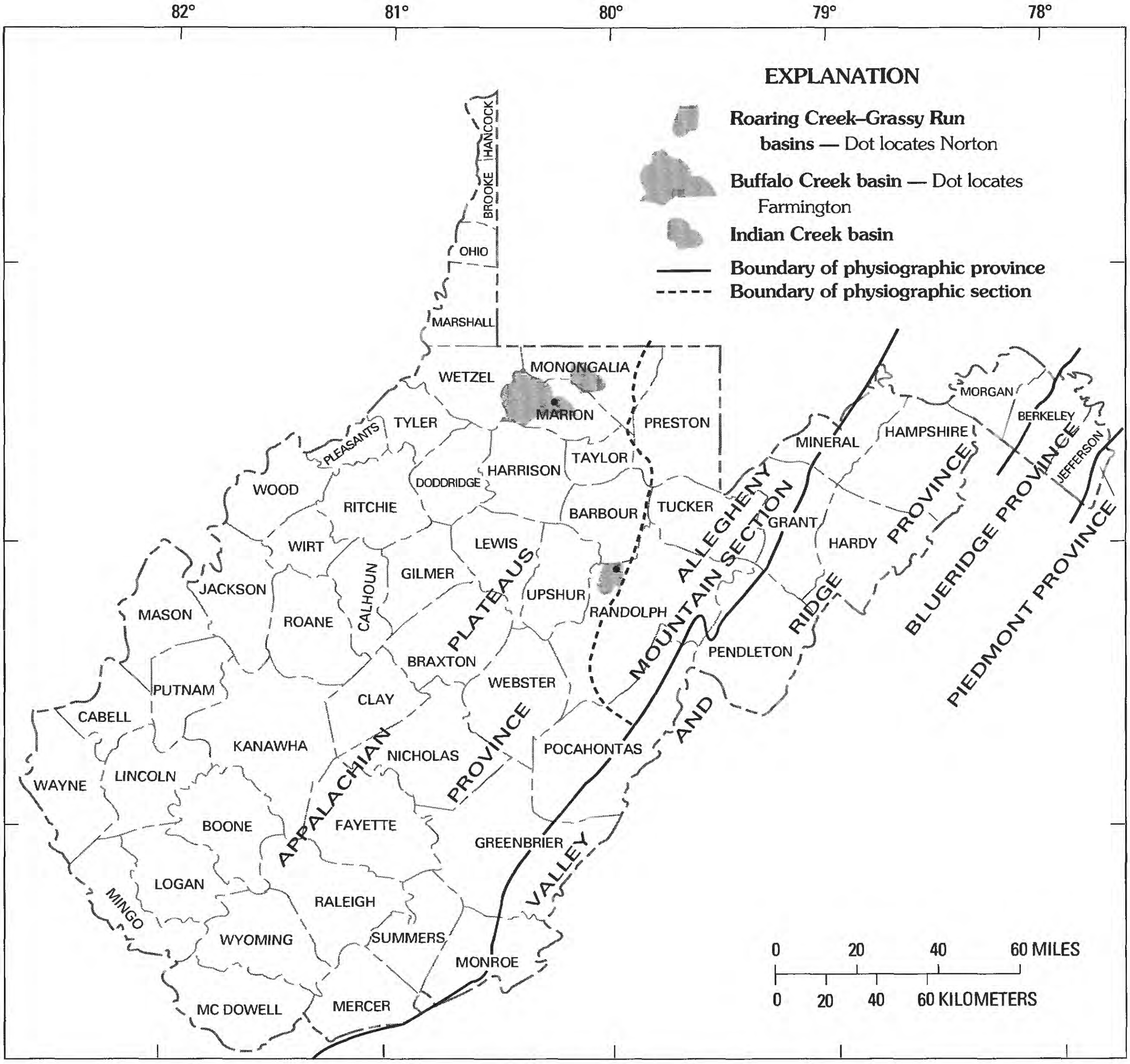



**Figure 1.1A.** Map showing basins included in this study and the physiographic provinces of West Virginia.

# Subsidence Features Range From Small, Subtle Cracks or Depressions to Gaping Cracks Large Enough to Envelop Horses or Cows

Most surface disruption occurs where the mine lies 150 ft or less below land surface.

Disruption of the land surface is most common above shallow underground mines with incompetent overburden. The two primary areas studied for this report show that most subsidence occurs where the overburden is less than 150 ft thick in the Norton, W.Va., area, but subsidence reaches land surface even where the overburden is 600–700 ft thick in the Farmington, W.Va., area. (Figs. 1.3C and D in the following section contain lithologic descriptions of the overburden.)

Subsidence features at the surface range from small cracks and depressions that are subtle and difficult to recognize, to large gaping cracks. Figures 1.2A through 1.2C show subsidence features in the vicinity of Farmington. Figures 1.2D and E show some effects of subsidence on hydrology in the Farmington area.

**Figure 1.2A.** Small subsidence crack on hilltop 600 ft above mine. Photograph was taken looking west on a hilltop about 1,000 ft north of the Farmington, W. Va., cemetery. This subtle subsidence crack is the slight linear depression marked by the black line. Woodchucks commonly build dens (center of picture) in subsidence cracks, probably because of easy digging.

**Figure 1.2B.** Three large subsidence cracks viewed from an airplane are on a hill about 450 ft above the mine. This site is at the northwest end of the Farmington, W. Va., cemetery. Snow is melted in places along the cracks.

**Figure 1.2C.** Ground view of the middle crack shown in figure 1.2B. Soil moving into cracks in underlying rocks has exposed a 6-in. gas line. The mine is about 450 ft below land surface.

**Figure 1.2D.** Spring that has been dried up by nearby mine subsidence cracks. Spring discharge pipe is in lower left corner.

**Figure 1.2E.** Water flowing at a rate of about 1 gal/min into a hole along a subsidence crack near the dry spring in figure 1.2D. Such holes are generally enlarged with time as the surrounding soil is flushed into them during heavy overland runoff. Note second hole at bottom center along the same subsidence crack.

# Most Water in Basins Is Derived From Precipitation; That Part Becoming Ground Water Moves Through Pores and Cracks in Rocks

Precipitation supplies most of the water to the basins investigated, but some interbasin transfer of water occurs underground. After water enters the rocks, it is essentially stored because it moves very slowly through pores and cracks in response to head differences and rock permeability.

The source of nearly all water in West Virginia is precipitation (fig. 1.3A). In places, some water is derived from underflow from adjacent basins. A minor amount of water may be released from the rocks where it was trapped as seawater when the sediments were deposited millions of years ago, but this water supply is probably insignificant in comparison to that derived from precipitation.

Ground water and surface water are intimately related. During dry periods, the ground-water contribution may be the total discharge of the stream, whereas during wet periods, the ground-water contribution may be insignificant. However, in places where the water table has been lowered, the reverse is true: that is, water leaks from the streams into the ground, particularly in some undermined areas. The geologic framework is a major factor governing the interrelationship between ground water and surface water, and how water occurs and moves through the rocks must be considered.

Water is contained in, and moves through, pores and cracks in the rocks in response to head differences and rock permeability. Because gravity is the dominant driving force in ground-water movement, water flows from places of higher head to lower head. Under natural conditions, ground water flows generally from topographically high places to low places. Nearly all water that enters the ground eventually comes back out; otherwise, in time, ground-water levels would rise to the land surface. When water levels in wells fluctuate around the same average level year after year, it simply means that annual discharge approximately equals annual recharge.

As most consolidated rocks in the study areas have little primary porosity, ground water moves along joints, faults, fractures, and caverns (fig. 1.3B). Some of these features are small and poorly connected, so that water movement is slow: for example, rates of movement through a shale or clay bed of low permeability may be only inches per year, whereas rates of movement through a cavernous limestone may be miles per day.

As ground water moves, it may become trapped or confined beneath a clay or shale layer. When such an aquifer is tapped by a well, the water level will rise above the top of that aquifer. If the pressure is great enough, water may flow out of the well. Water discharging from such an aquifer may be old and mineralized because it may have moved long distances underground from the recharge area. A well on a hilltop would get younger water because hills are normally recharge areas, whereas valleys are discharge areas. Because of this ground-water circulation pattern (flow from high head to low head), the water level in a deep well on a hill is generally lower than the water level in a shallow well. Conversely, the water level in a deep well in a valley is generally higher than the water level in a shallow well.

Most of the work for this study was done in mined areas near Norton and Farmington, W. Va. Thus, figures 1.3C and D are presented (pages 8–9) to familiarize the reader with the geologic and hydrologic framework of these areas and to aid in understanding other sections of this report.

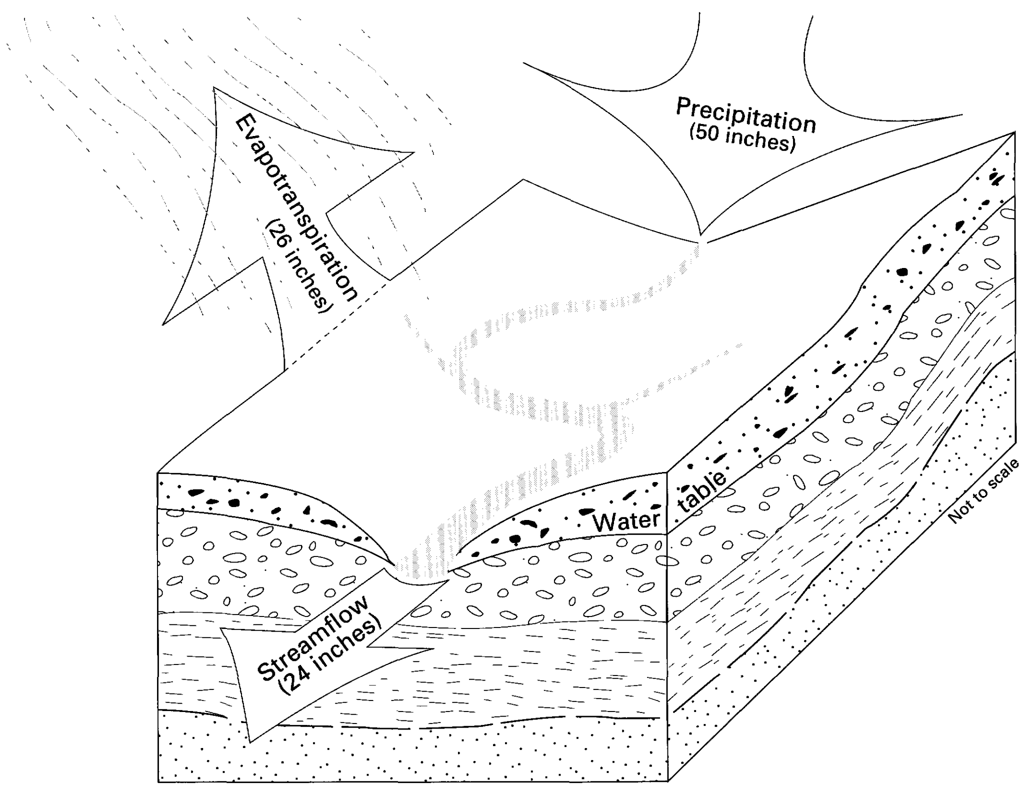



**Figure 1.3A.** Hydrologic cycle and hydrologic budget for the entire Monongahela River basin. (Modified from Bain and Friel, 1972; budget data from Friel and others, 1967.)

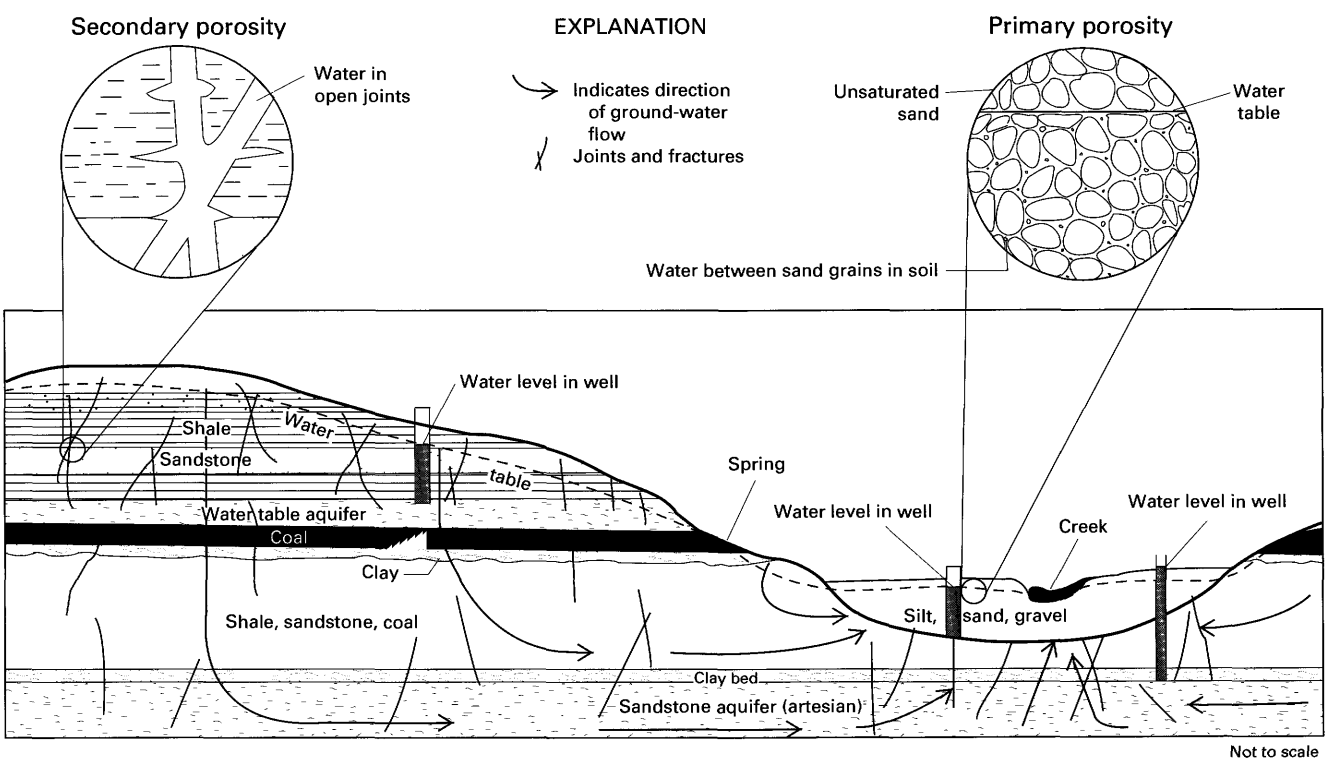



**Figure 1.3B.** Water-table aquifer (upper), artesian or confined aquifer (lower), and ground-water flow lines (arrows).

| SYSTEM | SERIES | GEOLOGIC UNIT | APPROXIMATE THICKNESS IN FEET | LITHOLOGIC AND STRUCTURAL CHARACTERISTICS* | HYDROLOGIC CHARACTERISTICS |
|---|---|---|---|---|---|
| QUATERNARY | HOLOCENE | ALLUVIAL DEPOSITS | 0–10 | Unconsolidated stream deposits of gravel, sand, clay, and silty clay. Deposits poorly sorted to well sorted and may form semiconfined aquifers in some areas. | Generally insignificant as aquifer. |
| PENNSYLVANIAN | UPPER PENNSYLVANIAN | CONEMAUGH GROUP | 0–95 | Alternating layers of shale, sandstone, siltstone, and some limestone, primarily grayish-red shale interbedded with greenish shale and siltstone. Basal part of group is predominantly fine-grained thin-bedded sandstone. Some thin beds of limestone, coal, and underclay throughout the group. Joints poorly to moderately well formed, open and vertical. Subsidence fractures may be encountered in underground coal mining. | Yields inadequate water for domestic or farm supplies where extensive mining and subsidence have partly drained some areas. Some water may be perched on semipermeable layers of clay or shale in mined areas. Well yields adequate for domestic supply in unmined areas, but high yields unlikely because unit is thin in Norton area, and found only on hilltops. |
| | | ALLEGHENY FORMATION | 265–300 | Alternating layers of sandstone, siltstone, shale, coal, underclay, and limestone. Upper part is primarily sandstone. One sandstone unit is 20–55 ft thick and grades laterally into siltstone and black carbonaceous shale. Beneath this sandstone is another cross-bedded conglomeratic sandstone 0–55 ft thick, beneath which is a fine-grained thin-to-thick-bedded sandstone. Middle part contains mined bed of Kittanning coal that varies 0–12 ft thick. Locally, coal bed is split into three benches by shale and clay partings. Coal is immediately overlain by shale and siltstone, and underlain by thin-bedded to massive sandstone 20–90 ft thick, grading eastward to dark shale. Basal part contains coal bed 1–6 ft thick and 25–80 ft of shale containing some thin-bedded to massive sandstone with thin beds of coal and underclay. Joints generally more widely spaced in sandstones and closer spaced in finer grained rocks and coal; patterns often regular. Joint sets usually open and vertical. Subsidence fractures are encountered in underground coal mining. | Yields adequate for small-to-moderate industrial and public water supplies in parts of basin. Yields of wells range from less than 1 to 350 gal/min and average about 26 gal/min in Monongahela basin. Aquifer untested in much of area. Underground mining has drained most of upper half of unit, but some perched water is found in many places. Ground-water conditions should be stable in unmined areas and may be enhanced in rocks beneath flooded parts of mines. |

*Descriptions modified from Englund (1969) and Subitzsky (1976).

**Figure 1.3C.** Geologic and hydrologic framework for Norton, W. Va., area. (Geologic names are those used by the West Virginia Geological and Economic Survey and do not necessarily conform to those used by the U.S. Geological Survey.)

| SYSTEM | SERIES | GEOLOGIC UNIT | APPROXIMATE THICKNESS IN FEET | LITHOLOGIC AND STRUCTURAL CHARACTERISTICS* | HYDROLOGIC CHARACTERISTICS** |
|---|---|---|---|---|---|
| QUATERNARY | HOLOCENE | ALLUVIAL DEPOSITS | 0–20(?) | Unconsolidated stream deposits of gravel, sand, clay, and silty clay. Deposits poorly sorted to well sorted and may form thin water table aquifer along stream. | Source of few domestic supplies. Yields range from less than 1 to 10 gal/min and average about 5 gal/min in Monongahela basin. |
| PENNSYLVANIAN AND PERMIAN | UPPER PENNSYLVANIAN AND LOWER PERMIAN | DUNKARD GROUP | 0–550 | Alternating layers of shale, sandstone, siltstone, limestone, coal, and underclay. Top and middle of unit made up of nearly equal amounts of shale and sandstone beds. Most shale beds range 10–60 ft thick. Sandstone beds range 20–40 ft thick with numerous interbeds of thin limestone, coal, underclay, shale, and sandstone. Basal part is about 55 percent sandstone; ranges 10–50 ft thick. This part also contains shale beds 4–60 ft thick, and numerous thin beds of limestone, coal, and clay. Some clay beds over 10 ft thick. Fracturing locally developed in silstone, shale, and limestone; joints are blocky and closely spaced in finer grained rocks, moderately spaced in sandstone. Joints vertical and open. Subsidence fractures are encountered in underground mining. | Yields adequate water for many domestic and farm supplies and a few small-to-moderate industrial supplies in Monongahela basin. Yields of wells range from less than 1 to 75 gal/min and average about 12 gal/min. Wells drilled as deep as 321 ft, average depth 77 ft.<br><br>Extensive mining in underlying Monongahela Group has partly drained some areas; ground-water conditions stable in some areas, but continually changing where heavy mine pumpage is maintained and periodically altered. |
| PENNSYLVANIAN | MIDDLE AND UPPER PENNSYLVANIAN | MONONGAHELA GROUP | 350–400 | Alternating layers of shale, sandstone, siltstone, limestone, coal, and underclay. Unit is capped by coal bed 5 ft thick, underlain by clay and beds of shale 10–13 ft thick alternating with sandstone beds 35 ft thick and thin beds of limestone and coal. Middle part generally contains thin beds of shale and siltstone and two beds of limestone 20–40 ft thick with streaks of clay. Lower part contains two thick beds of coal separated by about 120 ft of shale and limestone beds that are 20–25 ft thick, alternating with thin sandstone beds and several beds of clay or slaty clay 2–30 ft thick. Mined Pittsburgh coal is 6–12 ft thick and lies at base of unit. Joints vary from poorly to moderately well developed in limestone. Fracturing widely spaced in irregular intervals, generally blocky or platy patterns, and spacing closer in finer grained rocks. Joints usually open and vertical. Subsidence fractures are encountered in underground coal mining. | Yields enough water for many domestic and farm and small-to-moderate industrial supplies in Monongahela basin. Yields range from less than 1 to 75 gal/min and average about 13 gal/min. Wells drilled as deep as 385 ft, average depth 98 ft.<br><br>Extensive coal mining in Monongahela Group has partly drained some areas; ground-water conditions stable in some areas, but continually changing where heavy mine pumpage is maintained and periodically altered. |
| | | CONEMAUGH GROUP | 550–600 | Alternating layers of shale, sandstone, siltstone, limestone, coal, and underclay. Top of unit capped by about 5 ft of underclay, of Pittsburgh coal of Monongahela Group. The clay, in turn, is underlain by about 35 ft of massive sandstone. Upper part of unit is nearly 50 percent massive sandstone with several thick beds of shale and thin beds of limestone, coal, and clay. Middle part largely shale with alternating beds of massive sandstone 20–40 ft thick, thin beds of limestone, shale, coal, and underclay. Basal part about 75 percent massive sandstone with beds 15–60 ft thick. Beds of shale are up to 20 ft thick and there are numerous thin beds of limestone, shale, coal, and underclay. Joints poorly to moderately well formed, open and vertical. | Most developed aquifer in the Monongahela basin. Adequate yield for domestic, farm, and small-to-moderate industrial supplies. Yields of wells range form less than 1 to as much as 400 gal/min; however, average is about 16 gal/min. Highest yields reported from wells in valleys and tapping massive sandstones at base of Group. Wells drilled as deep as 985 ft, average depth 107 ft. |

*Description modified from Hennen and Reger (1913), Subitzsky (1976).

**Descriptions based on well data for entire Monongahela River basin by Friel and others (1967, p. 80).

**Figure 1.3D.** Geologic and hydrologic framework for Farmington, W. Va., area.

# 2.0 MINED BED ABOVE MAJOR STREAMS OR RIVERS

## 2.1 *Mining and Subsidence—Norton, W. Va., Area*

### 2.1.1 *Mining History and Methods*

# Underground Mining Began in the Norton, W. Va., Area About 1895 and Continued Until 1971

Underground mining began in the Lower Kittanning coal in Norton, W. Va., about 1895 and continued until 1971; surface mining continues to the present.

The mined area is in central northeastern West Virginia, in the Appalachian Plateaus, at the northwest edge of Randolph County (fig. 2.1.1A). About half the mined area is principally a ridge drained on the east by Roaring Creek and on the west by Grassy Run. The remainder is drained by Roaring Creek.

The Lower Kittanning coal of the Pennsylvanian Allegheny Formation is the principal bed of coal mined. Underground mining began in 1895 at Coalton and continued sporadically until August 1971. Between 1942 and 1950 the Lower Kittanning coal outcrop was strip mined, so that by 1950, almost all of the outcrop above the underground mines had been surface mined (about 990 a or 400 ha).

Drift-mine openings at Norton and Coalton, W. Va., were located downdip to realize the benefits of hauling coal downgrade and allowing gravity drainage from the mine. Mining was done mostly by the room-and-pillar method, although an unsuccessful attempt to mine by the longwall method was tried from 1920 to 1924.

Surface mining was done by stripping the coal at the outcrop, whereby the overburden was removed from the coal and the coal was mined around the hill. The overburden (spoil) was deposited along the outer edge of the bench or pushed down the hillside. The spoil pile commonly served as a dam, preventing water from leaving the pit and directing it toward the highwall and into underground mines in places. Because reclamation was not required by law during the period of strip mining, little or none was done.

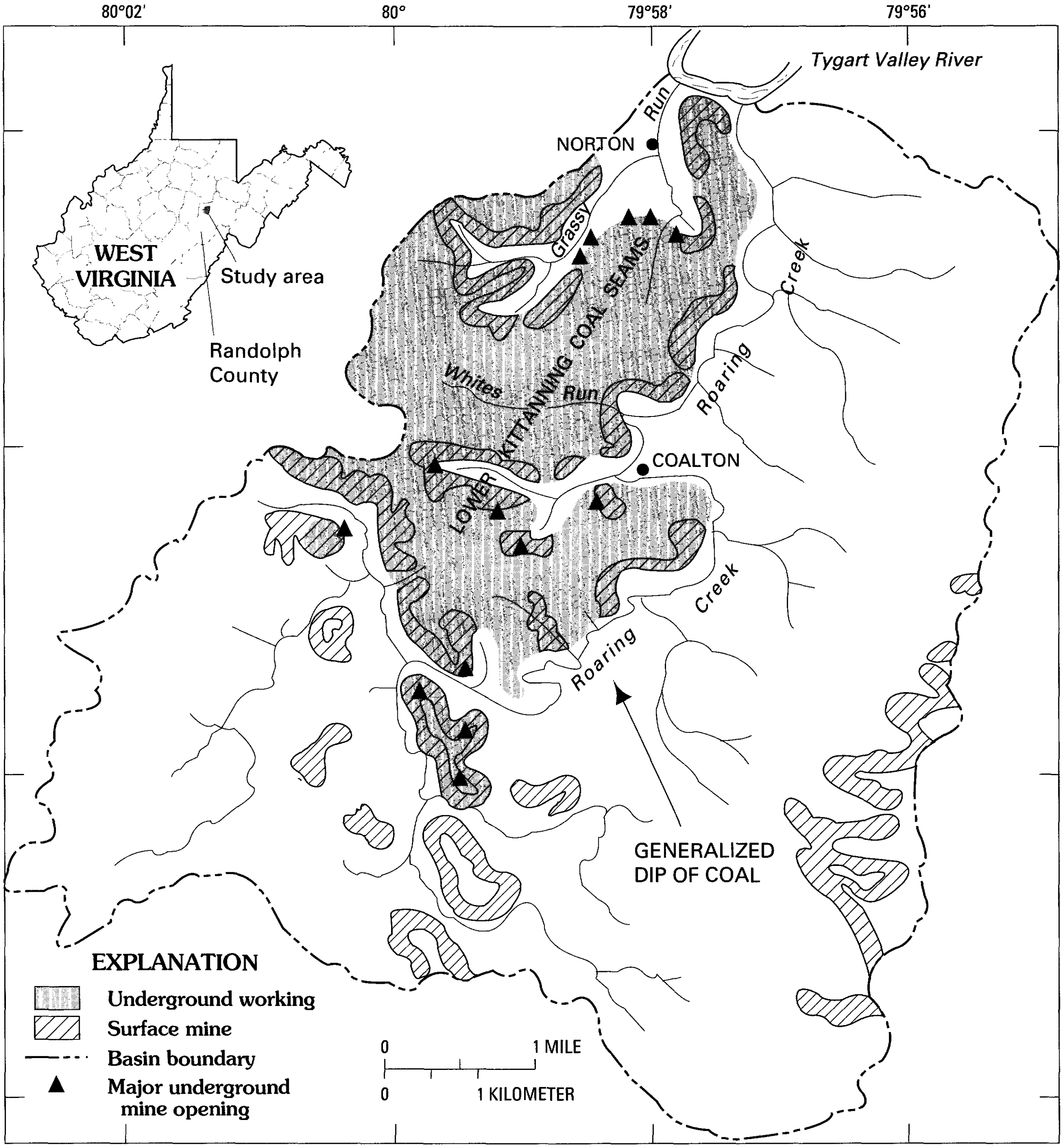



**Figure 2.1.1A.** Areas where mined bed of coal lies above major streams. (Modified from Industrial Environmental Research Laboratory, 1977.)

2.1.2 *Subsidence and Reclamation*

# Reclamation Efforts Were Made at Norton, W. Va., in 1934 and 1964, but Numerous Subsidence Effects Are Still Apparent

More than 1,600 surface subsidence holes or cracks were mapped. Attempts at grouting some of these were successful.

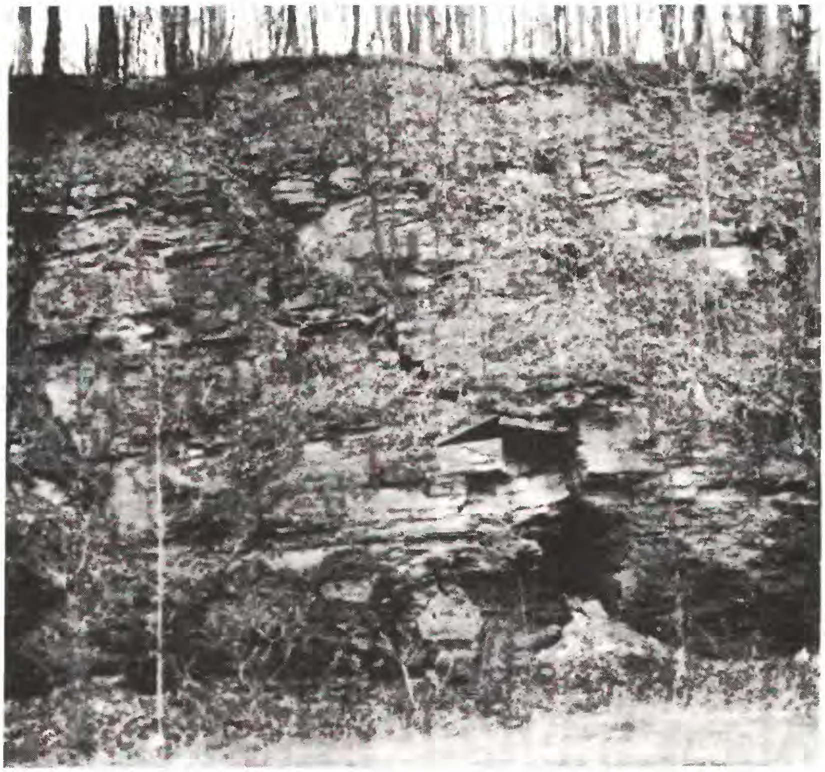
Photographs 2.1.2A and B show subsidence fractures in a 15-ft-high wall near Coalton, W. Va., with the reclaimed strip-mined area in the foreground. This area has also been deep mined, and the subsidence is particularly noticeable in the "slumping" feature in the soil zone in the woods above the high wall (fig. 2.1.2B). Notice in figure 2.1.2A that there appears to be only one major fracture, running from lower right to upper left in the high wall, whereas in figure 2.1.2B there are numerous fractures that are nearly vertical and appear to follow joints in the rocks. The degree of surface subsidence also appears to be greater in figure 2.1.2B, as indicated by the "slump" type feature. Subsided areas with numerous open fractures, such as in figure 2.1.2B, would be more effective in draining water from the surface or from overlying rocks than would subsided areas such as in figure 2.1.2A.

The map in figure 2.1.2C shows areas of subsidence and the thickness of rock over the mined coal bed. Apparently, most subsidence features are located where overburden is thin. Few subsidence cracks are mapped where the overburden is more than 150 ft thick. Data from test drilling with cable tool and coring rigs also indicate that, where the the overburden is thin, highly fractured rock is encountered near the surface; where the overburden is thick, highly fractured rock is encountered at greater depths. Some wells penetrated so much fractured rock at depth that water entering the wells at shallow depths drained down the well bore and out along the fractures at greater depth.

The Roaring Creek–Grassy Run area was involved in the first large-scale Federal mine-reclamation project, undertaken about 1934. Most reclamation work consisted of sealing air from abandoned mines with a masonry wall and sealing some surface cracks with rock and soil. Hodge (1938) indicated that, in places, surface water was diverted from the mines, resulting in a 75-percent reduction in the amount of effluent from some mines.

In 1964, another demonstration program on control of acid mine drainage was begun by the U.S. Public Health Service, Bureau of Mines, Bureau of Sport Fisheries and Wildlife, and the U.S. Geological Survey. This program was primarily aimed at sealing deep mines and recontouring strip mines, to exclude air from the mines and, in places, divert water from them. Because of reduced funding, only 69 percent of strip-mined areas were recontoured. Fourteen wet and 73 dry seals were installed in mine openings. Attempts to chemically grout some of the 1,600 or so subsidence holes (see fig. 2.1.2C) were unsuccessful, and none were sealed. Many of the data used here have been taken from earlier reports by the Industrial Environmental Research Laboratory (1977) and Englund (1969), and from unpublished data in the files of the U.S. Geological Survey.

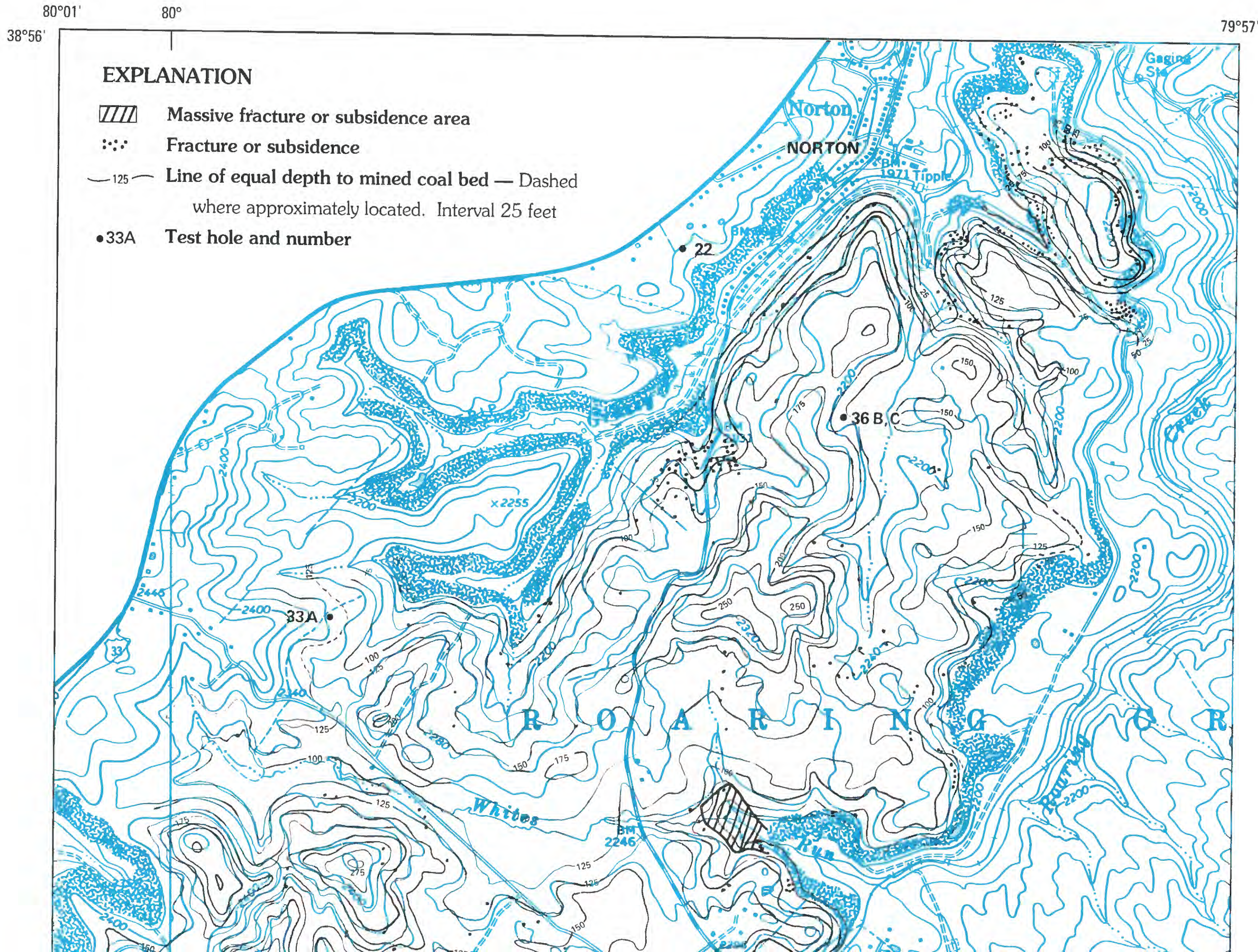
The more densely populated areas lie stratigraphically below the mined bed of coal. Thus, subsidence has done little damage to manmade structures. Some wells drilled as part of the latest reclamation study have been damaged by subsidence. For example, a 6-in. well (point 36B on fig. 2.1.2C) was 195 ft deep and cased with steel its entire length (the bottom 20 ft were slotted). Yet, on three different occasions, the well was pinched off at depth by rock collapse, and presently it measures 155 ft deep. Core hole 22 began to cave at depth before the drilling rig was removed from the site. The hole was reopened and cased to the bottom with 1 1/2-in. pipe slotted in the bottom 20 ft. Wells 26B, 33A, and 36C have also collapsed at points above their water levels.

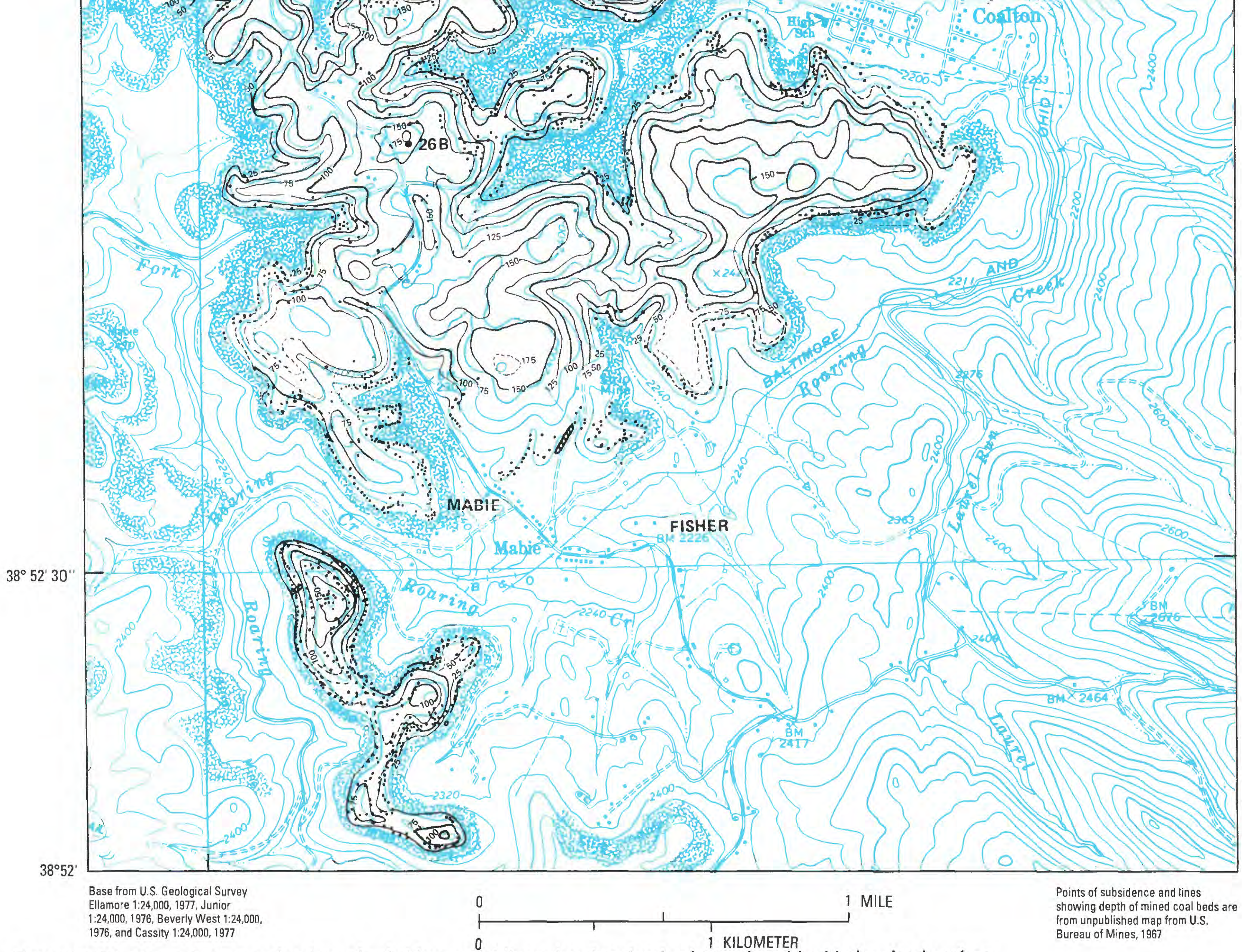


*A*

*B*

**Figures 2.1.2A,B.** Strip mine high wall near Coalton, W. Va., showing surface subsidence and fractures caused by rock collapsing into underground mines.


80°01'
80°
38°56'
79°57'
EXPLANATION
Massive fracture or subsidence area
Fracture or subsidence
125
Line of equal depth to mined coal bed — Dashed where approximately located. Interval 25 feet
33A
Test hole and number
Norton
NORTON
1971 Tipple
Gaging Sta
22
36 B,C
33A
x2255
ROARING CR
Whites
Run
Roaring
Creek
BM 2246
33




Base from U.S. Geological Survey Ellamore 1:24,000, 1977, Junior 1:24,000, 1976, Beverly West 1:24,000, 1976, and Cassity 1:24,000, 1977

Points of subsidence and lines showing depth of mined coal beds are from unpublished map from U.S. Bureau of Mines, 1967

**Figure 2.1.2C.** Mapped areas and points of subsidence and lines showing depth of mined coal bed below land surface.

2.2 *Streamflow*

2.2.1 *Base Flow*

# Undermined Basins Have Both Highest and Lowest Yield per Square Mile

Main cause of high and low yield per square mile is interbasin diversion of water through joints, fractures, subsidence cracks, and mines.

Measurements of base flow were made at 18 stream sites and 5 mine sites on April 20, 1979, and again at some of the same sites in October 1965 (data from U.S. Geological Survey files). Figure 2.2.1A, for April 1979, shows the ranges of yield per square mile, based on measured flows and surface drainage area. Note that the basins yielding less than 0.5 $(ft^3/s)/mi^2$ (cubic feet per second per square mile) are in areas shown by dye tracing (see section 2.2.2) to be losing water underground through joints, fractures, and subsidence cracks to Grassy Run basin.

Whites Run was measured at two sites: the upper, where the stream drains rocks that are entirely underlain by mines, and the lower, where the stream flows on rocks stratigraphically beneath the mined bed of coal. The yield at the upper site was 0.92 $(ft^3/s)/mi^2$ and at the lower site, 0.65 $(ft^3/s)/mi^2$. Although streamflow increased from the upper site to the lower site, yield per square mile of drainage area decreased, indicating that, although the stream may be receiving ground water in the lower reach, it is receiving less ground water than other small unmined basins, as shown in figure 2.2.1A (those basins not underlain by underground workings). Seepage measurements on May 17, 1979, again confirmed a lower water yield at the lower site (see section 2.2.3). Yield of the unmined basins ranges between 1 and 2 $(ft^3/s)/mi^2$. The computed yield for Roaring Creek at its mouth is 1.44 $(ft^3/s)/mi^2$, or in the same range as the unmined basins.

Figure 2.2.1B was prepared from low-flow data collected in October 1965 at some of the same sites measured in April 1979. These October measurements were made at a lower base flow, but they show many of the areas to be of the same high and low yields as the April data. The measured unmined areas also have low yields per square mile. All of the medium-to-high yields are from undermined basins.

It may be concluded from these data and the maps that

1. The main cause of high and low yield per square mile in mined basins is interbasin diversion of water.
2. At high base flow, the lowest yield per square mile is in completely undermined basins.
3. At low base flow, the lowest yield per square mile is in basins unaffected by mining.
4. At high and low base flow, the highest yield per square mile is in basins receiving water diverted underground through mines from nearby drainage basins.
5. A comparison of mined and unmined basins indicates that the overall effect of deep mining and mine collapse has been to moderate high flows and augment low base flows of streams topographically lower than the mined coal bed.

Note that, although the same colors are used in figures 2.2.1A and B to show the low-to-high order of yields for the various basins, the colors are assigned different value ranges on each map.

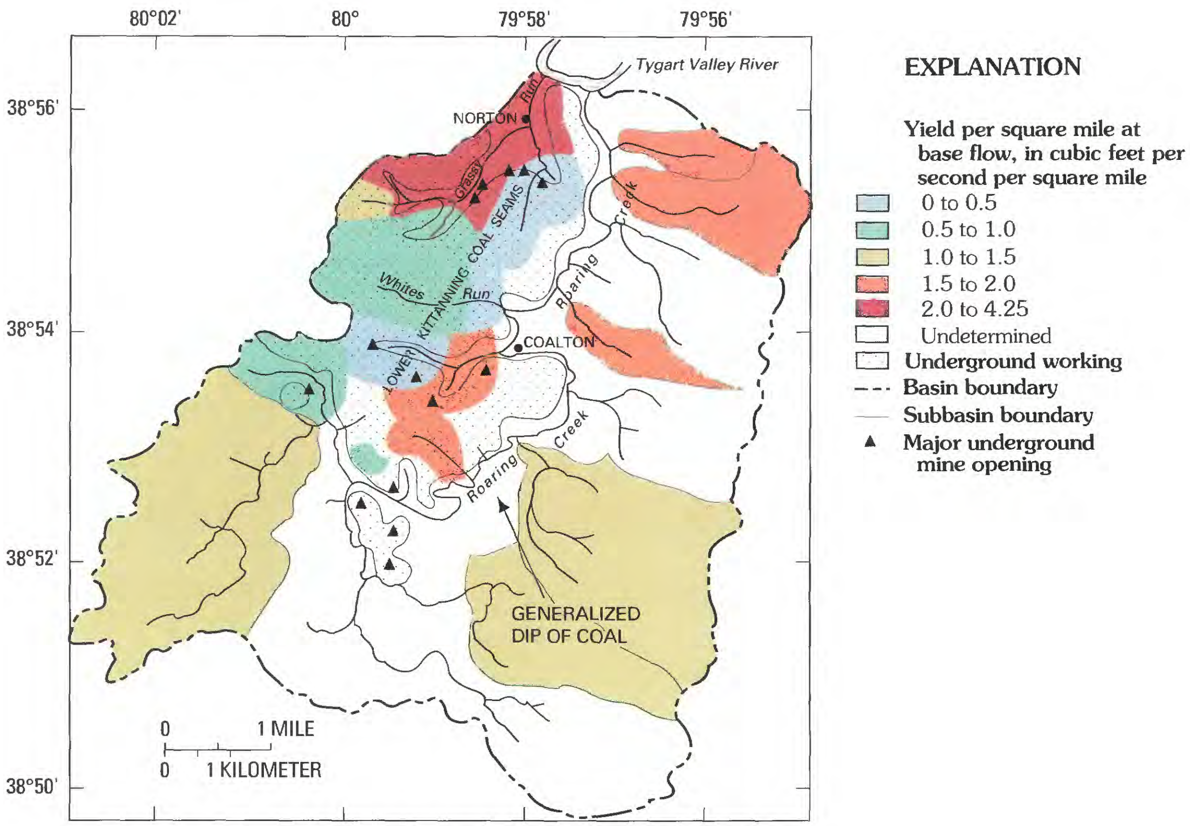



**Figure 2.2.1A.** Yield per square mile of small drainage basins, April 1979.

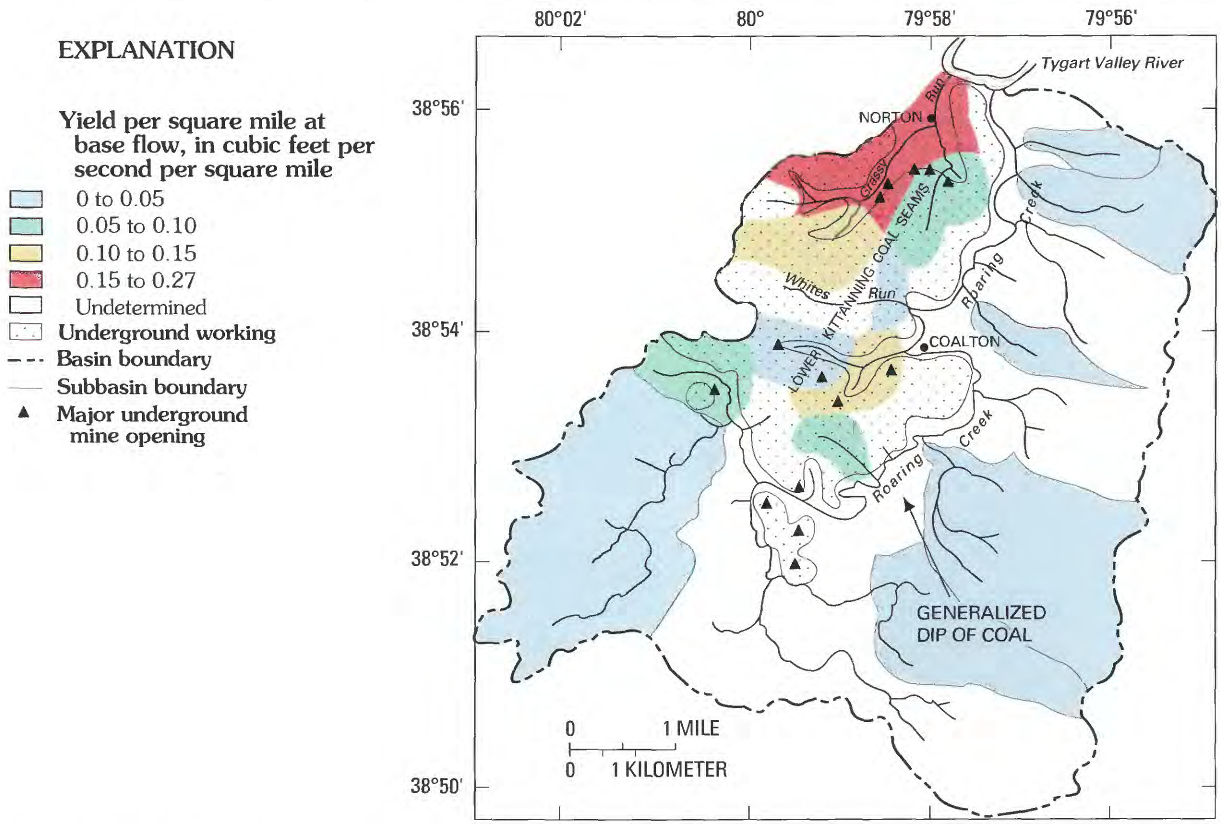



**Figure 2.2.1B.** Yield per square mile of small drainage basins, October 1965. (Base map modified from Industrial Environmental Research Laboratory, 1977.)

# Data on Flow Duration Indicate Interbasin Transfer of Water, Due to Underground Mining

Flow-duration curves show the base flow of Grassy Run is higher than that of Roaring Creek because ground water is diverted through mines from Roaring Creek basin to Grassy Run basin.

Grassy Run and Roaring Creek are adjacent drainage basins. However, the Grassy Run drainage basin is only about 10 percent of the size of Roaring Creek basin. Flow in both streams is derived from overland runoff and ground-water discharge. Overland runoff is storm water that runs overland directly into stream channels; weather changes affect runoff, and this is the principal cause of streamflow variation. Ground-water discharge is water stored in coal or rocks that gradually flows from joints, fractures, or mines into streams. The streamflow variations that cause the most concern are flood flows and low flows, brought about by weather changes. However, some flow variations in Grassy Run and Roaring Creek are brought about by underground mining of coal.

The map in figure 2.2.2A shows that the western two-thirds of Roaring Creek basin is mined out, and the eastern half is largely unmined. Nearly all of Grassy Run basin has been mined out. The Lower Kittanning coal bed and its mines slope from Roaring Creek toward Grassy Run.

Variations of streamflow are largely due to differences in precipitation, topography, vegetation, and geology. Precipitation, geology, and topography of the western part of Roaring Creek basin are similar to those of Grassy Run basin. However, the eastern part of Roaring Creek basin has higher relief, slightly different geology (but still principally shale and sandstone), and higher annual precipitation.

Flow data are available for Roaring Creek and Grassy Run at Norton, W. Va., from 1965 to 1969. These data were used to prepare the accompanying flow-duration curves (fig. 2.2.2B), which are useful when comparing flow characteristics of the two streams. Searcy (1959, p. 22), in discussing flow-duration curves, points out that "a curve with a steep slope throughout denotes a highly variable stream whose flow is largely from direct runoff, whereas a curve with a flat slope reveals the presence of surface- or ground-water storage, which tends to equalize the flow. The slope of the lower end of the duration curve shows the characteristics of the perennial storage in the drainage basin; a flat slope at the lower end indicates a large amount of storage, and a steep slope indicates a negligible amount."

At low flow, the slope of the curve for Grassy Run flattens, indicating that low flow is being sustained by water stored in the rocks and mines. The duration curve for Roaring Creek, on the other hand, does not show this condition. The arrows on the map (fig. 2.2.2A) show that, because of the mines, part of the ground water within Roaring Creek drainage basin is flowing into Grassy Run basin. In effect, this flow increases the recharge area of Grassy Run, and thus more stored ground water is available to maintain low flow. Conversely, the recharge area of Roaring Creek is reduced, and less stored ground water is available to maintain its low flow. Above the 96-percent duration point, the flow of Grassy Run is higher than that of Roaring Creek, despite the much larger drainage area of Roaring Creek. The slope of the lower part of the curve for Roaring Creek flattens only slightly, indicating less ground-water storage than in Grassy Run.

Sand Run is several miles west of Roaring Creek and Grassy Run. The Sand Run basin is geologically, topographically, and vegetatively similar, and average annual precipitation is about the same for all three basins. Thus, the shape of the curve for Sand Run should closely approximate the shape of the curves for Grassy Run and Roaring Creek before mining. On this basis, it seems that mining has had little effect on the shape of the curve of Roaring Creek, but it has had a great effect on the curve of Grassy Run.

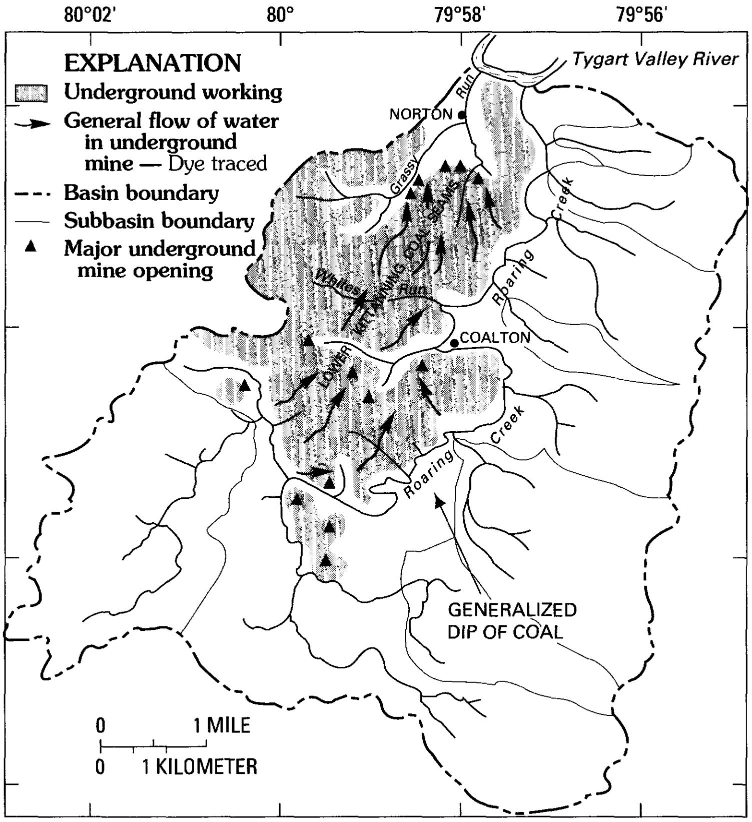



**Figure 2.2.2A.** Area of underground mining and general direction of ground-water flow. (Modified from Industrial Environmental Research Laboratory, 1977.)

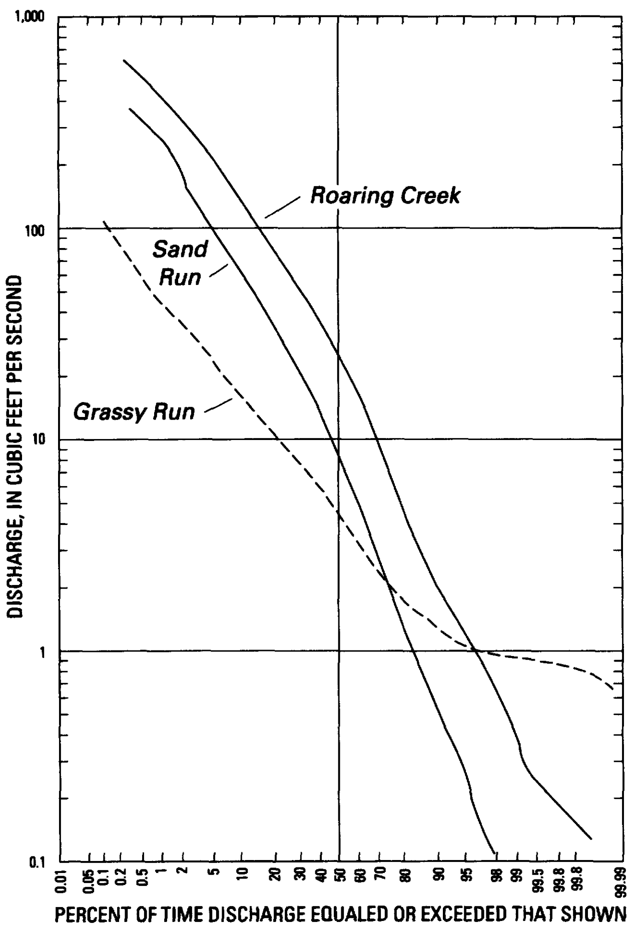



**Figure 2.2.2B.** Flow-duration curves of Roaring Creek, Grassy Run, and Sand Run (1965–69).

2.2.3 *Stream Seepage Measurements*

# Flow Measurements on Whites Run Indicate Both Gains and Losses

Whites Run gains 1.25 ($ft^3$/s)/mi in the upper part of the basin and loses 0.19 ($ft^3$/s)/mi in the lower part of the basin, where the stream lies less than 50 ft above the mine.

Figure 2.2.3A shows a cross section through the profile of Whites Run, a tributary to Roaring Creek. The sampling sites, variation in flow, specific conductance, and pH are also shown. The flow graph indicates an increase in flow of 1.25 ($ft^3$/s)/mi of stream length between sites 1 and 2, and a decrease in flow of 0.19 ($ft^3$/s)/mi between sites 2 and 4. Between sites 4 and 5, where the coal bed crops out, the stream gains water at a rate of 1.97 ($ft^3$/s)/mi.

The chemical composition of the stream water suggests that most inflow between sites 4 and 5 comes from below the mine or from rocks near the outcrop area of the coal. Measurements were made at sites 2 and 5 on Whites Run at two different times (fig. 2.2.3B). The gain of flow between the sites was 0.14 $ft^3$/s on April 20, 1979. Using the relationship $C_2Q_2+C_gQ_g=C_5Q_5$ (Hem, 1959, p. 231), the average conductance of the influent water between sites 2 and 5 can be computed, where $C_2$ and $Q_2$ are the conductance and flow at site 2, $C_g$ and $Q_g$ are the conductance and inflow of ground water entering between sites 2 and 5, and $C_5$ and $Q_5$ are the conductance and flow at site 5. As $Q_g=Q_5-Q_2$, the only unknown is $C_g$, which was calculated to be about 1,700. This value compares favorably with the measured conductance of mine discharges and strongly suggests that only mine water was entering the stream on April 20. However, for the May 17, 1979, measurements, the computed conductance for the inflowing water is 375 microsiemens. This value is not representative of mine water, but probably represents a mixture of mine water and overland runoff from the area just above or below the coal outcrop, as there was some rain on May 16 (0.20 in.).

In summary, the analysis of the data for April and May indicates that Whites Run is losing water between sites 2 and 4, even though the flow measurements at sites 2 and 5 suggest little or no water loss.

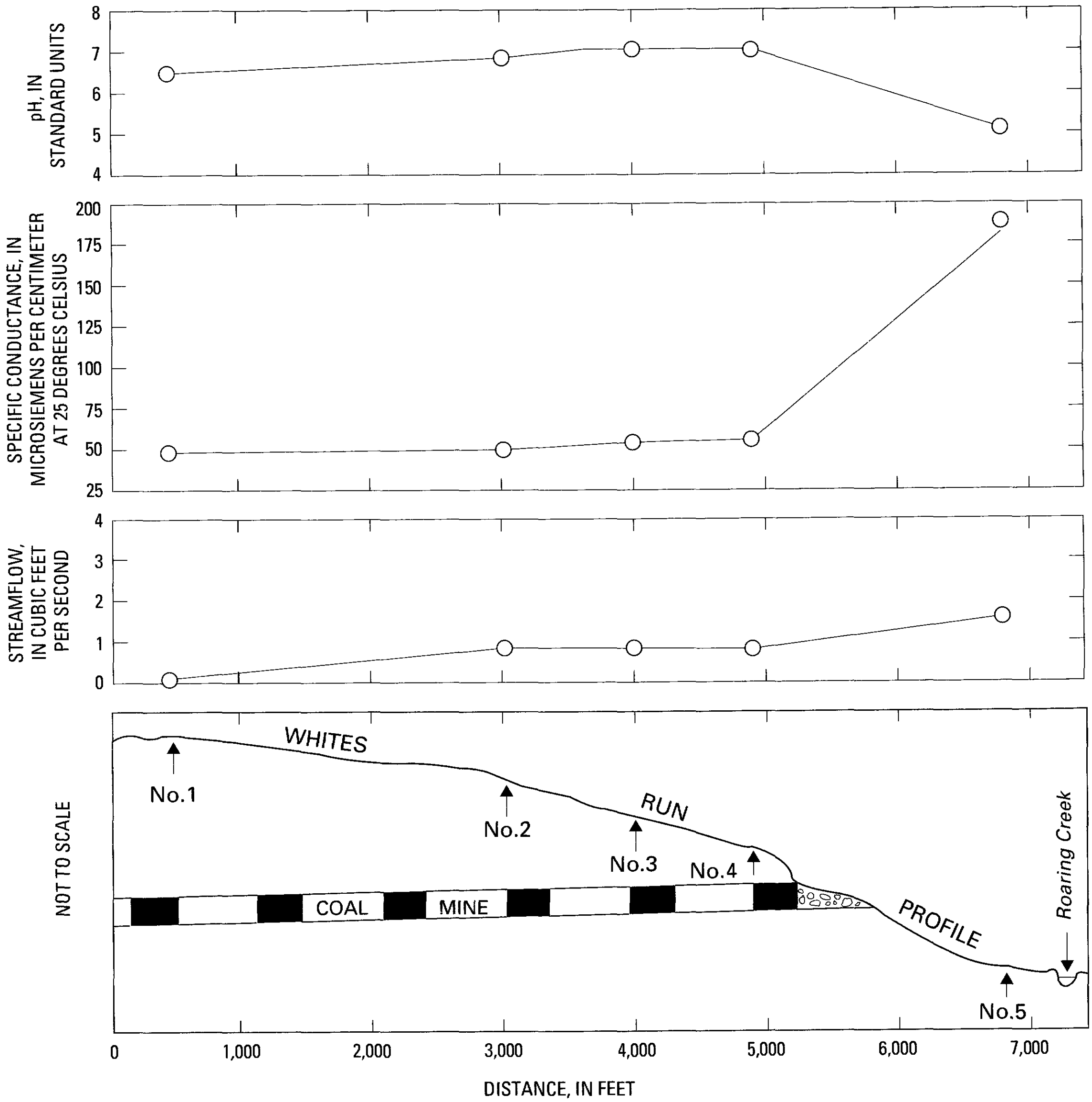



**Figure 2.2.3A.** Cross-section profile of Whites Run showing sampling sites and graphs of pH, specific conductance, and streamflow for seepage study, May 17, 1979.

| Site number | April 20, 1979 | | | May 17, 1979 | | |
|---|---|---|---|---|---|---|
| | Streamflow, in cubic feet per second | Specific conductance, in microsiemens per centimeter at 25 degrees Celsius | Yield, in cubic feet per second per square mile | Streamflow, in cubic feet per second | Specific conductance, in microsiemens per centimeter at 25 degrees Celsius | Yield, in cubic feet per second per square mile |
| 2 | 0.64 | 50 | 0.92 | 0.82 | 45 | 1.18 |
| Water inflow | 0.14 | 1,720 | NA | 0.58 | 375 | NA |
| 5 | 0.78 | 350 | 0.65 | 1.40 | 180 | 1.18 |

**Figure 2.2.3B.** Seepage gains between sites 2 and 5 on Whites Run.

# Streams Draining Mined Areas May Carry 100 Times or More Dissolved Minerals Than Streams Draining Unmined Areas

Streams draining mined areas may carry 100 times or more dissolved minerals than those draining unmined areas, but only at points below which mine drainage enters.

The graphs in figures 2.3A, B, and C were prepared from data collected from 1964 to 1972 by the U.S. Geological Survey, U.S. Federal Water Pollution Control Administration, and U.S. Bureau of Mines in a cooperative project in the Roaring Creek and Grassy Run drainage basins. The graphs compare flow and dissolved-solids load, in tons per year, carried by the headwaters of Roaring Creek (fig. 2.3A), the lower part of Roaring Creek (fig. 2.3B), and Grassy Run (fig. 2.3C).

The dissolved-solids load in the headwaters of Roaring Creek (which contains little or no mine drainage) is much smaller than the load in the lower part of Roaring Creek and Grassy Run (both of which contain mine drainage). The drainage areas for Grassy Run and for the headwaters site of Roaring Creek are nearly the same, yet the annual dissolved material carried by Grassy Run is 60 times to more than 200 times that carried by the headwaters stream. Thus the greater dissolved load carried by Grassy Run is probably primarily due to mine drainage entering the stream.

Most of the reclamation work in Roaring Creek basin involving mine sealing, backfilling, and grading was done between July 1966 and August 1967. Revegetation work was done between October 1967 and July 1968. Essentially no reclamation work was done in Grassy Run basin. Figure 2.3B shows that for the lower part of Roaring Creek the dissolved-solids load increased from 1965 to 1967 and decreased from 1968 through 1970. Peak loads in 1967 were probably caused by a combination of increased precipitation as well as by the oxidation of fresh rock exposed by backfilling and regrading along subsidence fissures.

The decrease in dissolved-solids load after 1967 is expected because

1. Mine seals were installed to flood the mines, reduce the entrance of air, and, hence, reduce the oxidation of minerals.
2. Strip mines were backfilled and contoured, thus reducing the surface area of mine wastes open to atmospheric oxidation.
3. The rate of weathering of fresh rock is reduced with time.
4. Some mine subsidence fractures were bulldozed shut with soil to reduce inflow of water from the surface.

In general, the dissolved mineral content carried by Roaring Creek continuously declined from 1967 to 1970, following reclamation. However, mean flow remained about the same as or increased slightly from the high mean flow in 1967. On the other hand, the dissolved mineral load in Grassy Run, where no reclamation was done, continues to fluctuate with mean flow, suggesting that reclamation has reduced the dissolved-solids load in Roaring Creek but not in Grassy Run. Acidity and sulfate loads increased considerably in Roaring Creek from 1970 to 1971, primarily because of increased mean flow. However, the loads were still lower in 1971 than in 1967, although the mean flows were essentially the same in those years.

Mine-subsidence features affect the quantity and quality of water that enters Grassy Run by increasing the amount of water entering the ground and by increasing chemical loads through exposure of more fresh minerals to a greater degree of chemical weathering. A part of the water that enters along subsidence cracks in Roaring Creek basin is diverted underground to Grassy Run basin through the mines. This diverted water increases flow and chemical load in Grassy Run and decreases flow and chemical load in Roaring Creek.

# Annual Load of Selected Dissolved Constituents

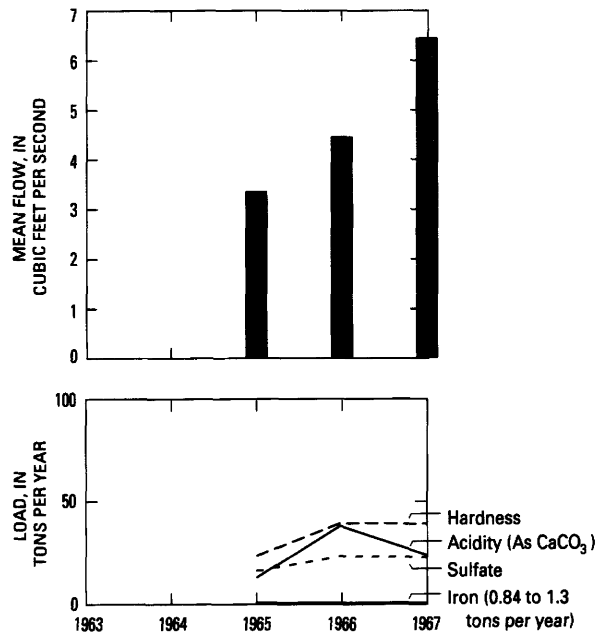



**Figure 2.3A.** Headwaters, Roaring Creek 1965–67 (drainage 2.25 mi²).

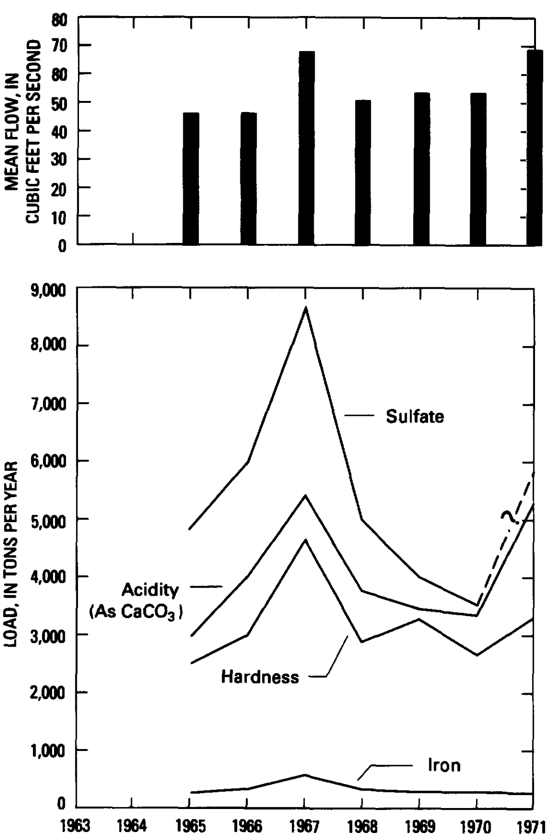



**Figure 2.3B.** Lower part of Roaring Creek 1965–71 (drainage 29.2 mi²).

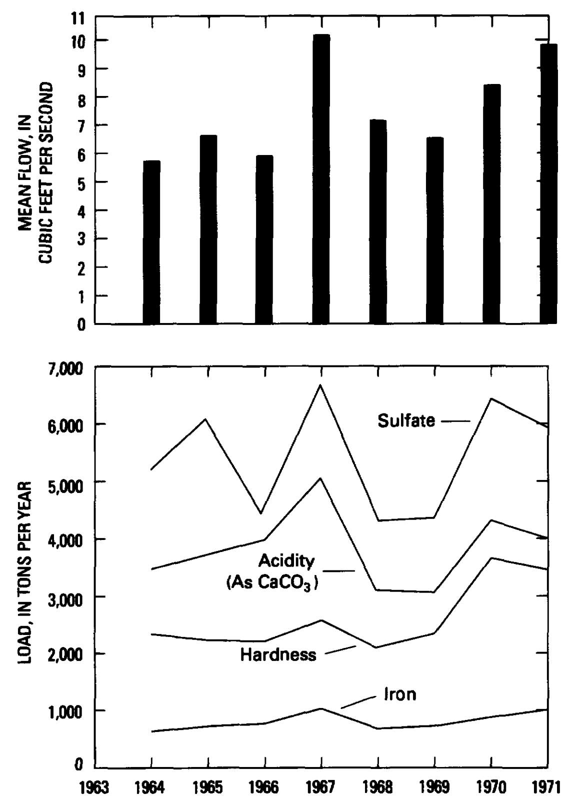



**Figure 2.3C.** Grassy Run 1964–71 (drainage 2.86 mi²).

Data from Industrial Environmental Research Laboratory (1977): headwaters of Roaring Creek, p. A–19; lower part of Roaring Creek, p. A–132, 133; Grassy Run, p. A–8, 9 (data estimated for last quarter of 1967).

# Specific Conductance of Streams Receiving Mine Drainage Is as Much as 1,750 Microsiemens at Low Flow in Spring

Specific conductance of streams at low flow in spring in unmined areas ranges from about 20 to 35 microsiemens; specific conductance of streams in mined areas ranges from 50 to 1,750 microsiemens.

Specific conductance of low-flow stream water is a good indicator of the presence of mining. The eastern and southern slopes of Roaring Creek basin are essentially unaffected by mining, and specific conductance of streams there ranges from 20 to 35 microsiemens (μS). The remainder of the basin, except for the western perimeter, is underlain by mines, and specific conductance ranges from 50 to 1,750 μS. Whites Run is undermined in its headwaters, but it is a losing stream, and its specific conductance at an upstream site is 36 μS; at a downstream site, below where mine drainage enters the stream, the conductance increases to 370 μS.

Highest specific conductance was measured in 1979 (fig. 2.3.1A) in the lower part of Grassy Run basin and in an unnamed stream draining into Roaring Creek at Coalton, W. Va. The high specific conductance primarily results from the large quantities of mineralized mine water that enters the streams.

Although specific conductance is high in places, it was even higher in the fall of 1965 (fig. 2.3.1B). Numerous measurements of specific conductance and other water-quality characteristics in streams were made in 1965 by the U.S. Geological Survey, prior to reclamation efforts.

It can be seen by comparing the maps for 1965 and 1979 that specific conductance of Grassy Run and the unnamed tributary at Coalton has remained about the same. However, specific conductance at many of the sites was lower in 1979. This decrease in specific conductance, and hence dissolved solids, may be attributable to

1. effects of reclamation between 1965 and 1969,
2. gradual reduction in amount of weathering of broken rock material that was relatively fresh in 1965, and
3. dilution of mine drainage by the higher base flow in spring 1979.

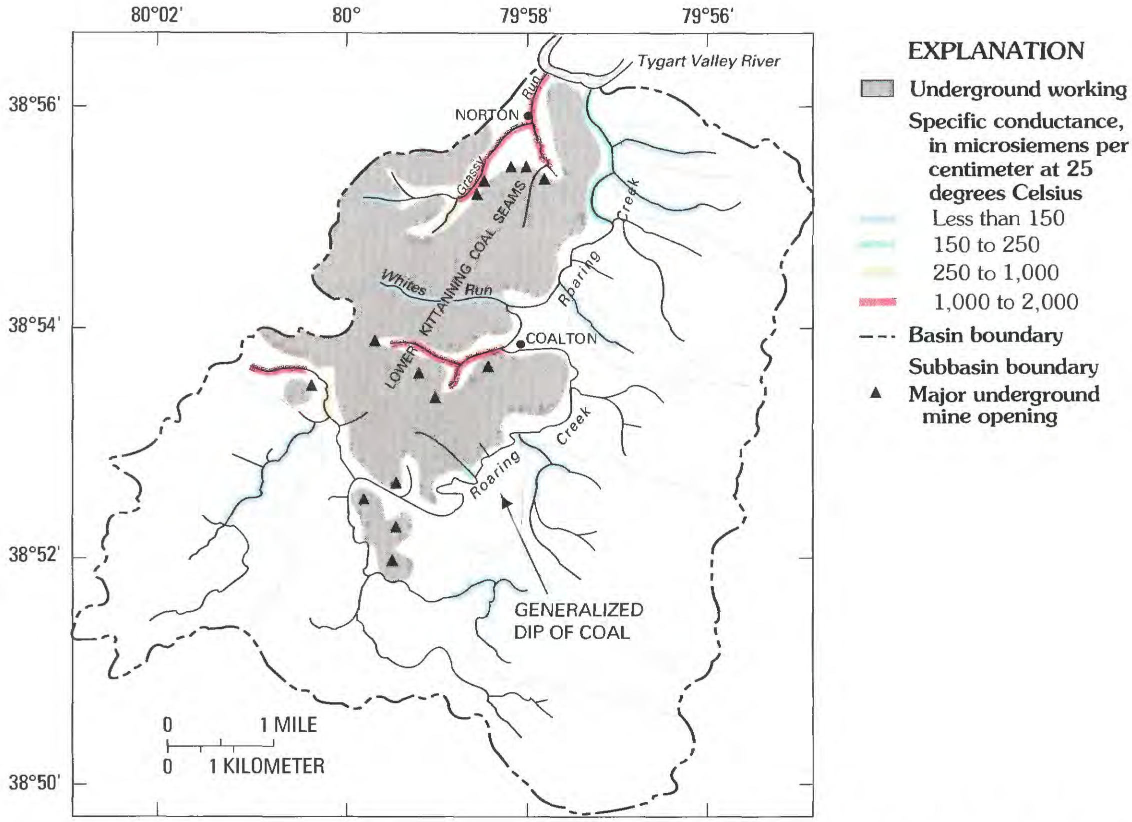



**Figure 2.3.1A.** Specific conductance in Roaring Creek and Grassy Run drainage basins, April 1979.

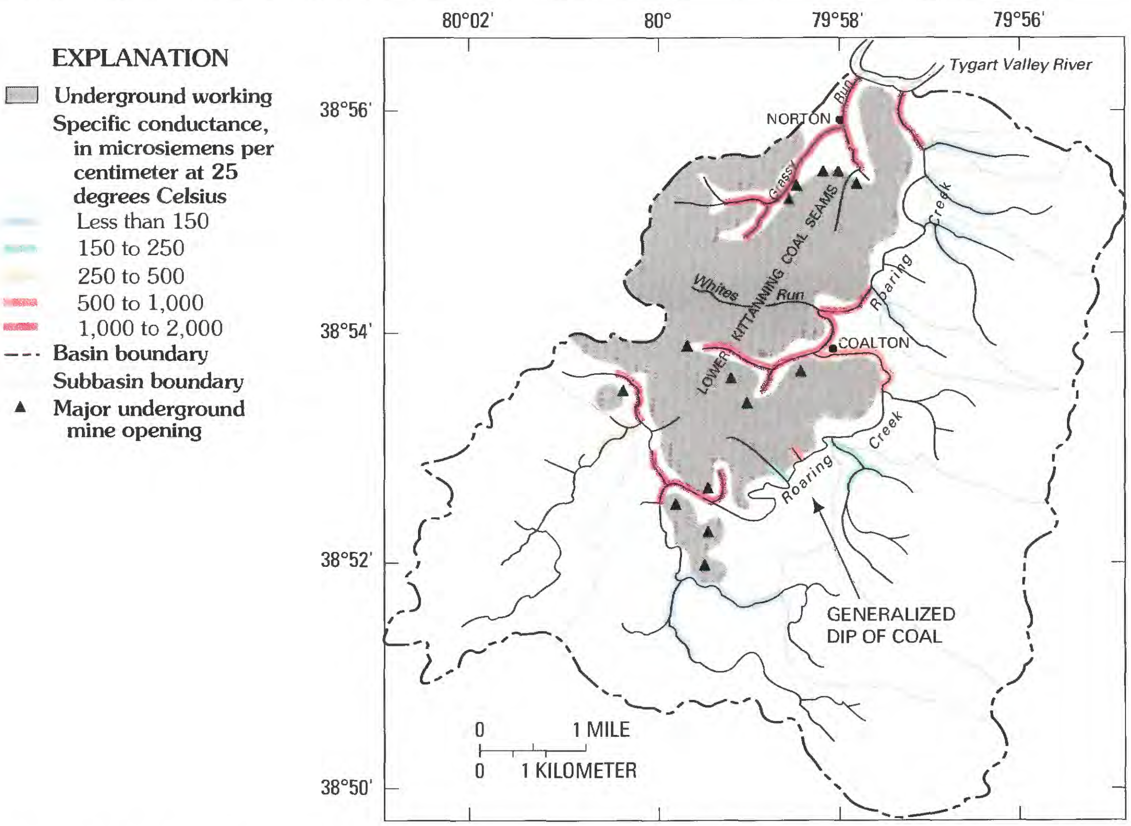



**Figure 2.3.1B.** Specific conductance in Roaring Creek and Grassy Run drainage basins, October 1965. (Base map modified from Industrial Environmental Research Laboratory, 1977.)

# Streams Receiving Mine Drainage Have pH From 2.6 to 6.3

Streams in unmined areas have higher pH, from 5.0 to 6.7; streams in mined areas have lower pH, from 2.6 to 6.3.

The pH of streams may also be an indicator of mining, despite the natural acidity of most streams in areas unaffected by mine drainage. The lowest pH on the maps generally shows where mine drainage is affecting the streams. The drastic change in pH that mine drainage can produce is illustrated by Whites Run on the 1979 map (fig. 2.3.2A). At the upstream site, pH is 6.7; at the downstream site, below where mine drainage enters the stream, pH is 3.4.

Chemical analysis shows that water at the upstream site is low in carbonate hardness (11 mg/L). Carbonate hardness normally acts to neutralize acid, but this water has so little hardness that the pH of the resulting mixture at the downstream site is only 3.4. The neutralization effect would be greater if the natural carbonate hardness of the water from the upstream site were greater.

Another example of the low buffering or neutralization effect of nonmine streamflow is at Roaring Creek at Norton, W. Va. Here the pH is 3.7, and the pH of the five streams containing mine drainage and feeding into Roaring Creek ranges from 2.8 to 3.4. The pH of streams free from mine drainage and feeding into Roaring Creek ranges from 5.0 to 6.7. Yet, when this water mixes with the mine drainage from the basin, the resulting pH is only 3.7 at the mouth of Roaring Creek.

The maps show that the pH of most streams has increased from 1965 (fig. 2.3.2B) to 1979, with the exception of Grassy Run. Here again, the increase in pH may be attributable to the following factors, which are listed in the order of importance:

1. effects of reclamation between 1965 and 1969,
2. gradual reduction in weathering of broken rock material that was relatively fresh in 1965,
3. dilution of mine drainage by higher base flow in spring 1979, and
4. mine-roof collapse, and subsequent exposure of limestone-bearing rocks in the overburden to water percolating into the mines.

In summary, streams unaffected by mining are mostly acidic; however, coal-mine drainage and weathering of mine-dump waste cause many streams to have extremely low pH.

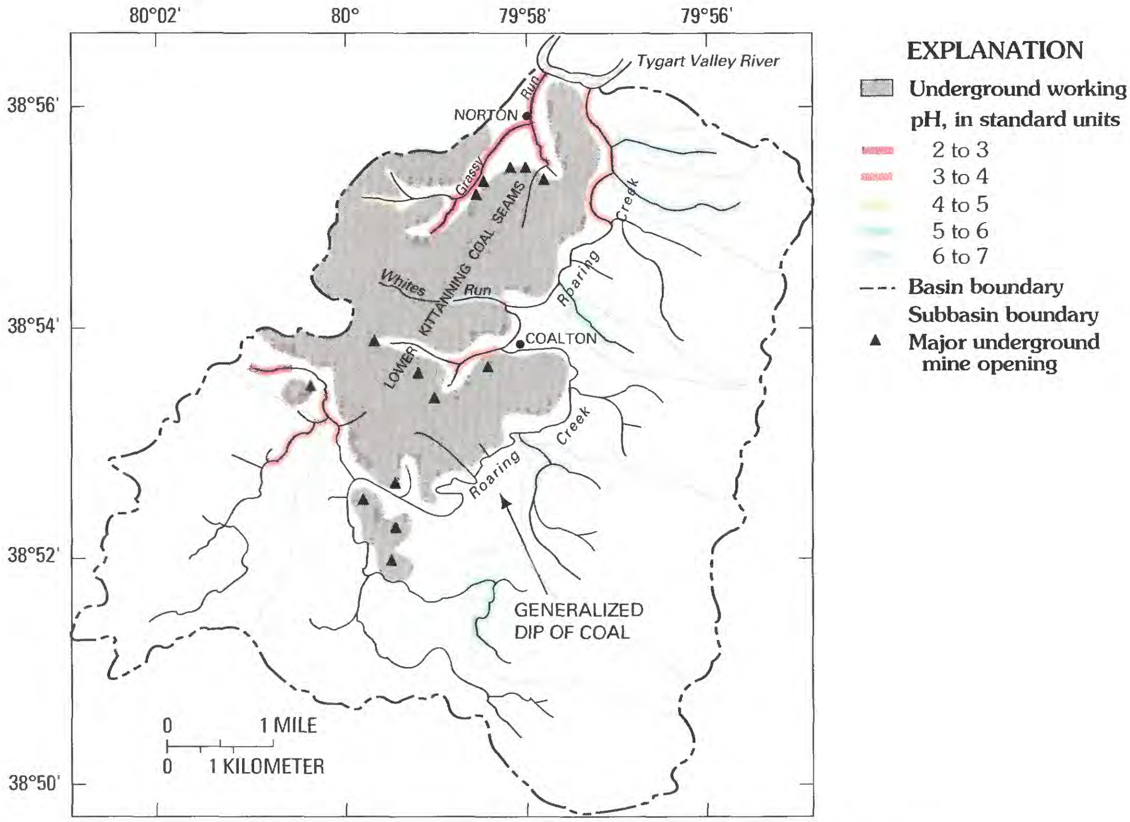



**Figure 2.3.2A.** The pH in Roaring Creek and Grassy Run drainage basins, April 1979.

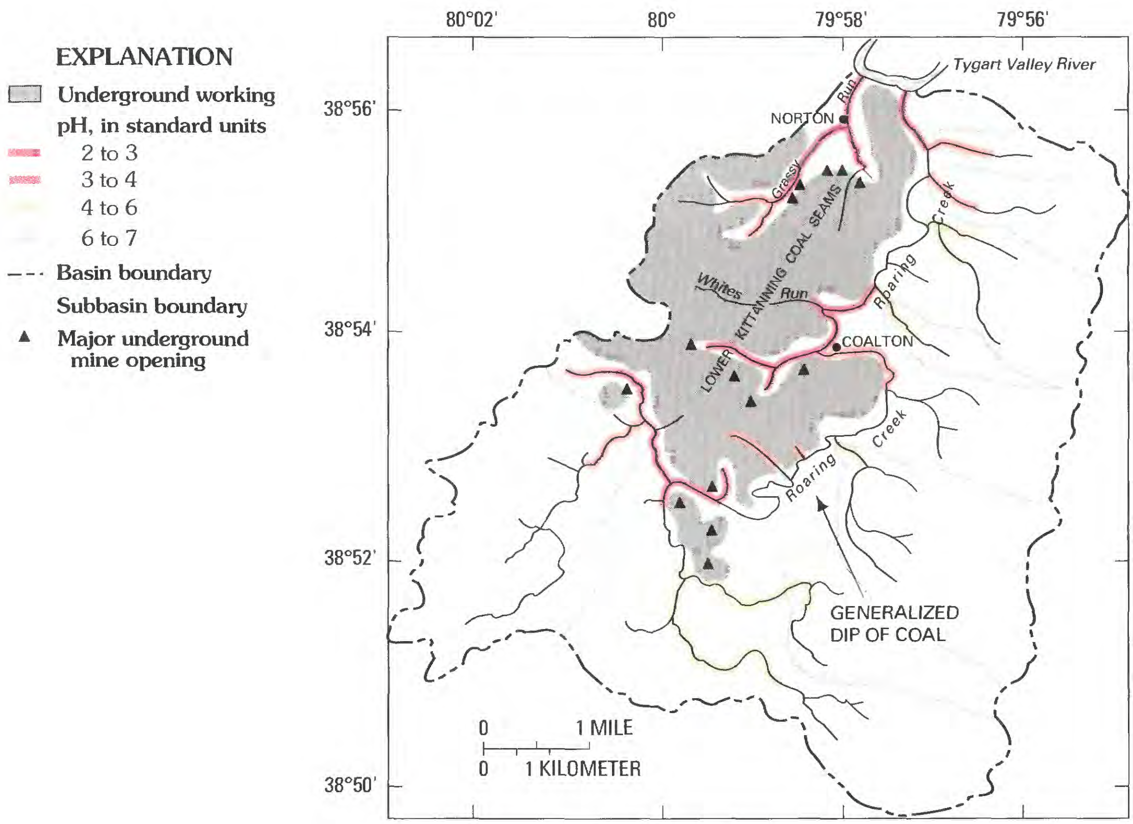



**Figure 2.3.2B.** The pH in Roaring Creek and Grassy Run drainage basins, October 1965. (Base map modified from Industrial Environmental Research Laboratory, 1977.)

# Depth to Water Greatest Beneath Ridge, Where Streams on Either Side Promote Ground-Water Drainage

At a given site above the mined coal bed, the highest water levels are generally found in shallow wells, but some are found in deep wells penetrating rocks of low permeability at depth.

In wells tapping the rocks above the mined coal bed, water levels range from less than 10 ft to more than 170 ft below land surface (fig. 2.4.1A). Shallow wells in the same locality as deeper wells generally have higher water levels. This occurrence is clearly indicated by the water levels in the clusters of wells drilled in the rocks above the mine (wells labeled A, B, C in the chart on figure 2.4.1B).

Cross section *B–B′* (fig. 2.4.1B) indicates that the northern part of the area has the lowest water levels in the cross section, probably because Grassy Run is deeply incised here and promotes good ground-water drainage from the mines in the narrow ridge that separates Grassy Run from Roaring Creek.

Some deep wells, such as well 25, penetrate the coal bed and the strata below and still have water levels that stay near land surface. Apparently, the perched water enters such wells through a few joints or fractures near land surface, and the rocks at depth are either of low permeability or the pores at depth have been plugged by the sediment contained in water moving down the well. Thus, little water is able to leak down the well bore and into the coal bed. The small annual fluctuation of water level of about 11 ft in well 25 further substantiates that the water level in the well is primarily representative of the water level in the perched zone.

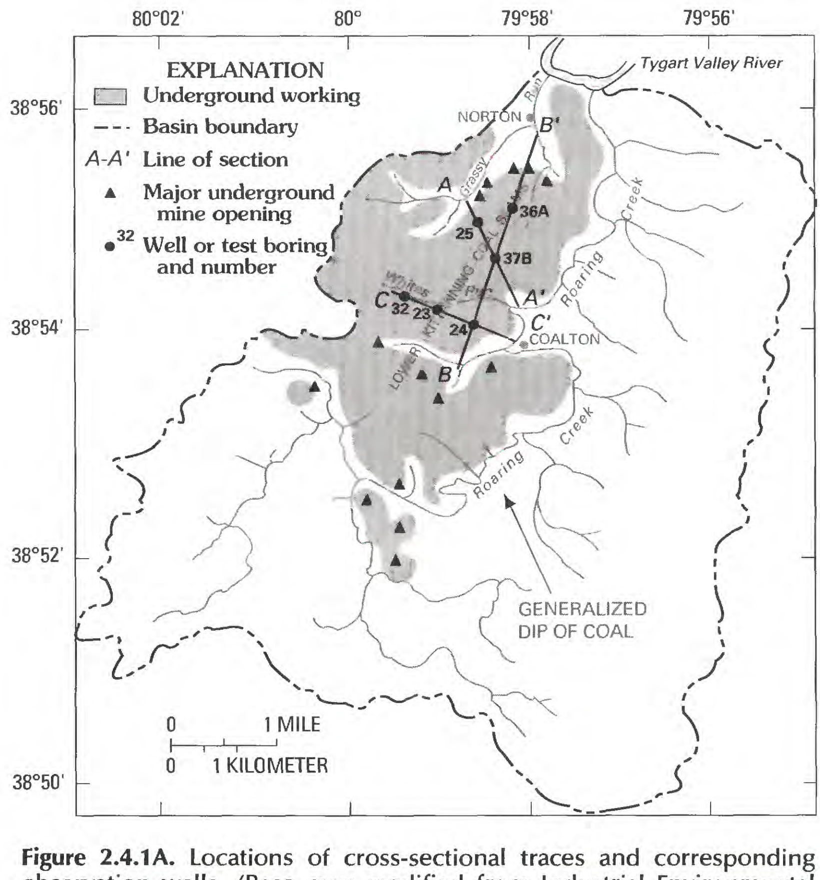
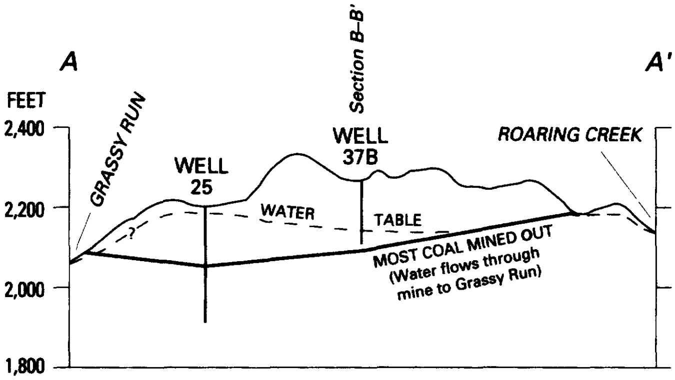



**Figure 2.4.1A.** Locations of cross-sectional traces and corresponding observation wells. (Base map modified from Industrial Environmental Research Laboratory, 1977.)

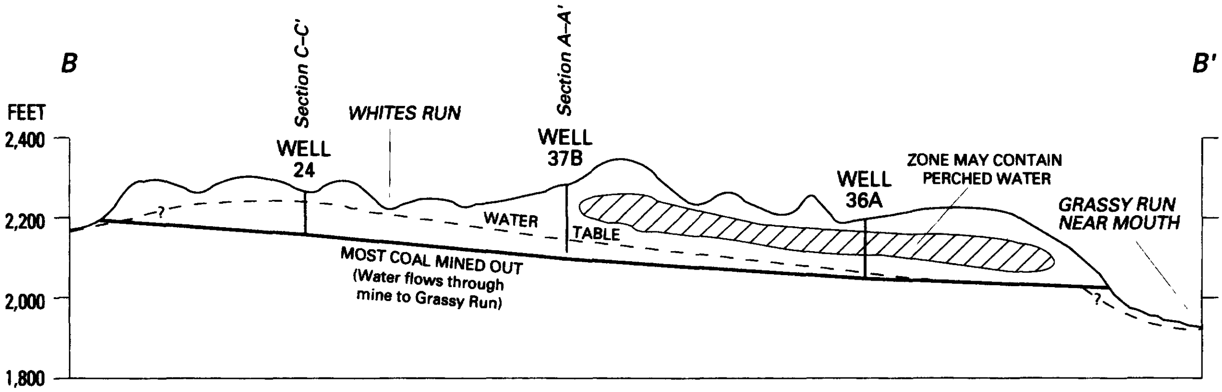


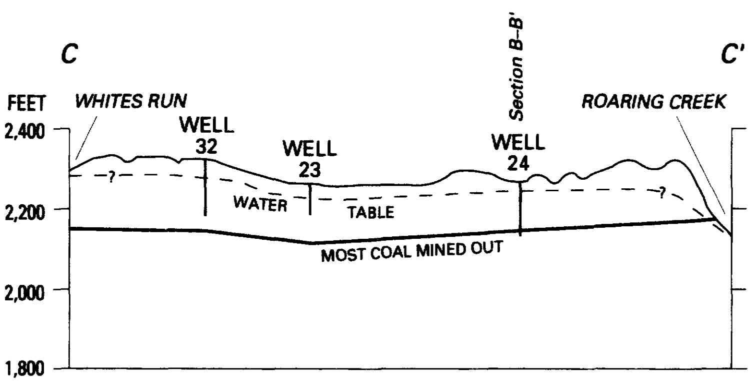

## WELL DATA

All 6-inch diameter wells drilled as 10-inch wells, but cased with 6-inch pipe and grouted from land surface to top of open section.

| WELL NUMBER | DEPTH (feet) | DIAMETER (inches) | CASING LENGTH (feet) | WATER LEVEL (feet below land surface) | WATER LEVEL DATE | DEPTH OF OPEN HOLE OR SLOTTED CASING (feet) |
|---|---|---|---|---|---|---|
| 18–3–21A | 170 | 6 | 160 | 133.25 | 7–31–67 | 155–175 |
| 21B | 135 | 6 | 128 | 132.34 | 7–31–67 | 118–147 |
| 21C | 54 | 6 | 43 | 23.24 | 7–31–67 | 33–54 |
| 23 | 81 | 2.5 | 20 | 39.43 | 7–31–67 | 20–81 |
| 24 | 134 | 2.5 | 7 | 18.61 | 7–28–67 | 7–134 |
| 25 | 294 | 2.5 | 14 | 20.74 | 7–28–67 | 14–294 |
| 26A | 194 | 2.5 | 18 | 81.02 | 7–31–67 | 18–194 |
| 26B | 195 | 6 | 195 | DRY | 8–28–67 | 175–195 |
| 26C | 59 | 6 | 59 | 22.81 | 7–31–67 | 39–59 |
| 32 | 146 | 2.5 | 16 | 47.66 | 7–31–67 | 16–146 |
| 36A | 156 | 6 | 150 | 143.69 | 7–23–67 | 135–156 |
| 36B | 117 | 6 | 117 | 110.63 | 7–23–67 | 95–117 |
| 36C | 69 | 6 | 69 | DRY | 8–22–67 | 46–69 |
| 37A | 133 | 3* | 127 | 131.34 | 7–28–67 | 110–133 |
| 37B | 162 | 3* | 162 | 139.89 | 7–28–67 | 134–164 |

*Equipped with packer and slotted casing.



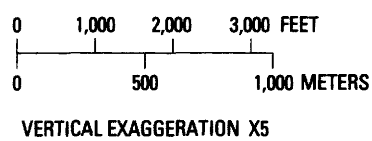




**Figure 2.4.1B.** Cross sections of mined-out area near Norton, W. Va., showing the approximate water table in the overburden, the mined bed (50 percent or more coal extracted) of Lower Kittanning coal, and chart of well data.

2.4.2 *Fluctuations*

# Mining Affects Ground-Water Levels in Vicinity of Mine

Underground mining and subsequent collapse of overlying rocks increase ground-water drainage and create annual water level fluctuations of as much as 100 ft.

Water levels have been measured in wells adjacent to mines and in wells completed directly over or penetrating a mined coal bed. The hydrographs (figs. 2.4.2A and B) show water level fluctuations observed in two wells, one penetrating rocks where the coal bed is unmined (well 21A), and the other penetrating rocks where the coal bed is mined out (well 26A).

Wells 18–3–21A and 21C are adjacent to each other and about 100 ft west of the limit of underground mining. The water level in the deep well (21A) is about 10 ft above the top of the coal bed, and in the shallow well (21C) is 26 ft below land surface. Annual fluctuation in the shallow well is only 1.5 ft, and in the deep well is 4.7 ft. The small fluctuations in these wells indicate small quantities of recharge and discharge, which, in turn, suggest poorly permeable rocks. When the water level in well 21A was pumped down to 171 ft, it recovered only 1.9 ft in 27 min. When the water level in well 21C was pumped down to 55 ft, it recovered only 1.9 ft in 6 min.

The greater fluctuation in the deep well is probably in response to leakage into the mine, which may vary seasonally or with head changes in the mine. Note that, in this and similar situations, future mine-roof collapse could propagate more fissures, which could transect water-bearing units in the overburden and increase the potential for ground-water drainage and lowering water levels in shallow wells.

The water level was measured in well 21A as it was drilled progressively deeper (fig. 2.4.2A). Notice that the water level continuously declines as the well is drilled deeper. When the well depth reaches the level of the coal bed, the water level declines at an increased rate and then begins to taper off at 61 ft. However, when the muck was bailed out of the well, the well depth was effectively increased, and the water level dropped to between 135 and 140 ft. This well is cased to a packer, set at 155 ft, and is open from 155 to 175 ft.

If this well were not cased all the way, it would provide a path for ground water (which is at a higher head, near the surface) to flow down the well bore, out through the coal, and into the abandoned mine, thus lowering local ground-water levels. Open vertical-subsidence fractures may lower local ground-water levels in much the same way, where water can drain downward along the fractures.

(*Text continues on page 32.*)

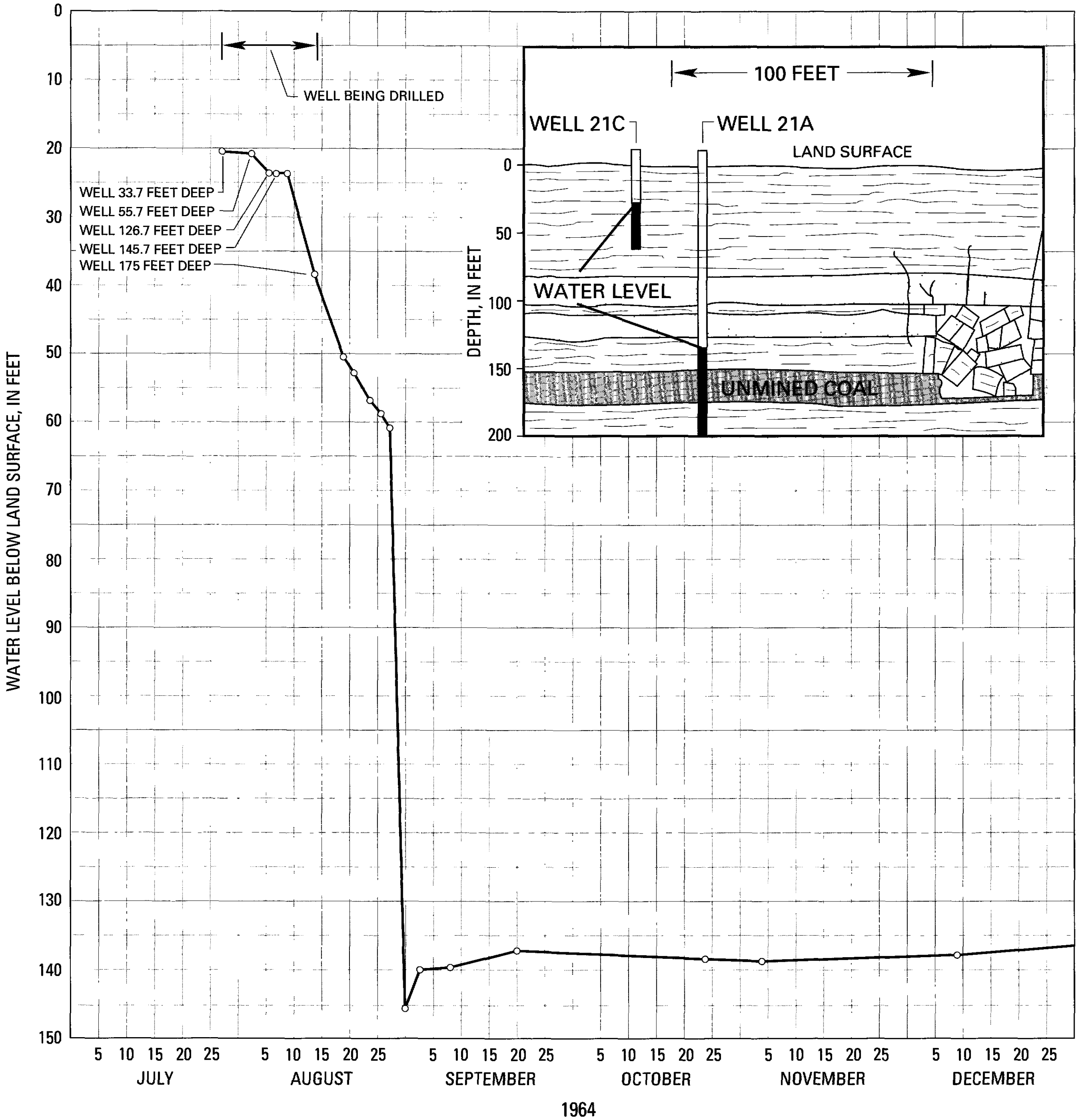



**Figure 2.4.2A.** Hydrograph of well 18–3–21A (well 21A in illustration) as it was being drilled, and for the following 4 months; and approximate physical setting at wells 21A and 21C. (Well 21A bailed on August 29, 1964, and muck removed from bottom; packer set at 155 ft.)

In contrast, wells 18–3–26A, 26C, and 36A are in areas where the coal has been removed. The water level in well 36A is at the bottom of the coal. The water level in well 26C is about 38 ft below land surface during summer and fall, and annual fluctuation in the well is 9.2 ft. This fluctuation suggests avenues of recharge to the well from the surface and leakage of ground water downward into the mine. Fluctuation in well 36A is about half a foot, and the water level does not get above the level of the mine floor.

The hydrograph for well 26A shows annual fluctuations of nearly 100 ft. This well is cased only to 18 ft, but it is 198 ft deep and penetrates a pillar of coal in the mine. Thus, the water level in the well represents the composite head of the various water-bearing zones found in the well between 18 and 198 ft. Large fluctuations in water level indicate that the rocks near land surface are fractured and permeable, permitting rapid recharge. Also, the rocks and coal near the bottom of the well are permeable enough to permit rapid discharge of water into the abandoned mine. Measurements at well 26A show that the water level has dropped as much as 85.5 ft in 21 days.

Part of the annual fluctuation at shallow well 26C is undoubtedly caused by discharge of shallow perched ground water downward along well bore 26A. Notice that in winter and spring of 1966 and 1967, the water level was relatively high, yet the measurements in 1977 and 1978 show a low water level for the same seasons. This low water level suggests that additional subsidence cracks may have opened at depth, permitting better drainage of water from the overlying rocks and well.

Well-construction techniques may have caused extremely low permeability (J.T. Gallaher, written commun., 1968) in material penetrated by some wells. When the packer in nearby well 18–3–21B was set and cemented, it is likely that cement entering fractures above the packer moved into the formation and sealed off the fractures from the open section of well. Such conditions are possible in well 21A and other wells similarly equipped with packers.

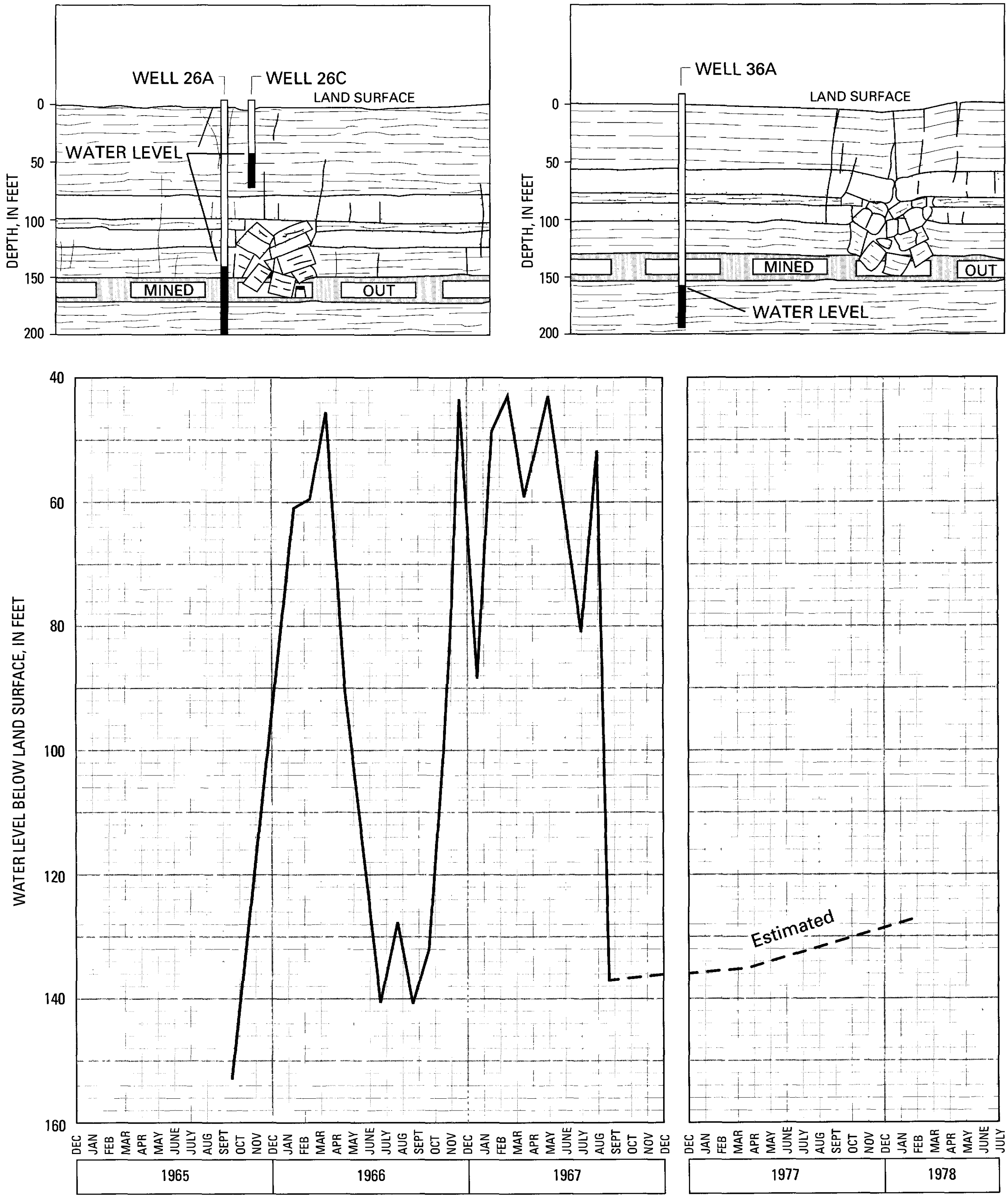



**Figure 2.4.2B.** Hydrograph of well 18–3–26A and approximate physical setting at wells 18–3–26A, 26C, and 36A.

# Mine Collapse Increases Rock Permeability for 150 Feet (or More) Above Mine

Tests on wells indicate the greatest transmissivity is generally found within 50 ft above the mined coal bed and near land surface.

Transmissivity values were estimated from specific-capacity tests on five wells and slug tests on nine wells (fig. 2.5A). These estimates were made from specific-capacity data using graphs by Walton (1962, p. 13) and from slug tests using a curve-matching technique by Cooper, Bredehoeft, and Papadopulos (Lohman, 1972, p. 27–30). Also, for comparison, variable-head permeability tests (U.S. Department of Navy, 1962, p. 7–4–9) were applied to the data where physical conditions at the well met requirements of the method. Generally, transmissivity values estimated from 10-min specific-capacity tests are too high, because the water stored in the well bore represents much of the water pumped during the test. The results using the permeability tests are probably more reliable.

Slug tests provide, at best, rough estimates of transmissivity values that support other data. According to Lohman (1972, p. 27), the "slug" method is strictly applicable to wells that fully penetrate artesian aquifers of low transmissivity and, if applied to wells in unconfined aquifers, the results should be regarded with skepticism.

Specific-capacity tests were done on 6-in.-diameter wells, and slug tests were done on 2.37-in.-diameter test borings. Lab permeability tests were performed on 78 cores obtained from these test borings. Hydraulic conductivities ranged from $5.3 \times 10^{-7}$ to $1.3 \times 10^{-1}$ ft/d, and the median hydraulic conductivity was $2.7 \times 10^{-6}$ ft/d (J.T. Gallaher, written commun.). These lab values are low because they reflect only intergranular, primary permeability and not secondary permeability features such as joints, fractures, and bedding plane separations that contain and transmit most of the ground water.

The transmissivity data for wells in the mined area indicate no clear-cut relationship between rock permeability and mining at depth. However, wells 21A, 21B, and 21C are cased and equipped with packers and slotted casings at intervals of 155–175, 118–147, and 33–54 ft, respectively. The computed transmissivity values indicate the highest value in the shallow well, the next highest in the deep well, and the lowest in the well of medium depth. Wells 21C and 26C are open 33 to 54 ft and 39 to 59 ft below land surface, respectively, and have transmissivity values of 9 and 12 $ft^2/d$. Wells 21B, 23, 31, 32, and 36B are open to rocks 12 to 54 ft above the mine and have transmissivities ranging from 0.0 to 26 $ft^2/d$.

The highest transmissivity determined for any of the wells in the area was 2,400 $ft^2/d$ at well 109 in Coalton, W. Va., which taps an artesian aquifer stratigraphically beneath the mined coal bed.

Wells 25 and 35B are open over nearly all of their lengths, penetrate the mined coal bed, but have water levels less than 26 ft below land surface. The slug tests indicate low rock permeability or clogging of the formation with fine drill cuttings or mud.

Well 26A (194 ft deep) is an uncased borehole several feet from well 26C (59 ft deep). The water level in well 26A fluctuates nearly 100 ft in a year. Its water level responds quickly to precipitation, indicating good hydraulic connection to land surface. Its water level may drop 85 ft in 1 month, indicating hydraulic connection to the mine below. Yet well 26C is open between depths of 39 and 59 ft and its water level may fluctuate 15 to 36 ft annually. A nearby fully cased well (26B) was originally 197 ft deep in October 1964, but subsequent collapse of rock reduced its depth to 154 ft. Thus, subsidence fractures exist at least 95 ft below the bottom of well 26C, but apparently no fractures of hydrologic significance penetrate upward to drain the water from the vicinity of well 26C.

| Well no. | Depth (feet) | Diameter (inches) | Casing length (feet) | Water level (feet below land surface) | Section open hole (feet) | Specific capacity at 10 minutes (gallons per minute per foot) | Transmissivity (feet squared per day) | | | Depth of coal bed below land surface (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Estimated from specific capacity | Estimated from variable-head permeability test | Estimated from slug test data | |
| **SPECIFIC–CAPACITY TESTS** | | | | | | | | | | |
| 18–3–21A | 175 | 6 | 163 | 133.92 | 155–175 | 0.23 | <5.0 | 0.3 | | 150 |
| 18–3–21B | 147 | 6 | 129 | 10.51 | 118–147 | (low) | [1] 0.0 | | | 150 |
| 18–3–21C | 54 | 6 | 46 | 24.00 | 33–54 | 0.34 | 11.0 | 9.0 | | 150 |
| 18–3–26C | 59 | 6 | 61 | 24.65 | 39–59 | 0.35 | 12.0 | | | 150 |
| 18–3–109 | 158 | 6 | 10 | 12.22 | 12–158 | | 2,400.0 | | | ---[5] |
| **SLUG TESTS** | | | | | | | | | | |
| 18–3–16 | 243 | 2.37 | <10 | 21.58 | 10–243 | | | | 41.00 | |
| 18–3–23[2] | 81 | 2.37 | 20 | 39.08 | 20–81 | | | | 26.00 | 135 |
| 18–3–25 | 294 | 2.37 | 14 | 18.07 | 14–294 | | | | 0.50 | 145 |
| 18–3–31[3] | 78 | 2.37 | 10 | 13.33 | 10–78 | | | | 0.13 | 105 |
| 18–3–32[4] | 146 | 2.37 | 16 | 47.66 | 16–146 | | | | (high) | 200 |
| 18–3–34 | 257 | 2.37 | 26 | 36.67 | 26–257 | | | | 7.00 | 95 |
| 18–3–35B | 223 | 2.37 | 21 | 26.05 | 21–223 | | | | (low) | ---[5] |
| 18–3–36A | 156 | 6 | 150 | 145.32 | 135–156 | 0.52 | | | 19.00 | 140 |
| 18–3–36B | 117 | 6 | 119 | 109.45 | 95–117 | | | | (low) | 140 |

[1] After pumping, water level recovered only 0.16 feet in 34 days.
[2] Well penetrated mine at 135 feet; plugged back to 81 feet depth so it would hold water.
[3] Well penetrated mine at 105 feet; plugged back to 78 feet depth so it would hold water.
[4] Well penetrated mine at 200 feet; plugged back to 146 feet depth so it would hold water.
[5] Well penetrates rocks stratigraphically lower than the mined coal seam.

**Figure 2.5A.** Transmissivity data as determined from wells, using various testing methods.

# Underground Mining and Some Strip Mining Modify Hydrologic Budget of Roaring Creek and Grassy Run

Underground mining and subsidence cause increased rock permeability, lower ground-water levels, decreased evapotranspiration, and interbasin transfer of water.

The coal bed in the ridge separating Roaring Creek and Grassy Run basins has been deep mined, and in some outcrop areas the coal has been strip mined. Mining activity has diverted water from Roaring Creek basin to Grassy Run basin in some places because both the coal bed and the hydraulic gradient in the coal mine generally dip from Roaring Creek to Grassy Run. Thus, water that enters the rocks in parts of Roaring Creek basin leaks into the mine and is eventually channeled through the mine and into Grassy Run. The net result is that the drainage area contributing ground water is increased for Grassy Run and correspondingly reduced for Roaring Creek.

The graph in figure 2.6A shows monthly runoff from the nearby unmined basin of Sand Run and monthly combined runoff from the mined basins of Roaring Creek and Grassy Run. The Roaring Creek–Grassy Run basins have the greater yield per square mile of surface drainage area. Sixty-five percent of the points plot above the line of equal runoff, indicating a greater yield from the mined basins, assuming similar precipitation in the basins. Thus, Grassy Run receives not only atmospheric precipitation, but also subsurface water diverted from Roaring Creek basin (fig. 2.6B). The water entering Grassy Run basin underground is not subject to evapotranspiration until it is discharged to the surface. Thus, Grassy Run basin has decreased evapotranspiration.

Surface water similarly may be captured and diverted to another drainage basin. Before the reclamation in Roaring Creek basin, overland runoff was captured in some strip mine excavations. The water would then seep through the coal or flow into mine openings and move downdip to Grassy Run.

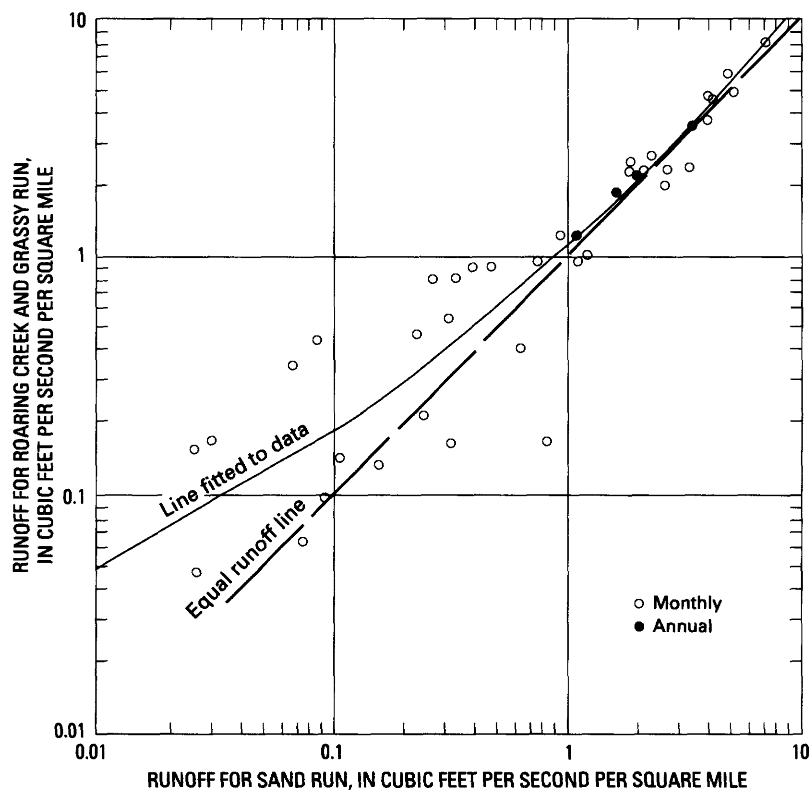



**Figure 2.6A.** Monthly and annual runoff relationship of Sand Run basin (drainage area 14.5 mi$^2$) to combined Roaring Creek–Grassy Run basins (drainage area 32.1 mi$^2$).

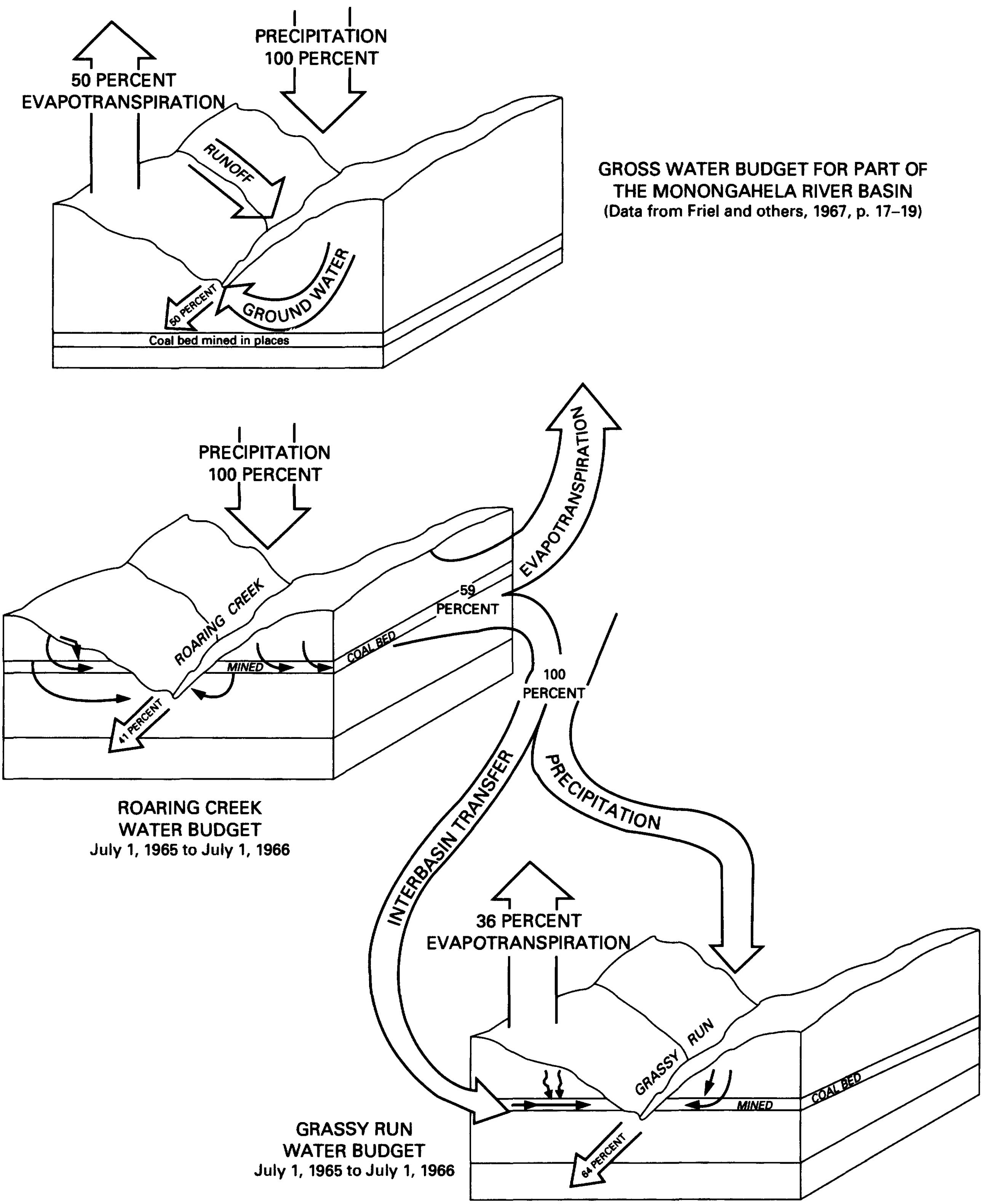



**Figure 2.6B.** Approximate percentages of water in parts of the hydrologic cycle in Roaring Creek and Grassy Run basins, compared to the gross water budget for part of the Monongahela River basin in West Virginia.

# 3.0 MINED BED BELOW MAJOR STREAMS OR RIVERS

## 3.1 *Mining and Subsidence—Farmington, W. Va., Area*

### 3.1.1 *Mining History and Methods*

# **Farmington, W. Va., Area Mined From Early 1920's Until 1971**

Room-and-pillar mining began in the Farmington, W. Va., area in the early 1920's, and continued until July 1971, when the mine was abandoned.

The Pittsburgh coal is about 7 ft thick and lies 270 to 300 ft below the village of Farmington, W. Va. The following mining history at Farmington is summarized from GAI Consultants, Inc. (1977):

The mine underlying the general area opened in the early 1920's and operated until July 1971. Mining beneath Farmington was conducted from 1959 through 1961. The mine (fig. 3.1.1A) had been developed using a conventional room-and-pillar system, with 15-ft-wide entries driven on 90-ft centers, to develop square pillars 75 ft on a side. During retreat mining, these pillars were systematically removed in a total-extraction operation. Beneath the town, about 50 percent of the coal was removed by splitting the pillars.

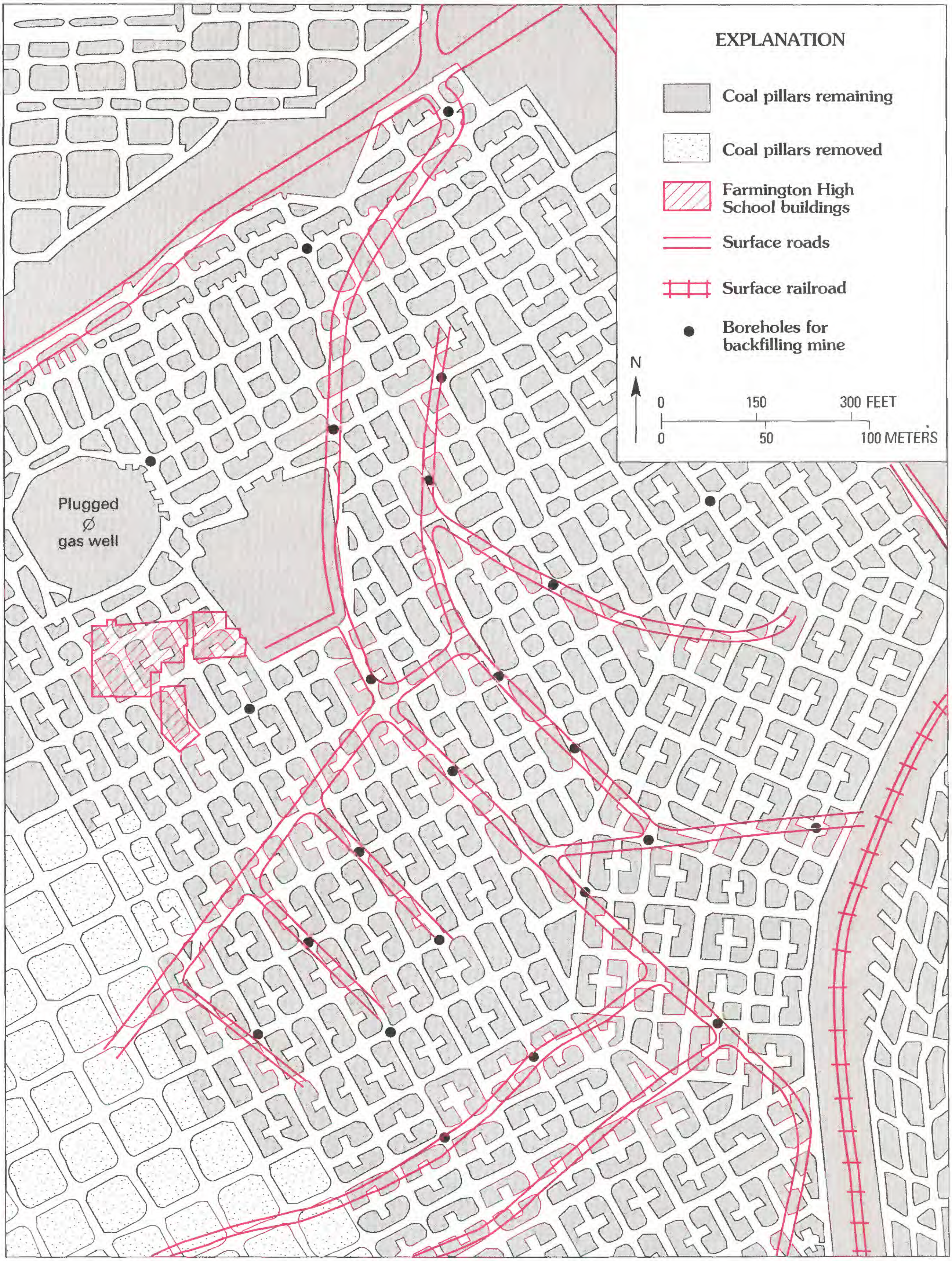



**Figure 3.1.1A.** Mine map of the Farmington, W. Va., area. (Modified from map supplied by U.S. Bureau of Mines.)

# Surface Subsidence Began About 12 Years After Mine Abandonment

Surface subsidence began about 12 years after mine abandonment. Now cracks are found more than a mile from Farmington, W. Va., and more than 600 ft above the mine.

Subsidence, which began about 12 years after mine abandonment, was not confined to the immediate vicinity of Farmington, W. Va. Surface subsidence fractures were found 1 mi or more from Farmington and 600 ft or more above the mine.

Some investigators (GAI Consultants, Inc., 1977, p. 118) believe that subsidence in the Farmington area may have been caused by the coal pillars pushing into the underlying clay. Another factor that may have contributed to the areal collapse is the synclinal (downwarped) rock structure found there, which would tend to have less supporting strength than an anticlinal (upwarped) structure. Jointed or fractured zones of weakness in the rock are also indicated by photo lineaments. Thus, the combined effects of soft underclay, geologic structure, and fractured zones may have caused massive areal subsidence.

In 1978 the U.S. Bureau of Mines attempted to prevent further subsidence at Farmington by pumping 85,000 tons of fine shale and water slurry into the mine through a series of about 30 boreholes. To date, no conclusions have been made as to the effect of this backfilling on subsidence.

To evaluate the effects of underground mining on the overlying rocks and the potential leakage from surface reservoirs, the U.S. Soil Conservation Service tested borehole permeability at a dam site in Middle Wheeling Creek basin (fig. 3.1.2A), and took pictures in an 8-in. well (½ mi north of Dallas, W. Va.), where the mined Pittsburgh coal is 590 ft below land surface (fig. 3.1.2B).

Figure 3.1.2A shows how hydraulic conductivity (permeability) varies with depth in two boreholes at the dam site. The generally high hydraulic conductivity in the upper zone is largely due to greater rock fracturing and jointing near the land surface. Tests in the other boreholes indicate that hydraulic conductivity in the upper zone (approximately the first 50 ft of rock below the valley floor) ranges from 0.0 to 21.1 ft/d. The higher values generally are closer to the surface. Tests were done only to a depth at which low permeabilities were found. Although there are no test data for the 100 ft of rock above the mine, geologists' descriptions in well logs suggest that the most broken and permeable rock is 100 ft or less above the mine, and 50 ft or less below the valley bottom.

The photographs in figure 3.1.2B of a well located about 40 mi northwest of Farmington in stratigraphically similar rocks may give some insight into the effect of subsidence on the rock and ground water above the mined Pittsburgh coal in Buffalo Creek basin. Pictures taken in the well from 145 ft above the coal to about 20 ft below the coal show that subsidence may have caused cracks as high as 94 ft above the mine. However, most cracks are in the 30 ft of sandstone and shale that lie just above the mine. Thick beds of sandstone and limestone above 496 ft may retard the upward migration of subsidence fractures. Geologists' descriptions of core samples from 2 of 11 boreholes located in the area behind the Wheeling Creek dam, about 3 mi west of the 8-in. well, indicate that subsidence cracks extend about 83 ft above the mine. In one hole, fracturing may have extended 146 ft above the coal, but in eight holes there was little indication of subsidence cracks more than 10 ft above the mine.

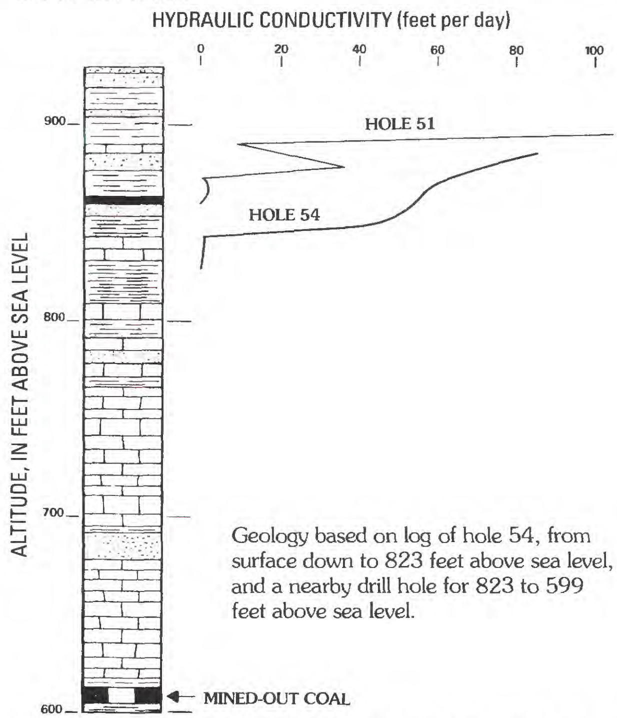



**Figure 3.1.2A.** Composite geologic log for drill holes at Wheeling Creek Dam site 7, and hydraulic conductivity graph for two drill holes. (Logs and hydraulic conductivity data courtesy of U.S. Soil Conservation Service.)

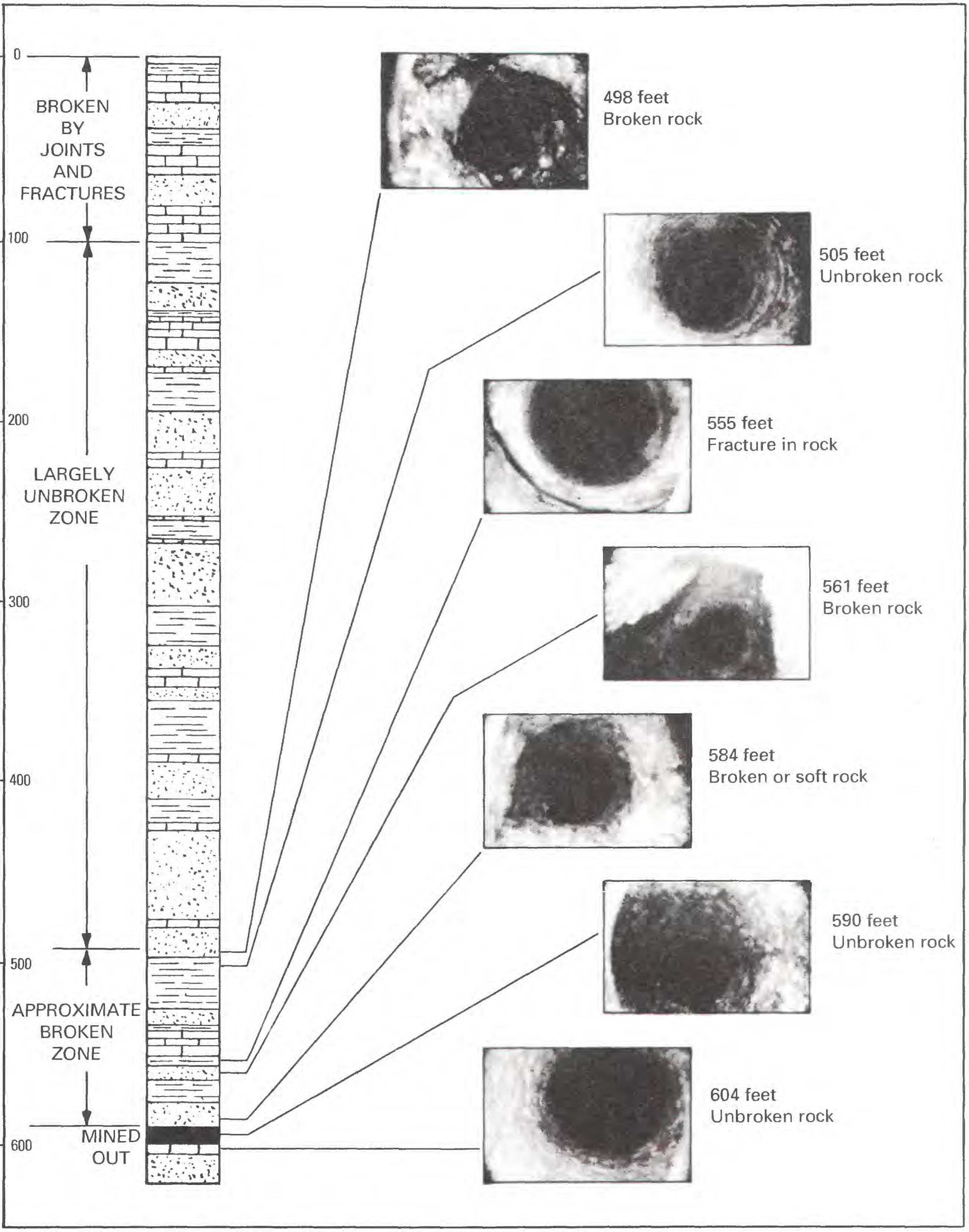



**Figure 3.1.2B.** Geologic log and photos in an 8-in. well penetrating rocks above a mine in the Pittsburgh coal in Ohio County, W. Va. (Photographs courtesy of U.S. Soil Conservation Service.)

3.1.3 *Orientation of Subsidence Fractures*

## Subsidence Cracks Commonly Develop Along Existing Rock Joints; Mine Collapse Commonly Occurs Where Lineaments Intersect

Nearly all consolidated rocks contain joints and fractures or faults. Joints are relatively short planar fractures along which there has been no apparent movement parallel to the joint plane. Rocks commonly contain parallel sets of joints that reflect stresses applied to the rocks. For example, if horizontal or vertical pressure, or release of pressure (such as that caused by erosion) is exerted on this rock, joints may develop in response to these stresses. Joint orientation is apparently independent of rock type; that is, joint orientation is approximately the same in sandstone, shale, limestone, or coal. Principal joint orientations are shown in figure 3.1.3A for the general region of Farmington and Northern West Virginia.

Lineaments are linear features that appear on aerial photographs or other imagery, but cannot easily be identified and mapped from the ground. Lineaments are generally caused by differences in plant types, soil tone or moisture content, alignment of disrupted rock outcrops, or alignment of topographic features such as straight segments of stream channels. Lineaments often represent fractures, faults, or joint systems, which generally are zones of structural weakness and increased permeability.

Three lineaments pass through the Farmington, W. Va., area (fig. 3.1.3B). Mine Safety and Health Administration (MSHA) officials report a correlation between roof falls in mines and intersections of lineaments mapped from aerial photographs and satellite images (K. McCabe, J. Jansky, oral commun., 1978). Additionally, water and gas problems in mines have been noted at depth beneath surface lineaments.

Various investigators (Diamond and others, 1975) have determined that the orientation of photo lineaments reflects the orientation of major joints in bedrock and the "cleat" in coal beds. The straight, linear nature of mine-subsidence cracks suggests that they may develop along existing joints. The orientations of 55 subsidence cracks measured near Farmington are shown in figure 3.1.3B. Comparing the orientation of these cracks to the orientation of major joints in the rose diagram (fig. 3.1.3A), 71 percent of the cracks fall within the shaded ranges of the major joint trends. Another set of less prominent orthogonal joints trend about N90° and N0°W, as indicated in the rose diagram. If subsidence cracks oriented in these directions are considered, then the orientation of 90 percent of the subsidence cracks falls within the ranges shown for major joints.

The subsidence cracks on the side of a hill and nearly parallel to the valley seem to be the widest, probably because the subsidence may be accompanied by downslope movement of the rock. Numerous springs or seeps were mapped from thermal imagery of the area (section 3.4.3); most are located above clay layers. Note the dry springs shown near mapped subsidence cracks (fig. 3.1.3B).

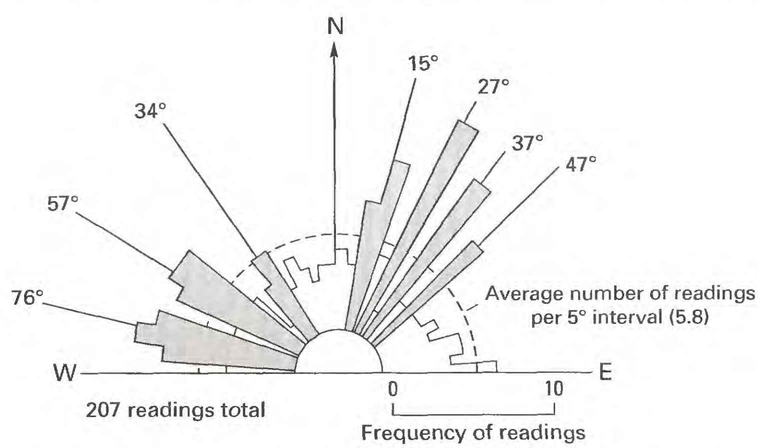



**Figure 3.1.3A.** Composite rose diagram of principal bedrock joint trends. (Modified from Bench and others, 1977, p. 19.)

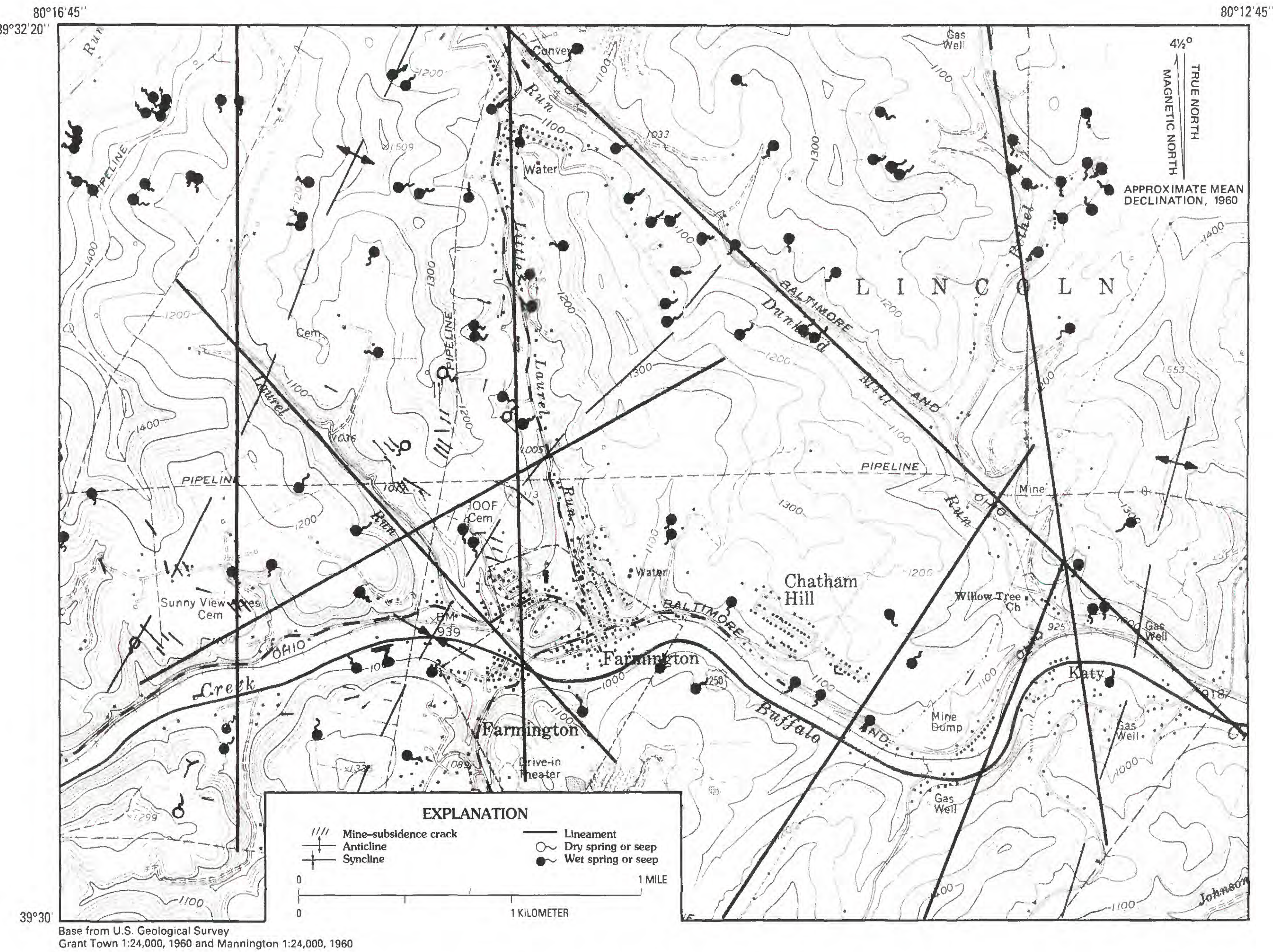



**Figure 3.1.3B.** Map showing mine-subsidence cracks, wet and dry springs, geologic structure, and lineaments. (Anticline and syncline axes from, or inferred from, L.B. Heffner, 1966, Geology of the Grant Town, W. Va., quadrangle, and N.L. Williamson, 1967, Geology of the Shinnston 7.5′ quadrangle, both unpublished theses, West Virginia University.)

## 3.2 *Streamflow*

### 3.2.1 *Base Flow*

# Base Flow of Streams Generally Highest From Areas Underlain by Abandoned Mines

Base-flow measurements of streams show highest yields from areas underlain by abandoned mines, lowest yields from areas underlain by active mines, and median yields from areas that are largely unmined.

Approximately 50 streams and 20 mine-discharge sites were measured and sampled over a 5-day period in October 1977. Five of these sites were at temporary gaging stations equipped with continuous recorders (Hibbs Run 10, Laurel Run 26, Davy Run 39, Stewart Run 49, and Indian Creek 50). The drainage area for all of the stream sites was measured from topographic maps. After subtracting mine discharge from the stream discharge, discharge per square mile of drainage area was computed for each site (figs. 3.2.1A,B). Discharge ranged from 0.12 to 0.78 $(ft^3/s)/mi^2$, the higher yields being in the lower parts of both basins, where they are largely underlain by abandoned mines. The lowest yields are in central Buffalo Creek basin and upper Indian Creek basin, where they are largely underlain by active mines. Median yields are found in upper Buffalo Creek basin, where it is largely unmined.

(*Text continues on page 46.*)

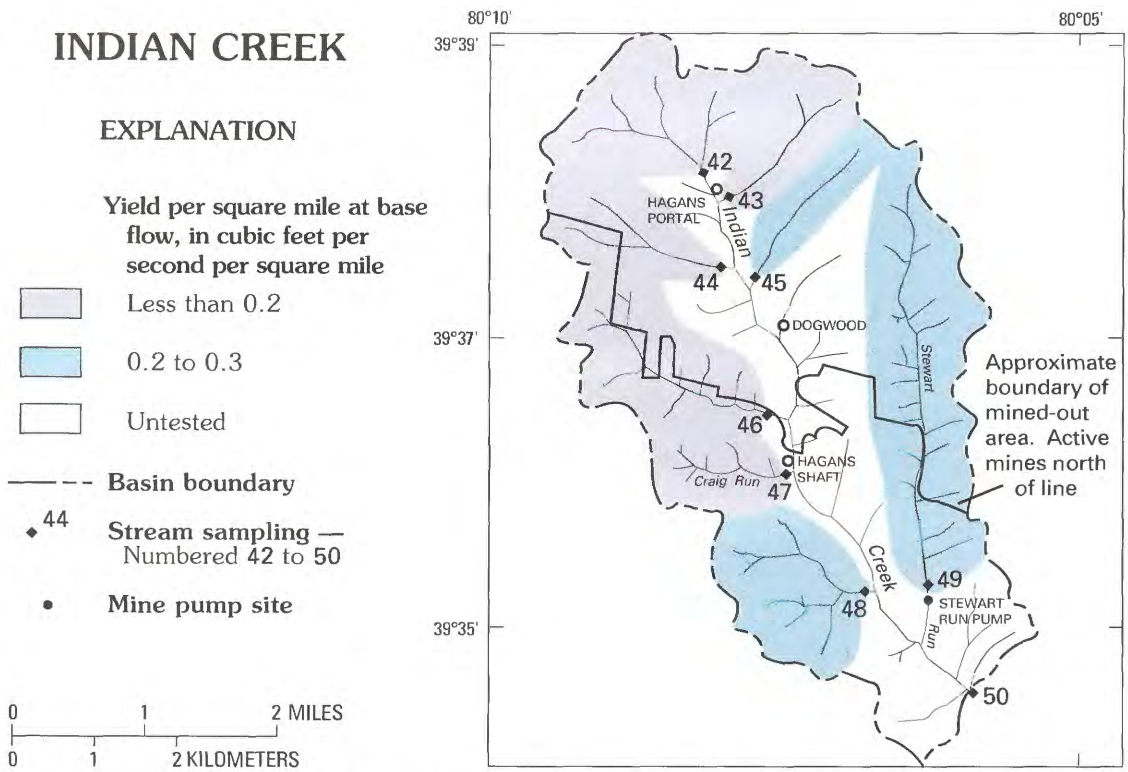



**Figure 3.2.1A.** Yield per square mile at base flow, Indian Creek, October 1977.

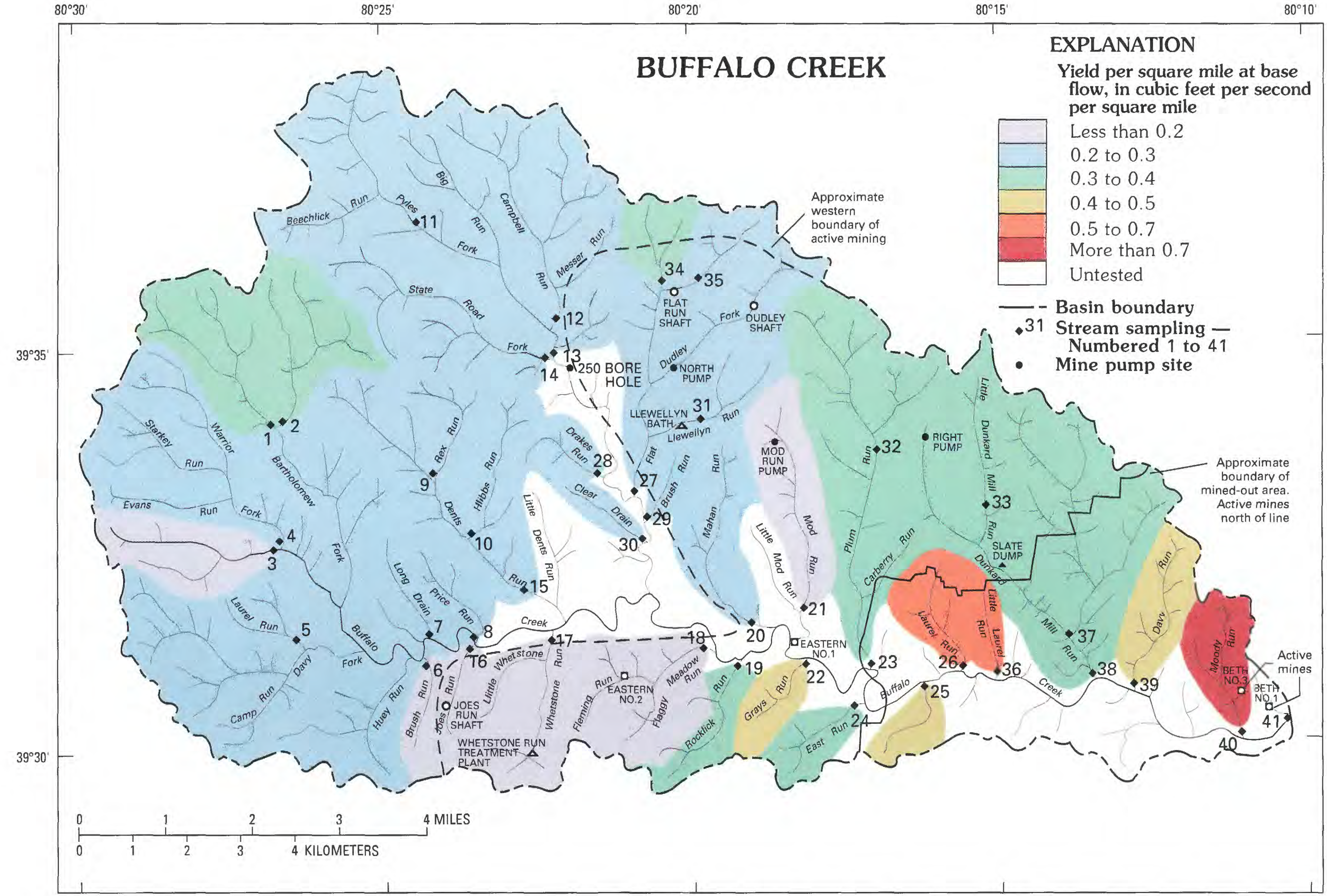


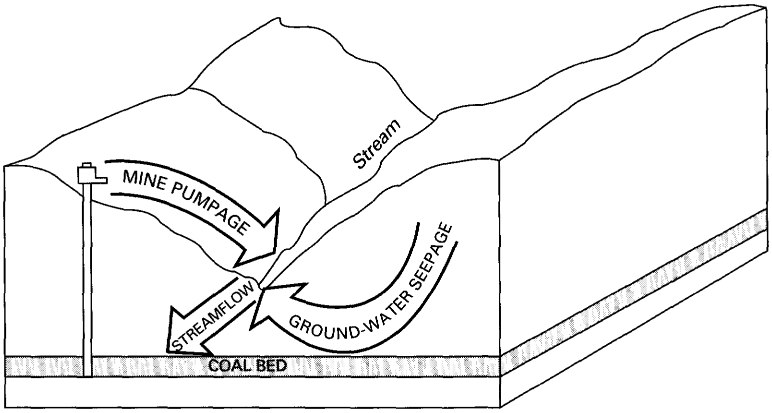

**Figure 3.2.1B.** Yield per square mile at base flow, Buffalo Creek, October 1977.

Base-flow measurements in Buffalo Creek basin and Indian Creek basin showed that 10 percent of the flow of Buffalo Creek at Barrackville, W. Va., was derived from mine pumpage, whereas 35 percent of the flow of Indian Creek at Crown, W. Va., was derived from mine pumpage (fig. 3.2.1C). At the time of the base-flow measurements, a part of the mine water discharging into Indian Creek was derived from a mined area outside of the basin. Pumpage from this point ceased after these base-flow measurements were made, and the water level in the mine rose approximately 2 ft. The fact that the water level rose no further suggests that water from this area now drains to another pump site outside the drainage basin.

Some factors that may influence low-flow yield per square mile, other than underground mining and mine pumpage, are as follows:

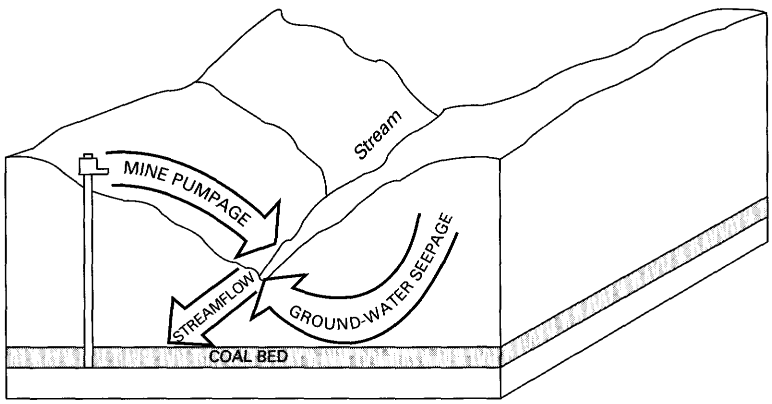
1. Changes in geology from the lower to the upper parts of the basins. Change in geology is thought to have little effect because the yields of wells drilled in the Dunkard and Monongahela Groups of rocks are nearly the same and average 12 and 13 gal/min, respectively (Ward and Wilmoth, 1968, p. 5).
2. Abandoned drift mines in the Waynesburg coal bed may act as drainage conduits. The Waynesburg coal is 5 ft thick and lies at the base of the Dunkard Group. The amount of drainage from these mine openings depends upon the size of the underground workings and the degree of subsidence and fracturing of overlying rocks. There is some discharge from a mine into Little Laurel Run. Underground mines that extend beneath or close to topographic divides of adjacent basins can modify underground drainage patterns and significantly alter the size of the area contributing water to the basin. Via interbasin transfer of water through the mines, the actual drainage area of one basin may be increased, whereas that of the adjoining basin is correspondingly reduced. Thus, the ground-water divide does not correspond to the topographic divide. The outcrop of the Waynesburg coal in Buffalo Creek is about 8 mi upstream from the gage at Barrackville. The outcrop in Indian Creek is about 3¼ mi upstream from the gage at Crown.
3. Precipitation may vary from one basin to another. Rain gages at three sites in Buffalo Creek basin near Mannington, W. Va., show that rainfall in 1978 varied over short distances by about 7.3 in./yr. Evapotranspiration losses may also vary because of different amounts of forest cover in the basins.
4. Discharge of domestic waste water through septic systems. Most public-supply water for the Farmington, W. Va., area is piped from Fairmont, W. Va., which lies outside the study area. Most of this water is discharged through septic tank drain fields. The amount of water supplied by Fairmont to the Ices Run water district (includes Farmington, Chatham Hill, and Katy areas) in lower Buffalo Creek basin averaged 62,000 gal/d from 1973 to 1976. This is about 43 gal/min or 0.096 $ft^3/s$ on a continuous basis. Assuming that the entire 0.096 $ft^3/s$ were supplied to homes and discharged along Little Laurel Run, then subtracting this amount from the flow of the stream would yield a discharge of about 0.54 $(ft^3/s)/mi^2$. This value is still nearly double the yield of streams in unmined areas. Also, Laurel Run and East Run do not have public water supplies, nor do some of the other streams that show high yields in lower Buffalo Creek basin.

Abandoned drift mines in the Waynesburg coal and variations in both precipitation and evapotranspiration are probably the main factors that could mask the effect of the deep mines and subsidence on basin yields.




BUFFALO CREEK BASIN — OCTOBER 1977

Mine pumpage equals 10 percent, or 4.6 cubic feet per second.
Ground-water seepage equals 90 percent, or 41.9 cubic feet per second.
Streamflow equals 100 percent




INDIAN CREEK BASIN — OCTOBER 1977

Mine pumpage equals 35 percent, or 1.4 cubic feet per second.
Ground-water seepage equals 65 percent, or 2.7 cubic feet per second.
Streamflow equals 100 percent

**Figure 3.2.1C.** Amounts of water contributed to Buffalo Creek and Indian Creek from mine pumpage and ground-water discharge at base flow.

3.2.2 *Flow Duration*

# Flow-Duration Data Indicate Higher Average Flow and Base Flow From Undermined Areas

Higher average and base flows from areas that are undermined are mainly due to (1) increased infiltration, and hence less evapotranspiration, and (2) increased ground-water storage created by subsidence fracturing.

Flow records are available for Buffalo Creek at Barrackville, W. Va., from 1915 to present (except for 1924–31). Coal mining began in the early 1900's in the lower part of the basin near Barrackville. Since then, mining has progressed to the west. Presently, underground mines are active 2–3 mi southwest of Mannington, W. Va.

Flow records for Buffalo Creek were analyzed for selected years having nearly average precipitation, based on rainfall records at Mannington and Fairmont, W. Va. A streamflow-duration curve (fig. 3.2.2A) was prepared from the combined data for 1916, 1918, and 1922, showing little or no effects from mining. The curve for 1935, 1936, and 1943 shows some effects of mining, and the curve for 1971, 1972, and 1976 shows the greatest effects of mining.

The base flow (or lower part) of the 1971, 72, 76 curve is higher than the base flow of the other two curves, even though the 1971, 72, 76 period was preceded by 8 to 10 years of below-average precipitation. This increase in base flow may be due to (1) mine subsidence and its associated fracturing, lowering the water table and causing increased infiltration and reduced evapotranspiration; (2) increased storage of surface water by mine treatment ponds, and its subsequent release; (3) increased ground-water storage in subsidence fractures; and (4) interbasin transfer of water underground.

The average annual flow of Buffalo Creek has also increased. The average flow for the period of record at Barrackville is 177 $ft^3/s$. This flow is equaled or exceeded 24 percent of the time on the curves for 1916, 1918, 1922, 1935, and 1936. The 24-percent duration point on the 1971, 72, 76 curve is about 25 $ft^3/s$ (or 14 percent) higher than average flow. Average estimated and measured mine pumpage for 1976 was 2.75 $ft^3/s$ in Buffalo Creek basin, or about 11 percent of the 25 $ft^3/s$ increase in average flow for 1971, 72, 76. The increased average annual flow may be due to the same factors causing increased base flow.

In summary, underground mining and mine collapse in Buffalo Creek basin, particularly in the Farmington, W. Va., area, have cracked the rocks and increased near-surface permeability more than permeability at depth (see sections 3.5.1 and 3.5.2). The surface fractures improve ground-water recharge from precipitation, but, at the same time, drainage along mine-collapse fractures lowers the water table and, in conjunction with mine pumpage, reduces evapotranspiration. The high base flow of Buffalo Creek is partly the result of mine-discharge water, but primarily of reduced evapotranspiration and greater ground-water recharge.

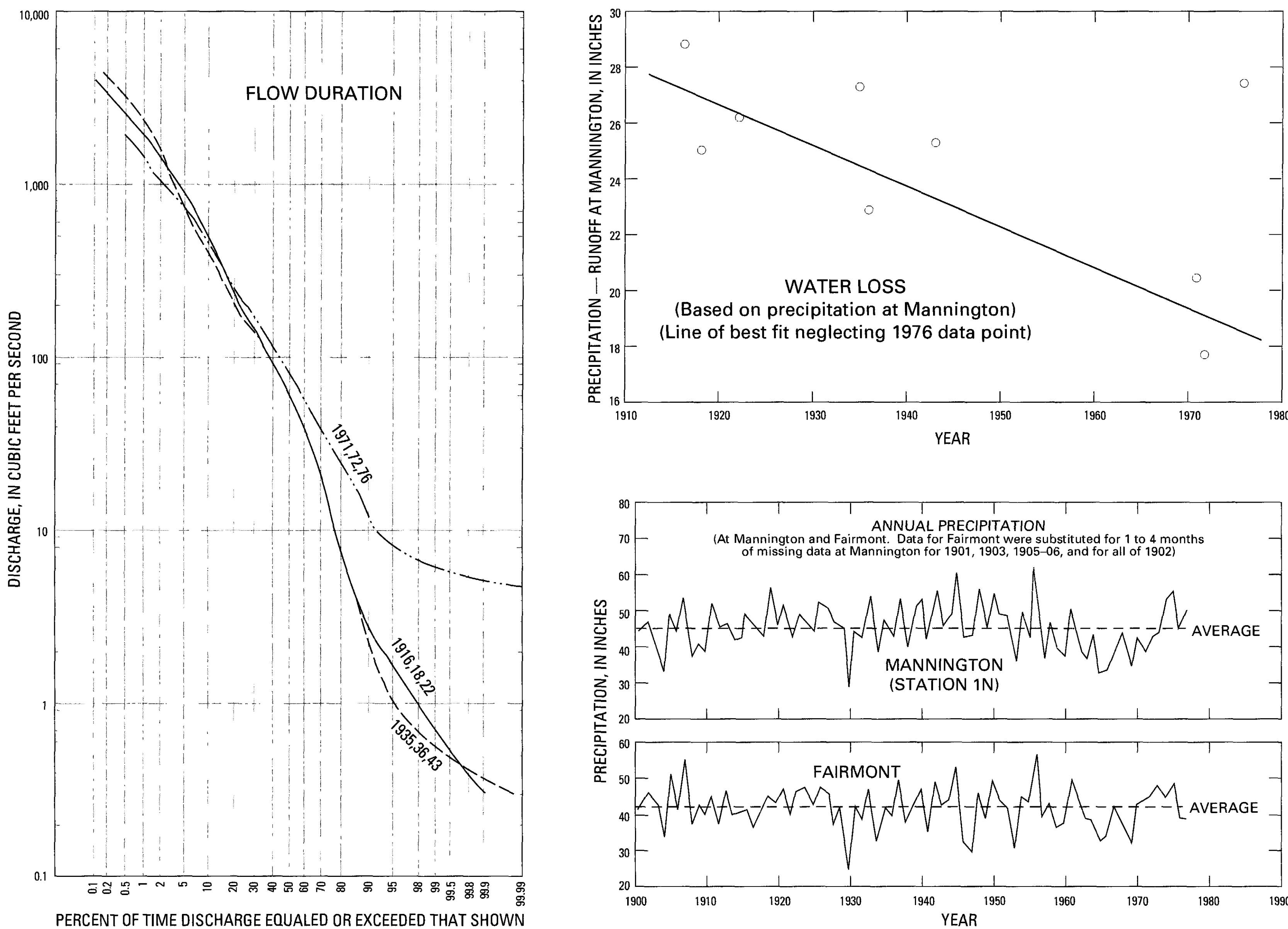



**Figure 3.2.2A.** Flow-duration, water-loss, and precipitation curves for Buffalo Creek basin.

3.2.3 *Stream Seepage Measurements*

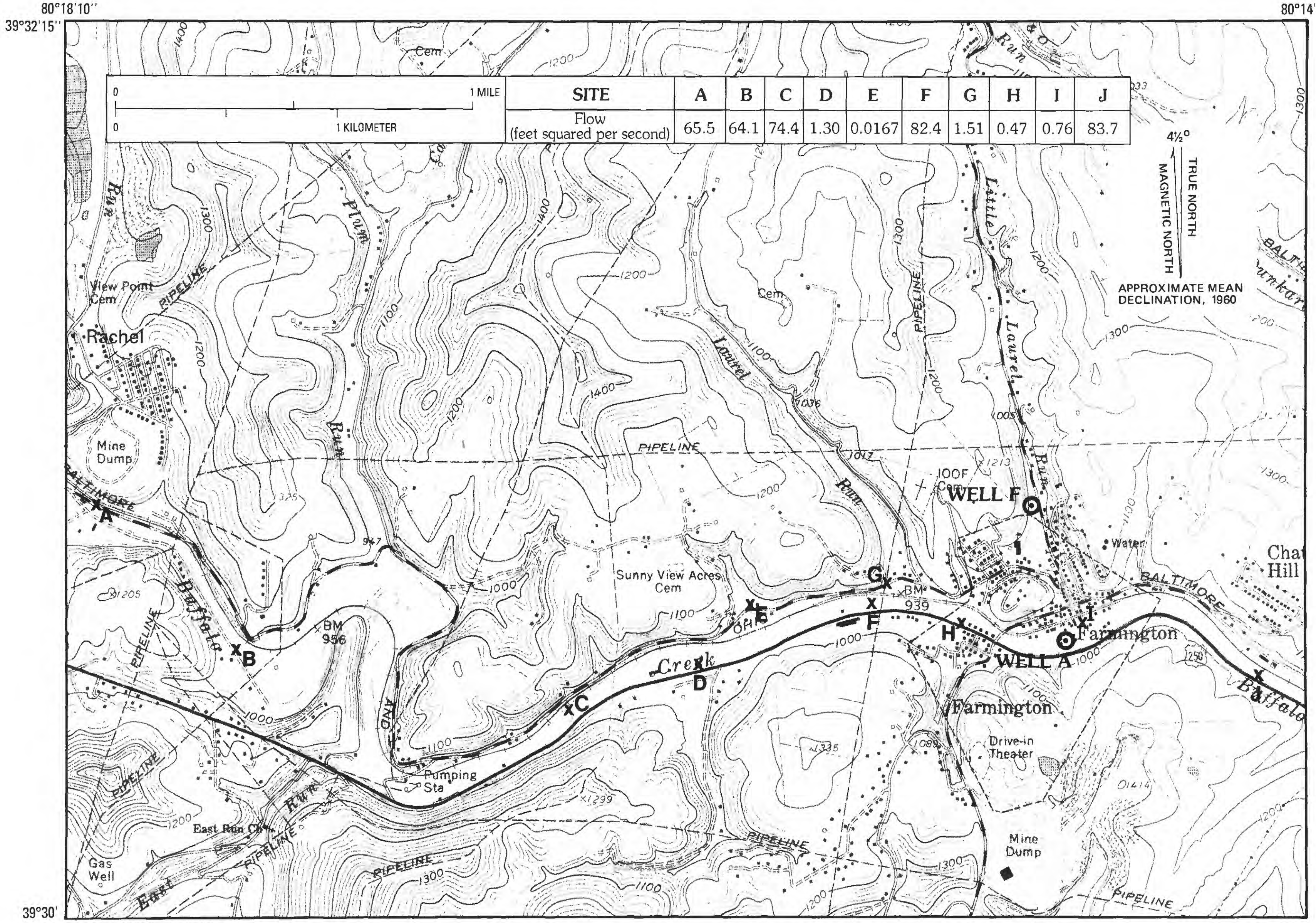
# Seepage Measurements on Buffalo Creek Near Farmington, W. Va., Indicate Both Gains and Losses in Undermined Areas

Seepage measurements on Buffalo Creek indicate losses of 1.1 to 1.8 ($ft^3/s$)/mi and a gain in one reach of 6.7 ($ft^3/s$)/mi.

Figure 3.2.3A shows flows measured on Buffalo Creek and some tributaries near the collapsed area at Farmington, W. Va. The measurements show a gain in flow between sites B and C and between sites C and F. The increase between sites B and C is probably due to inflow from Plum and East Runs (not measured). The inflow from tributaries between sites C and F was measured and, after subtracting this inflow, a gain of 6.7 ($ft^3/s$)/mi is still realized in this reach.

A loss of 1.4 $ft^3/s$ was measured between sites A and B, and 1.4 $ft^3/s$ between sites F and J (loss between sites F and J equals F+G+H+I–J). The loss between sites A and B may be due to a fractured zone along the lower part of this reach, which follows a lineament. Also, dewatering the coal bed by mine pumpage at Rachel may induce water from Buffalo Creek to flow downward along the lineament. The loss in this reach is 2.15 ($ft^3s$)/mi, whereas the loss is 1.1 ($ft^3s$)/mi for the area between sites F and J, which is known to be affected by mine subsidence.

The water level in observation well F, which is open to the mine beneath Farmington, is 199.6 ft below land surface. Well A is one of several wells formerly used by the village of Farmington. The water level in this 98-ft-deep well (originally 128 ft deep) at the time of the flow measurements was 70 ft below land surface, or about 57 ft below the level of the stream. These wells were used for a public water supply until drainage by the mines lowered local ground-water levels and well yields. The low water level in both wells indicates that there is potential for water loss from Buffalo Creek, although the measured loss is only 1.4 $ft^3/s$ out of 83.7 $ft^3/s$, or 1.7 percent of the total flow. An excellent streamflow measurement is considered to be within 2 percent of the actual flow; thus, the measured loss is less than the accuracy of the measurement. (All flows were measured by S.M. Ward using the same equipment on May 11, 1979, so as to minimize differences in flow measurement due to operator, technique, or equipment variables.)




| SITE | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| Flow (feet squared per second) | 65.5 | 64.1 | 74.4 | 1.30 | 0.0167 | 82.4 | 1.51 | 0.47 | 0.76 | 83.7 |

Base from U.S. Geological Survey
Grant Town 1:24,000, 1960 and Mannington 1:24,000, 1960

**Figure 3.2.3A.** Sites, shown by crosses, measured to determine flow gain or loss in Buffalo Creek near Farmington, W. Va.

3.3 *Stream Quality*

3.3.1 *Specific Conductance at Low Flow*

# Specific Conductance Is Elevated at Low Flow in Streams Receiving Water Pumped From Mines

Specific conductance of streams at low flow in unmined areas ranges from 95 to 155 microsiemens; specific conductance of streams in mined areas ranges from 150 to 3,600 microsiemens.

Treated mine water contributes large amounts of dissolved minerals to streams, which, in turn, increase the specific conductance of the streams. This occurrence is particularly noticeable in dry fall weather, when streams are low and dilution by precipitation is minimal.

Specific conductance is a good indicator of mining activity. The western part of Buffalo Creek basin is essentially unmined, and specific conductance of streams ranges from 95 to 155 μS (see figs. 3.3.1A and B). The central and eastern parts of the basin are underlain by mines, and specific conductance ranges from 150 to 3,600 μS. Nearly all of Indian Creek basin is undermined or currently being mined, and specific conductance of streams in this basin ranges from 165 to 2,300. (This highest conductance value, measured in Indian Creek, is at the most downstream site and below a point where mine discharge enters from Stewart Run.) The specific conductance of streams, such as Laurel Run and Little Laurel Run (near Farmington, W. Va.), is high because of suspected increased infiltration and weathering along subsidence cracks.

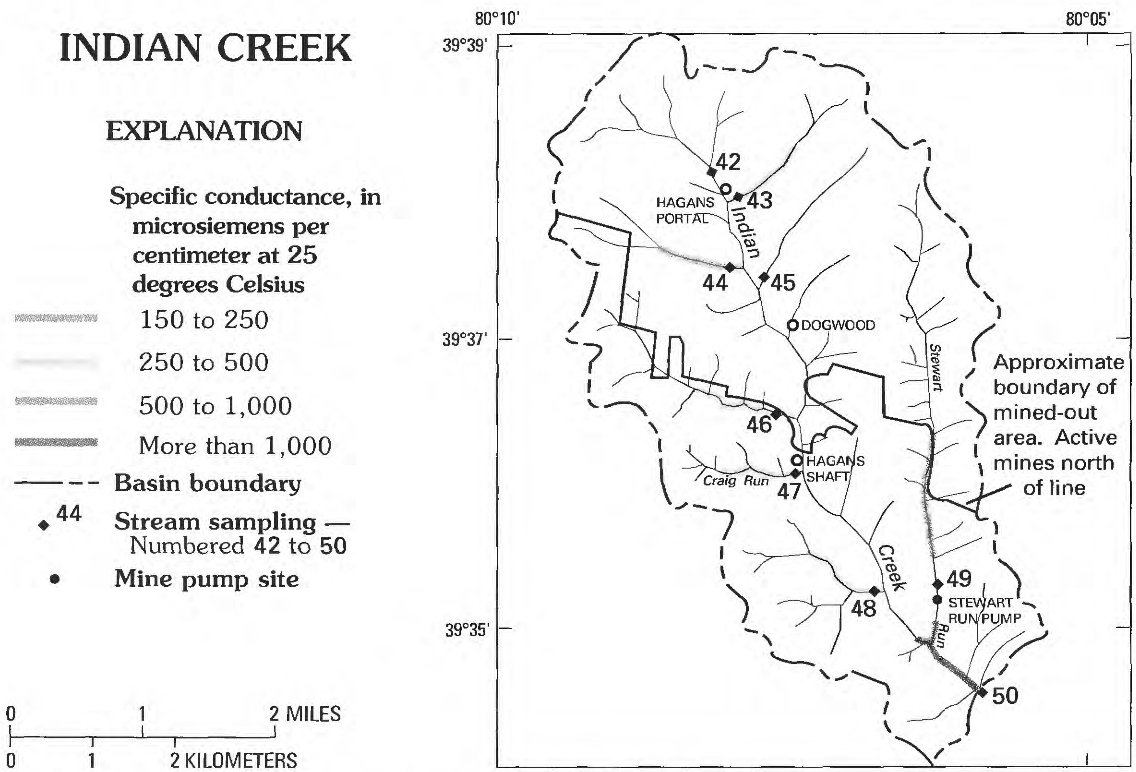



**Figure 3.3.1A.** Specific conductance at base flow, Indian Creek, October 1977.

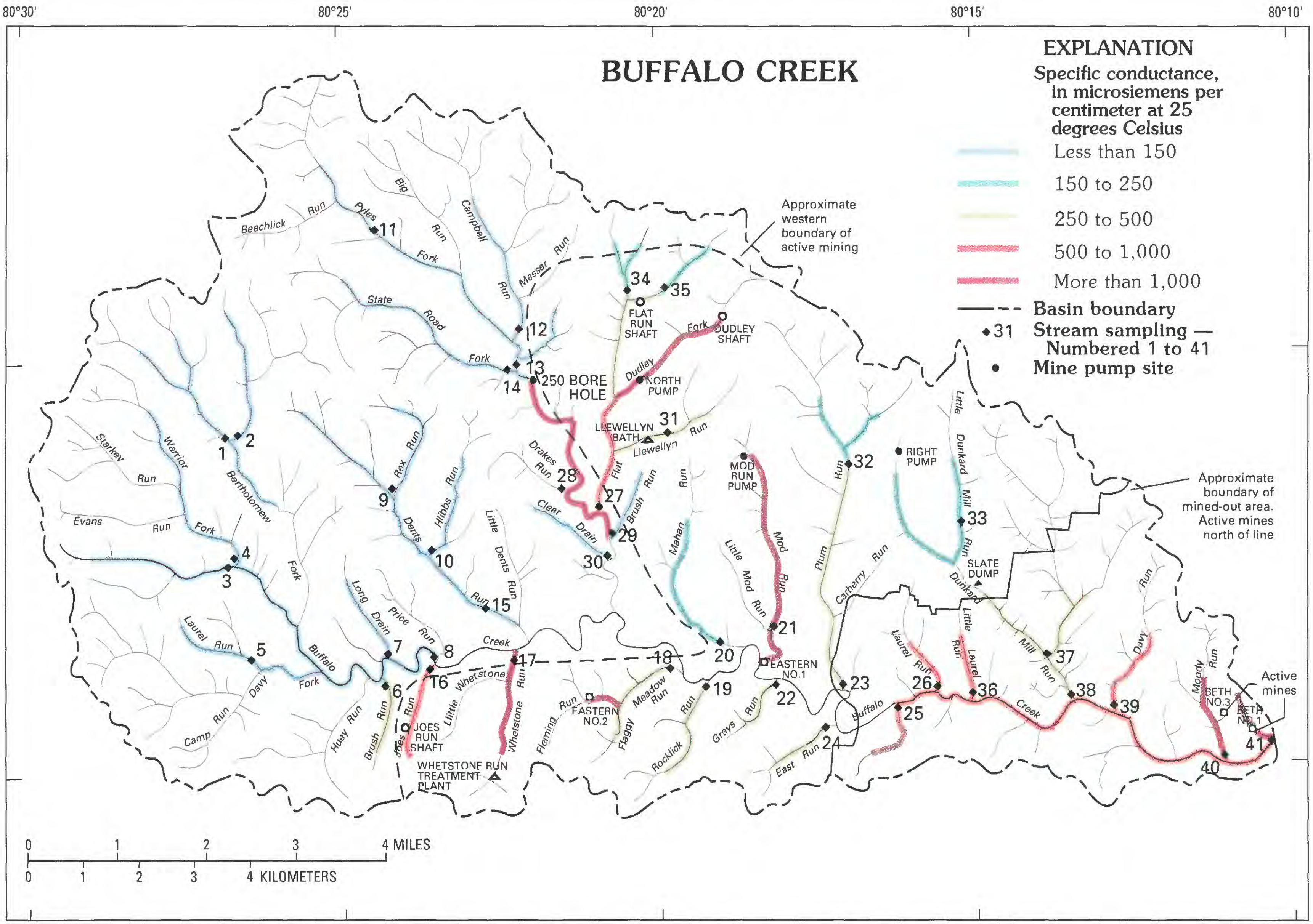



**Figure 3.3.1B.** Specific conductance at base flow, Buffalo Creek, October 1977.

## Stream pH at Base Flow Varies From 6.2 to 8.5

Lower pH values are found in streams both affected and unaffected by mining; higher pH values are generally found in undermined streams in the lower parts of the basins.

Although most of Indian Creek and Buffalo Creek basins are undermined, the lowest pH value measured at base flow in October 1977 was 6.2 (see figs. 3.3.2A and B). The pH of streams unaffected by mining or mine pumpage ranges from 6.7 to 7.6. The pH of streams affected by mine pumpage ranges from 6.2 to 8.5. This greater range of pH in streams affected by mine pumpage may be due to variations in the treatment processes used for mine water, to limestone dusting in the mines, or to increased numbers of limestone beds in the eastern parts of the basins.

Here again, as with specific conductance, basins such as Laurel Run and Little Laurel Run contain numerous subsidence cracks and have pH values higher than most streams. Hardness is generally high in these two streams, perhaps as a result of water percolating along subsidence cracks and joints, dissolving carbonate material from the rocks. As the carbonate material dissolves, calcium and magnesium are released and hydrogen ions from the water are tied up with $CO_3$. The net result is increased carbonate hardness and pH.

In summary, the pH maps (figs. 3.3.2A,B) show that coal mining is not causing low pH in streams, but may be causing pH that is higher than normal.

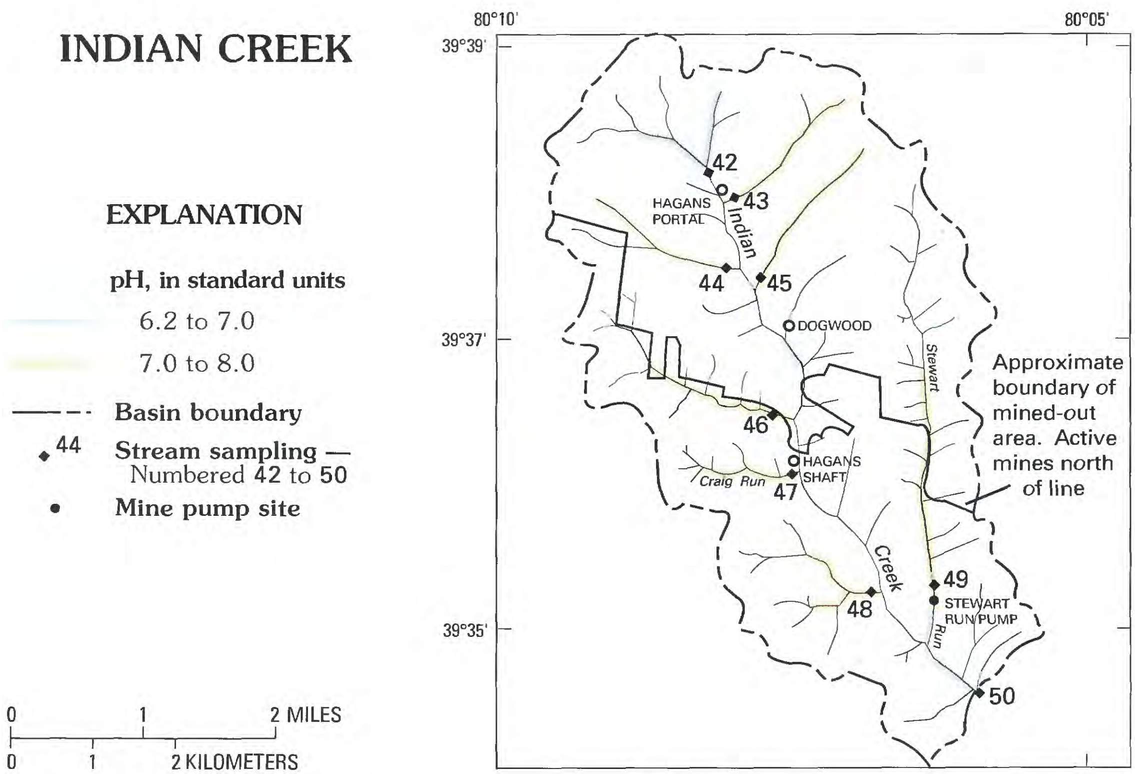



Figure 3.3.2A. The pH at base flow, Indian Creek, October 1977.

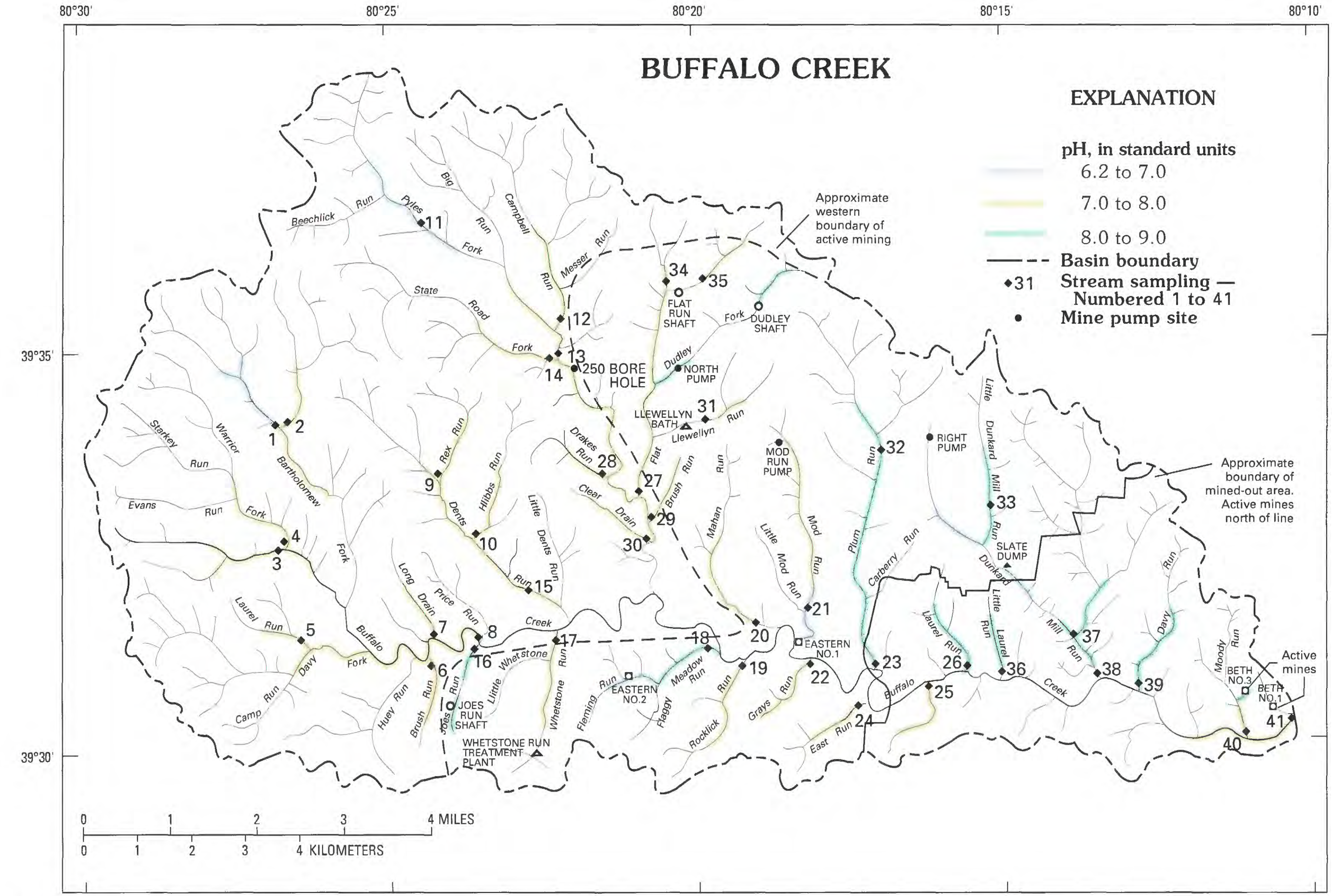



**Figure 3.3.2B.** The pH at base flow, Buffalo Creek, October 1977.

3.3.3 *Natural Water Quality Compared to That Affected by Mining*

# Streams in Mined Areas Carry More Dissolved Minerals Than Streams in Unmined Areas

Streams in mined areas carry more dissolved minerals than those in unmined areas, even when no mine pumpage enters the streams. Presumably, both subsidence fracturing and lowering of the water table are contributing factors.

The sites sampled in October 1977 included 50 streams and 20 mine-discharge points. Most of these sites (42) could be separated into four groups: (1) streams unaffected by mining, (2) streams undermined and having low yield per square mile but receiving no mine pumpage, (3) streams undermined and having high yield per square mile but receiving no mine pumpage (may receive some drainage from old drift mines in Waynesburg coal), and (4) treated and untreated mine pumpage.

These four groups were analyzed, and duration curves were prepared for sulfate and iron (fig. 3.3.3A) and hardness and chloride (fig. 3.3.3B). It is apparent from these graphs that, for each parameter, the concentration, in order from lowest to highest, is found in groups 1, 2, 3, and 4, except for iron. For iron, the lowest-to-highest concentration is found in groups 3, 2, 1, and 4. The general reversal of order of groups 1, 2, and 3 may be due to the increase in pH from the unmined area to the mined-out area downstream, as shown in section 3.3.2. As pH increases, iron generally cannot be dissolved and will not remain in solution. Thus, the iron curve for group 4 (treated and untreated mine pumpage) ranges from 30 to 45,000 μg/L. Because the mine-water treatment raises pH, the iron concentrations can be low. Thus, the iron contained in the treated mine water is less than that contained in streams unaffected by mining.

Figure 3.3.3C shows relative amounts of the major dissolved constituents at several sites in October 1977 at base flow and in December 1978 at high flow. The three westernmost sites (5, 13, and 10) in Buffalo Creek basin are unaffected by mining and are chemically similar. The chemical characteristics of Laurel Run (site 26) at Farmington, Davy Run, and Stewart Run (where mines are either abandoned or operating) are also similar. The large chemical load at the Indian Creek site in October 1977 is largely due to pumping from a mine on Stewart Run. When sampled in December 1978, this pumpage was no longer entering the stream.

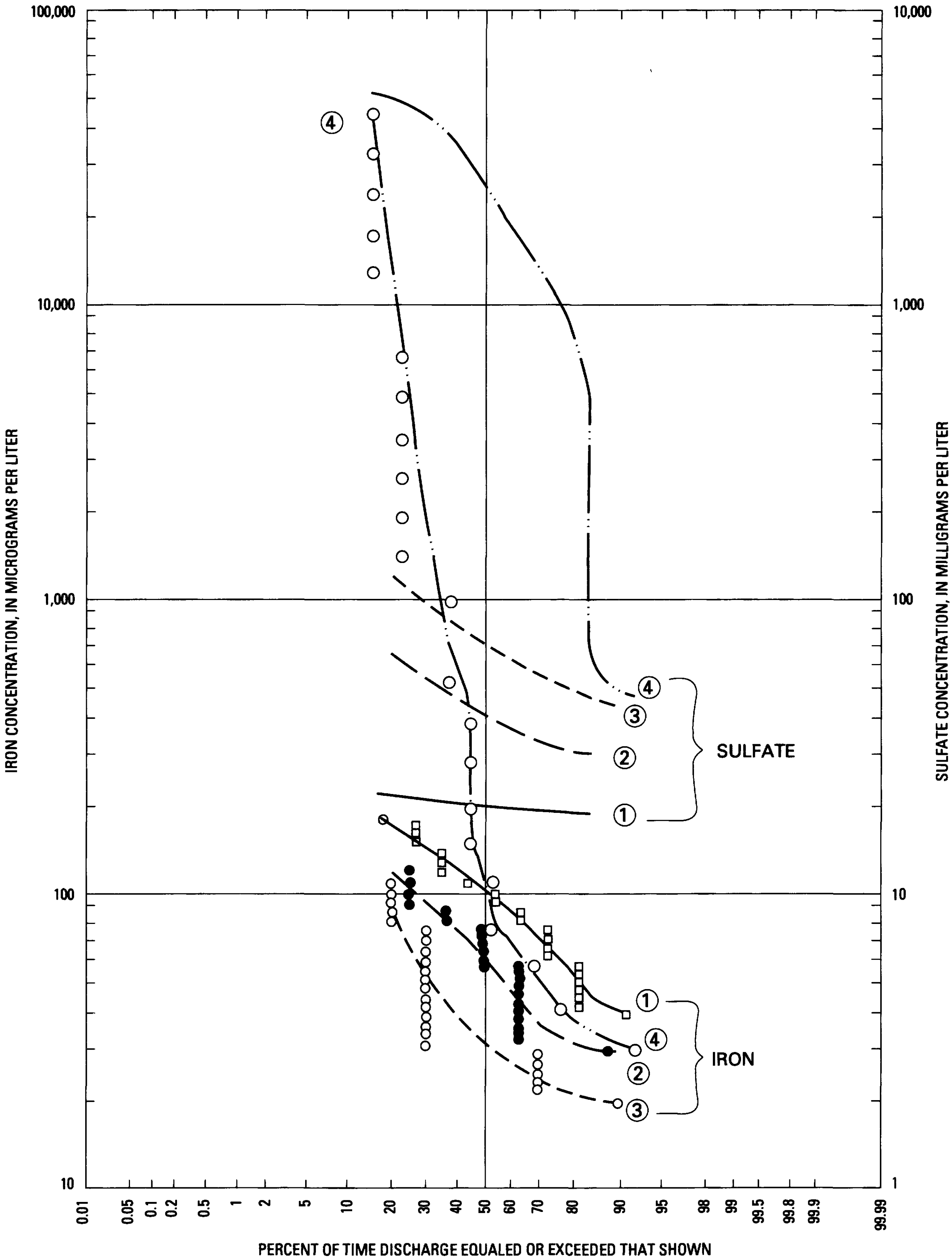



**Figure 3.3.3A.** Duration curves for sulfate and iron content for streams (1) in unmined basins, (2) in mined basins with low water yield, (3) in mined basins with high water yield, and (4) for treated and untreated mine water.

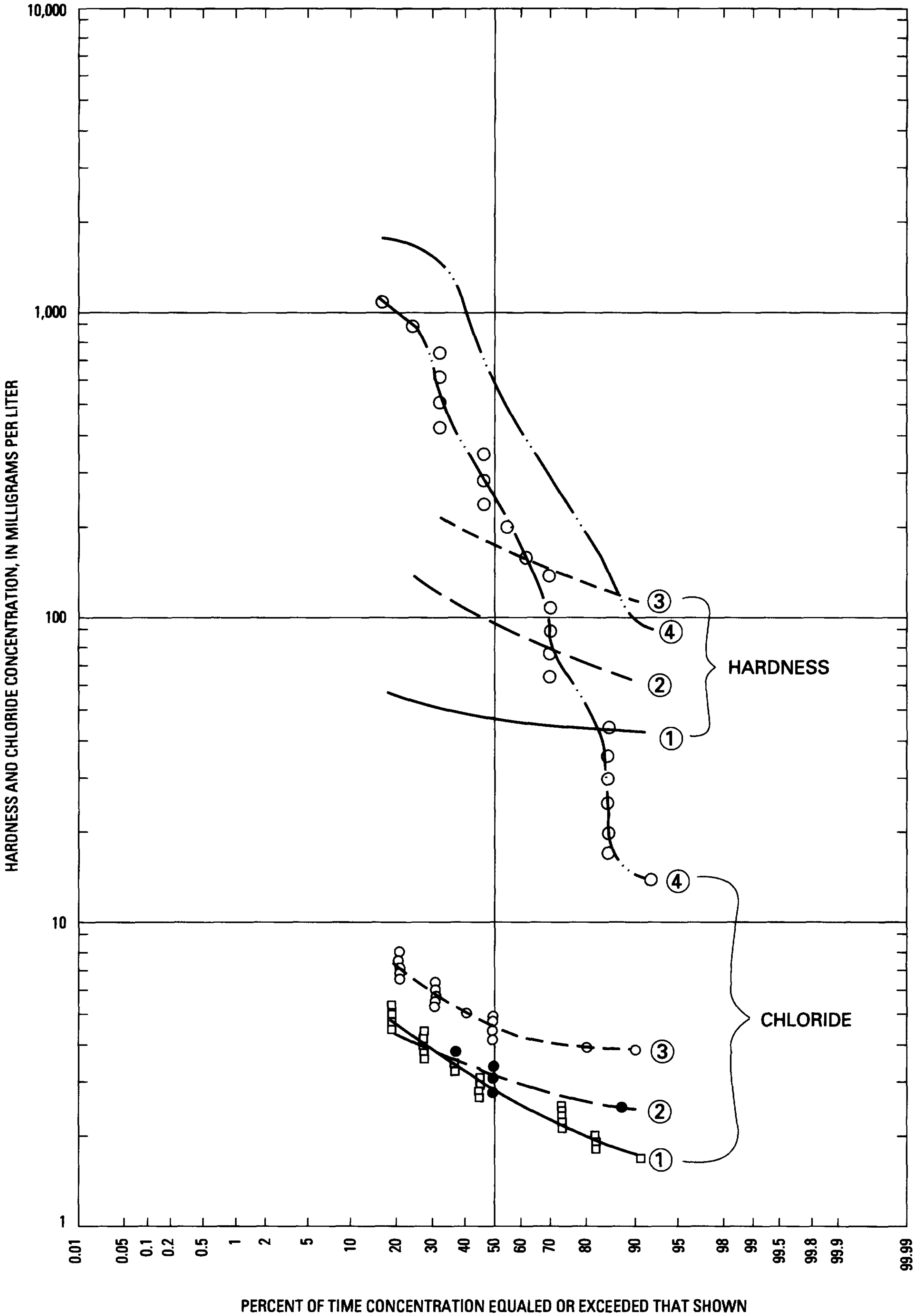



**Figure 3.3.3B.** Duration curves for hardness and chloride for streams (1) in unmined basins, (2) in mined basins with low water yield, (3) in mined basins with high water yield, and (4) for treated and untreated mine pumpage.

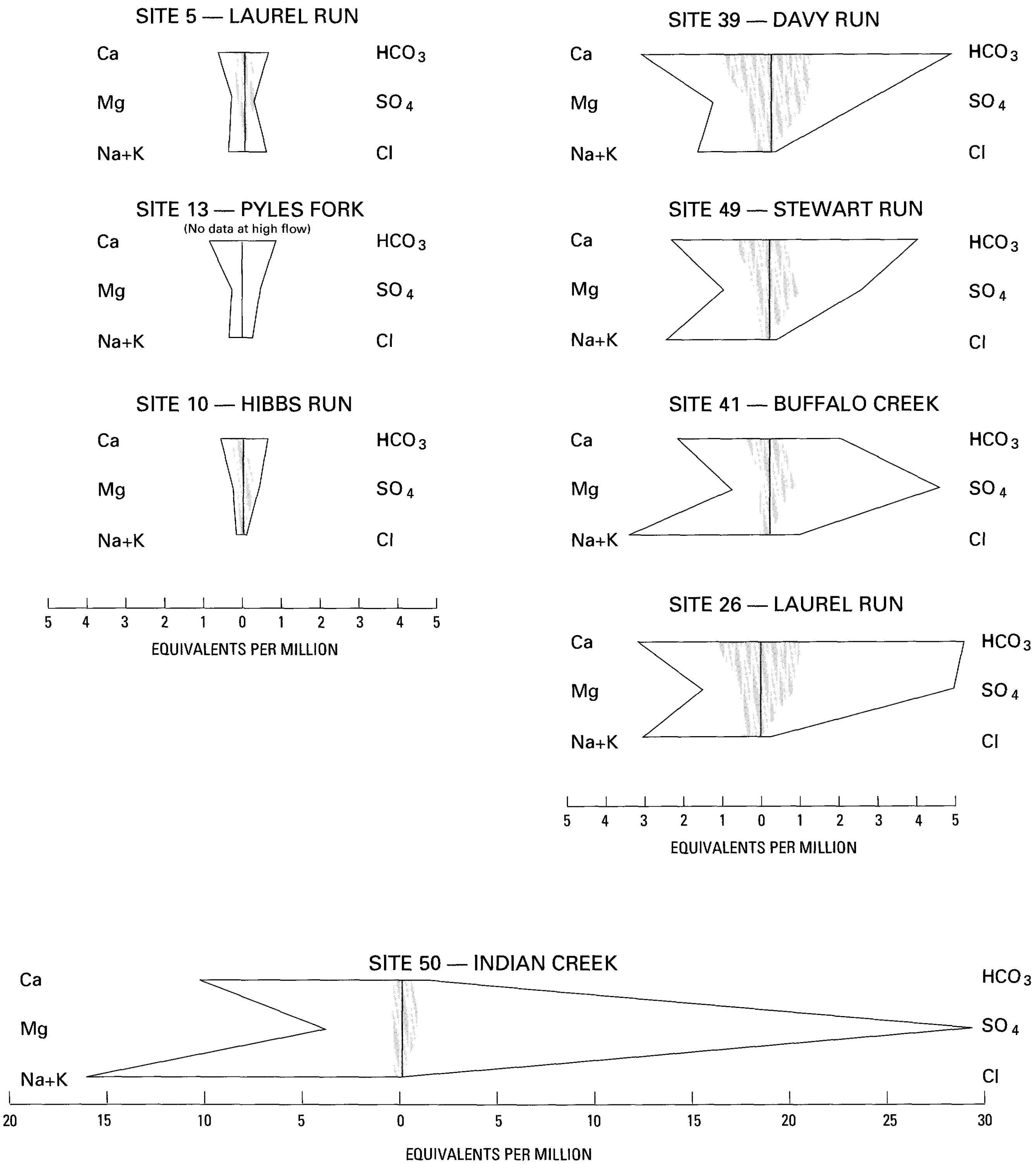



**Figure 3.3.3C.** Relative chemical content of streams at base flow in October 1977 (unshaded areas) and at high flow in December 1978 (shaded areas).

## 3.4 *Ground Water*

### 3.4.1 *Areal Water Levels*

# Underground Mining Has Lowered Ground-Water Levels in Some Mine-Subsided Areas; Little Effect in Other Areas

Where mine subsidence has occurred, highest water levels are generally found in shallow valley wells; deepest water levels are found in deep valley wells or deep hilltop wells.

Deep mining has apparently lowered ground-water levels in the study area, where massive collapse has occurred, and in some areas of active mining and pumping. Of the numerous wells visited and measured in the valley along Indian Creek, only one well owner reported an effect from local mining. At this well, mining was taking place in the Sewickley coal, from which the well may have derived all or part of its water. Because the Indian Creek basin is undermined, there is a possibility that fissures propagated by mine-roof collapse may transect water-bearing units in the overburden, thus causing drainage and lowering ground-water levels.

In the subsided area near Farmington, W. Va., water levels have decreased by more than 40 ft in some wells on hills and by more than 50 ft in some valley wells near Buffalo Creek. On the map in figure 3.4.1A, the numbers beside wells or springs indicate reported or estimated lowering of water levels caused by mining or mine collapse at these points. The ground-water levels in wells adjacent to Buffalo Creek had to be at or above the level of the creek prior to mining, as indicated in section 1.3. Thus, the numbers shown on the map are the differences between creek levels and current water levels in the wells.

Cross sections A and B show the approximate water table through the Farmington area. The water table is approximately drawn, using water level data collected in wells that ranged from 50 to 140 ft deep. The approximate head in the abandoned backfilled mine is known from an observation well in the mine beneath Farmington. In nearby mines where there is active pumping and mining, the water level is probably at about the same elevation as the coal bed. Underclays associated with coal beds at about 1,000- and 1,100-ft elevation cause perched or semiperched water table conditions, which give rise to numerous springs and seeps. (Springs are mapped in section 3.4.3.)

There are indications that ground-water levels are being lowered in relatively new mining areas unaffected by surface subsidence. When base flow measurements of streams were made in October 1977, low yields per square mile were noted for several streams, including Joe's Run. In 1979, owners of domestic wells in this area began reporting problems of low yields (P. Lessing, West Virginia Geological and Economic Survey, oral commun., 1979). Thus, even before mine collapse or subsidence, there are sufficient vertical fractures in the rock to partially drain the overlying strata and lower ground-water levels. Pumpage from the mine at Joe's Run mine shaft along Joe's Run averages 60,000 gal/d (40 gal/min). Water draining downward along the mine shaft may also contribute to dewatering of the Joe's Run area.

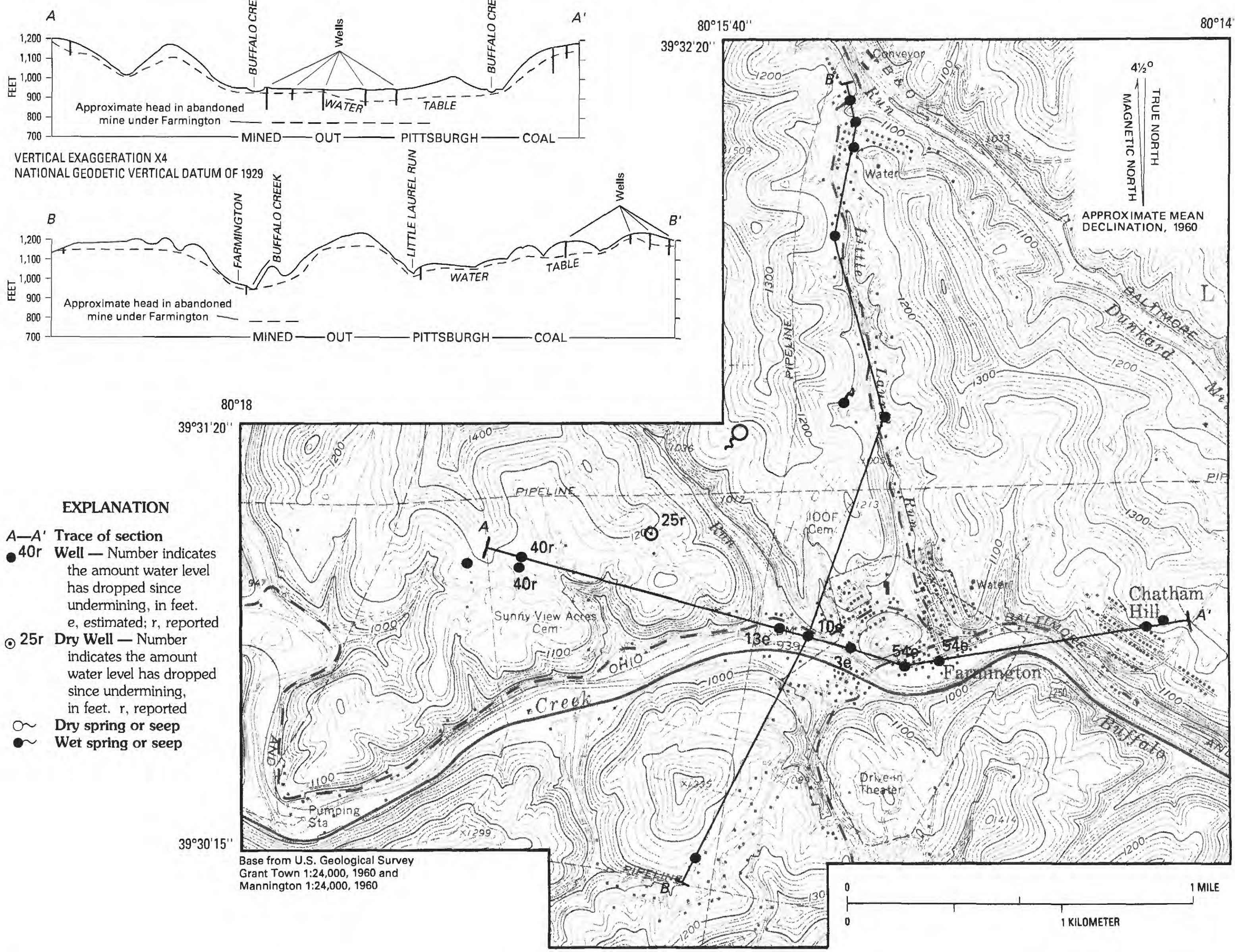



**Figure 3.4.1A.** Map shows locations of cross sections and wells. Cross sections *A–A'* and *B–B'* show approximate ground-water levels in the Farmington, W. Va., area, 1978. Numbers at wells indicate how many feet the water level has dropped since undermining.

# Mine Subsidence Causes Large Fluctuations in Ground-Water Levels

Large and rapid fluctuations in ground-water levels occur in some areas of mine subsidence, and water levels in flooded abandoned mines respond to pumping in nearby active mines.

The hydrograph for the R. White well (equipped with water level recorder) shows the rapid response of the well to precipitation and the subsequent drop in the water level as the water drains from the rocks (fig. 3.4.2A). Prior to local subsidence, the static water level in this well is reported to have been 10 to 12 ft below land surface. Also, an area less than 100 ft east of the well was wet and swampy year-round. Since subsidence, the swampy area has dried up, and the static water level in the well is, at times, 50 ft below land surface. The owner of the observation well and his neighbors no longer use the well but rely on a public-supply system for water.

Observation well 6–6–8 (fig. 3.4.2A) is located in Lewis Wetzel Public Hunting Area in Tyler County, W. Va., 20 mi west of the R. White well. This well is unaffected by mining, and weekly measurements show maximum fluctuation of about 14 ft since 1971.

(*Text continues on page 64.*)

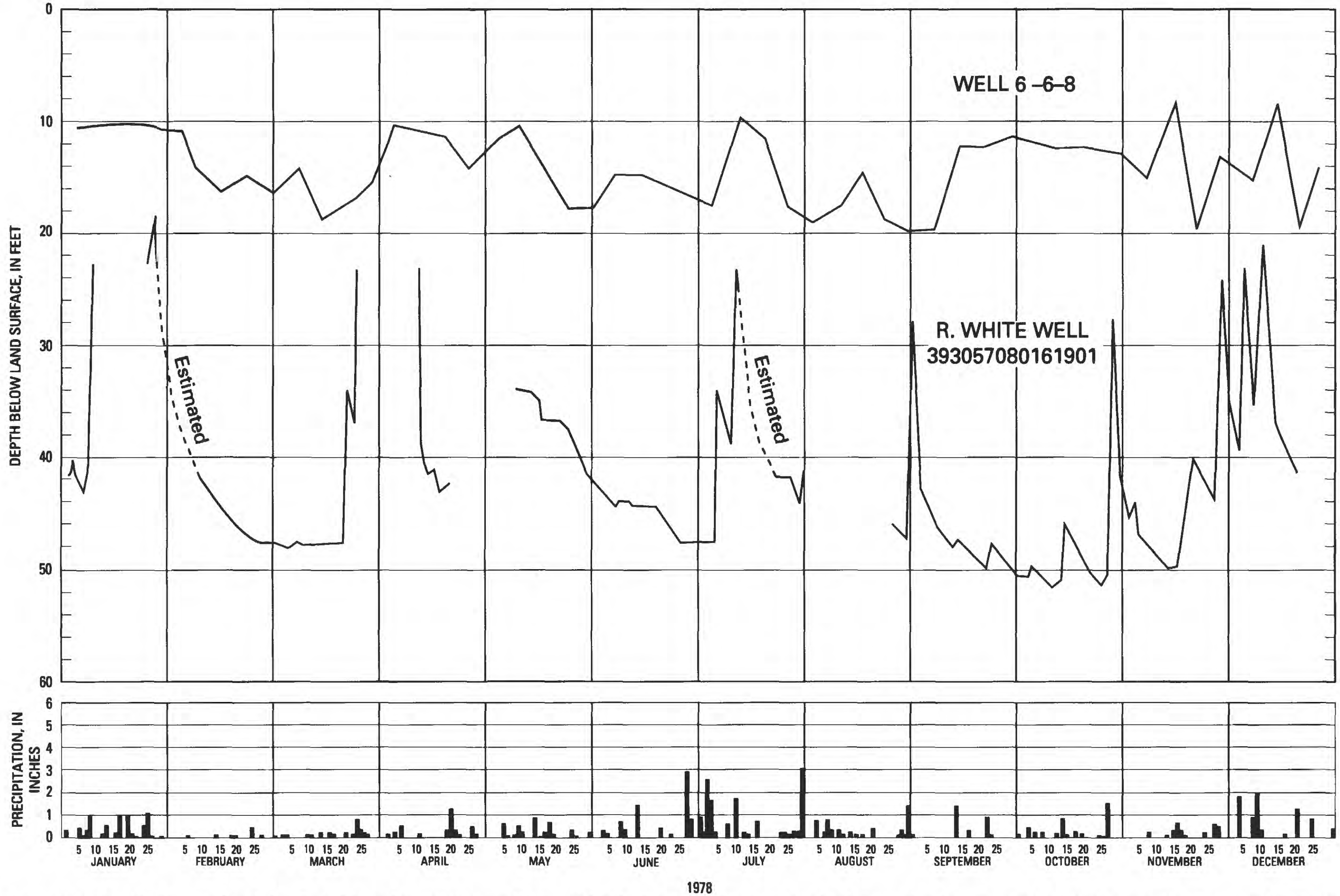



**Figure 3.4.2A.** Hydrograph of the R. White observation well in a subsided area, compared to hydrograph of Lewis Wetzel Public Hunting Area observation well (6–6–8) in an unmined area, 1978.

The hydrographs in figure 3.4.2B are for two wells open to flooded mines in the Pittsburgh coal. The well at Farmington, W. Va., is one of several that were used by the U.S. Bureau of Mines to backfill the abandoned mine by pumping a slurry of 84,660 tons of mine-refuse material into the mine cavity in an attempt to prevent further subsidence (John Capp, U.S. Bureau of Mines, oral commun., 1979). The backfilling operation was completed in January 1978, and all the wells were destroyed except the observation well. Since completion of the backfilling operation, the water level in the mine gradually rose through February 1979, and daily fluctuations averaged less than 1 ft.

In early March 1979, a rapid rise of the water level began and has now reached a level more than 70 ft above the level of the mine. This continuous rise suggests that the backfilling operation considerably reduced the porosity and permeability of the rocks and mine. However, in December 1978 a mine adjacent to the one beneath Farmington was sealed, and its subsequent flooding in March 1979 is largely responsible for the increase in water level at the Farmington well.

The Crown observation well, located about 9 mi northeast of Farmington, is also open to the mined-out Pittsburgh coal. This 10-in. well is reportedly cased to the mine and was previously used as an entrance for power lines to the mine. In early November 1977, pumping from the abandoned mine was discontinued. The water level in the mine rose slowly from that time to present, and a major rise occurred in March and April 1979. Although this mine is abandoned and flooded, mining and pumping continue in adjacent areas. This pumping keeps water levels low in the flooded areas because water leaks from the flooded mine toward sump areas in the active mines. Thus, water levels in flooded mines remain low as long as pumping continues in hydraulically connected nearby mines.

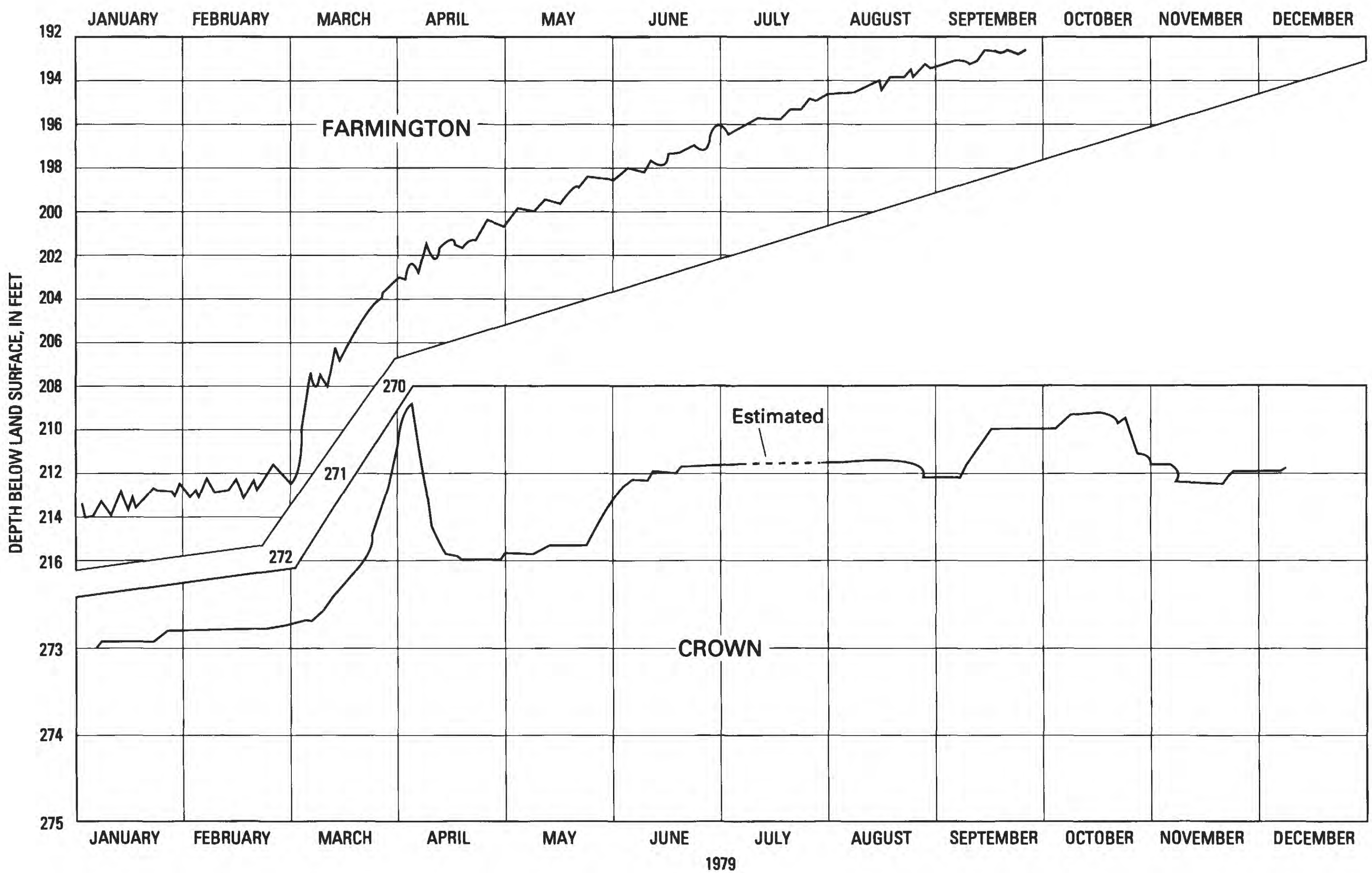



**Figure 3.4.2B.** Hydrographs of wells open to abandoned flooded mines at Farmington, W. Va., and Crown, W. Va.

3.4.3 *Seepage Points*

# Thermal Imagery Shows Springs, Seeps, Mine Drainage, and Large Mine-Subsidence Cracks

Springs, seeps, and mine drainage are points of ground-water discharge that can be detected by thermal imagery for inventory purposes or for mapping coal beds.

Thermal imagery covering about 40 $mi^2$ in Buffalo Creek basin between Mannington, W. Va., and Barrackville, W. Va., was made between 10:00 p.m. and midnight March 18, 1978. The imagery was taken to detect warm air escaping from "breathing" subsidence cracks. The technique would have been a valuable aid in mapping subsidence features, but the method proved to be less effective for detecting subsidence cracks than regular black-and-white aerial photography taken when the ground is snow covered. The thermal imagery was useful, however, in mapping springs, seeps, mine drainage, and streams (fig. 3.4.3A).

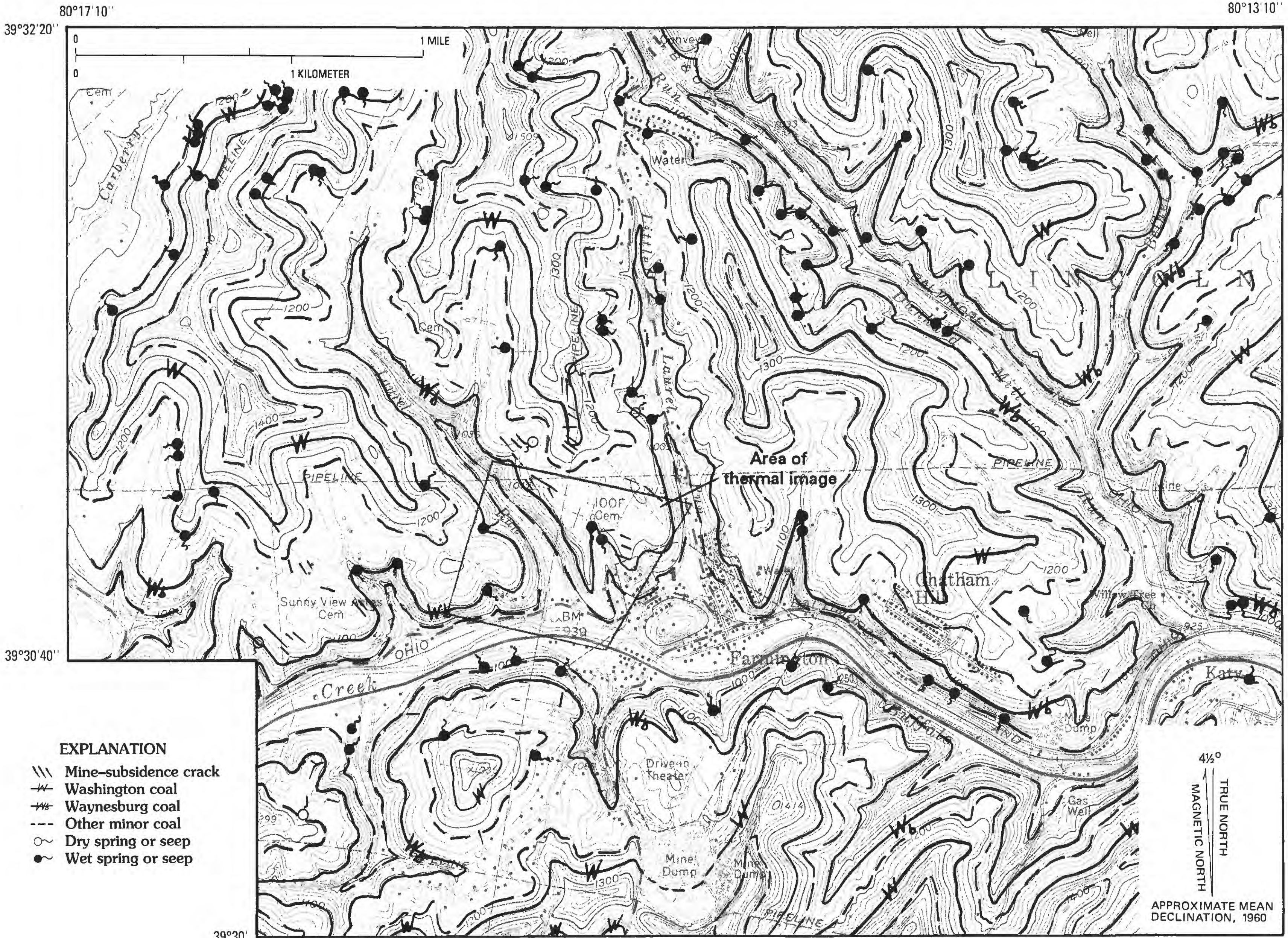
As shown on the map (fig. 3.4.3B), there is a correlation between mapped beds of coal and ground-water discharge points. Approximately 70 percent of the springs or seeps are on or near mapped coal beds and accompanying underclays. This percentage might even be high if precise maps of the coal beds were available. Perhaps the accuracy of many coal maps could be improved by using springs or seeps mapped from thermal imagery as guides in drawing coal contacts.

Notice the mine-subsidence crack at the upper left corner of **figure 3.4.3A**. There are other large cracks in the woods that run almost parallel to the observed crack, but they are not apparent on the imagery. (See figs. 1.2B, C, photographs of this site.)

When the thermal imagery was acquired, there was light snow cover in places. Air temperature at ground elevation was 3 °C when the flight started and 5 °C when completed. Wind at ground level was out of the southwest at 10 mph; at 2,000 ft (flight altitude) it was 40 mph and the temperature was −3 °C. The temperature of seven streams in the area ranged from 3.0 °C to 5.0 °C, and the temperature of springs and seeps ranged from 10 °C to 12 °C. Winds at ground level may have caused the dispersion of any heat escaping from the subsidence cracks and thus prevented their detection.

Acquisition of this imagery was a joint venture with the U.S. Bureau of Mines. Imagery of the Watson area in Fairmont, W. Va., was acquired at the same time. This imagery was successfully used by the U.S. Bureau of Mines in 1979 to locate potential sites of slurry leakage when pumping fly ash slurry into abandoned mines situated above river drainage (M. Magnuson, U.S. Bureau of Mines, oral commun., 1979).


**Figure 3.4.3A.** Thermal image of area shows springs or seeps, and a mine-subsidence crack.




Base from U.S. Geological Survey
Grant Town 1:24,000, 1960 and Mannington 1:24,000, 1960

Coalbeds mapped from Hennen and Reger (1913) and, in part, from Heffner, L.B., 1966, Geology of Grant Town, West Virginia Quadrangle, West Virginia University unpublished thesis, 82p.

**Figure 3.4.3B.** Map locates springs, seeps, mine-subsidence cracks, and coal beds.

# Areal Aquifer Tests Indicate Mine Collapse Is Associated With Relatively High Rock Permeability, Mostly at Shallow Depths

Transmissivity values from areal aquifer tests range from 2.2 to 55 $ft^2/d$, the greatest transmissivity generally being in areas affected by mine collapse.

Areal transmissivity of various areas in Buffalo Creek basin was determined (fig. 3.5.1A) by two methods—Jacob's (1943) equation, and Darcy's law. The methods used relate the gain or loss in streamflow over a given reach to the height of the water in wells or to the slope of the water table at some distance from the stream.

1. Jacob's equation

$$T=2.29(10^{-4})W(\frac{ax}{h_0}-\frac{x^2}{2h_0})$$

where $T$=transmissivity ($ft^2/d$), $W$=constant rate of recharge to the water table (in./yr), $a$=distance from the stream to the ground-water divide (ft), $x$=distance from the stream to an observation well (ft), and $h_0$=elevation of the water table, at the observation well, with respect to the mean stream level (ft). The value of $W$ is found by computing the average ground-water contribution ($Q_b$) to the base flow of the stream per unit length of stream channel, and substituting this value in the equation $W=4.22(10^5)Q_b/a$. The value of $W$ is used in the first equation with the other measured values.

Three values of $T$ were computed for Little Laurel Run near Farmington, W. Va., using the discharge over one reach of the stream and the water level in three different observation wells. The values of $T$ (fig. 3.5.1A) ranged from 45 to 55 $ft^2/d$. Little Laurel Run is the only small stream measured in the subsided area near Farmington, and it has a higher transmissivity than Brush Run, Rex Run, and Mahan Run, which lie in unmined areas. Transmissivity for rocks adjacent to these streams ranges from 2.2 to 20 $ft^2/d$.

2. Darcy's law

Another estimate of areal transmissivity was made using a form of Darcy's law:

$$K=\frac{Q'}{IA}$$

where $K$=hydraulic conductivity (ft/d), $Q$=streamflow loss ($ft^3/d$), $I$=hydraulic gradient (ft/ft), and $A$=area of streambed ($ft^2$).

The average width of Buffalo Creek is about 30 ft through the Farmington area. Thus, a 1-mi reach of the streambed covers about 158,400 $ft^2$. Using this area, and 120,960 $ft^3/d$ for water loss (1.4 $ft^3/s$—see section 3.2.3), and an approximate hydraulic gradient of 1 (approximate average gradient based on water levels in wells A–E), the hydraulic conductivity of the streambed is estimated at 0.76 ft/d.

Transmissivity ($T$) equals hydraulic conductivity times aquifer thickness. Assuming aquifer thickness of 30 ft (equal to the width of the stream), the approximate transmissivity is 23 $ft^2/d$.

However, this value of transmissivity may be too high. As indicated in figure 3.5.1B, the area through which flow occurs beneath the stream expands in a triangular fashion. Thus, the area used in Darcy's equation probably should be greater than the area of the streambed. If the area is increased by 2, then the hydraulic conductivity and transmissivity are cut in half. Realistically then, transmissivity is probably less than 23 $ft^2/d$.

The table and block diagram (figs. 3.5.1A,B) summarize the various permeability and transmissivity values. Note that the untested rock just above the mine roof is probably fractured and highly permeable.

The transmissivity computation using streamflow in Buffalo Creek is at best an approximation, because

1. at the same time the stream is losing water, it may be gaining water from the bank alluvium. If so, then the $T$ of the rocks should be greater than that shown.
2. the determined value would be for vertical rather than horizontal transmissivity.
3. the measured loss of streamflow in this reach may be less than the degree of accuracy of the flow measurement.
4. the hydraulic conductivity of the sediment in the streambed (if less than that of the bedrock) will partially control the amount of leakage from the stream.

In spite of these possible interfering effects, the computed transmissivity is reasonable, compared to the range of computed transmissivities using the flow of small streams.

| Area | Stream name | Date | Yield of reach (gallon per minute) | Transmissivity (feet squared per day) |
|---|---|---|---|---|
| UNMINED AREA | Brush Run | November 3, 1977 | 23 | 8 |
| | Rex Run | November 3, 1977 | 97 | 20 |
| | Mahan Run | November 3, 1977 | 28 | 2.2 |
| MINED AREA | East Run | November 3, 1977 | 94 | 7.7 |
| | Little Laurel Run (known subsidence) | November 8, 1977 | 53 | 47 |
| | | November 8, 1977 | 53 | 45 |
| | | November 8, 1977 | 53 | 55 |
| | Buffalo Creek | May 11, 1979 | 630 (loss) | 23 |

**Figure 3.5.1A.** Areal transmissivity computations for unmined, mined, and mine-subsided areas in Buffalo Creek basin.

| Well | Depth (feet) | Diameter (inches) | Depth cased (feet) | Water level: Below land surface (feet) | Water level: Below creek (feet) | Water level: Date measured in 1979 |
|---|---|---|---|---|---|---|
| A | 98 | 8 | 30 | 70.2 | 60 | June 28 |
| B | 80? | 8 | ? | 71.6 | 60 | April 3 |
| C | 145? | 8 | 20–30 | 14.0 | 3–4 | June 28 |
| D | 52 | 8 | ? | 22.5 | 10 | June 28 |
| E | 132 | 8 | ? | 25.3 | 12 | June 28 |
| F | 265 | 8 | 252 | 196.2 | 165 | June 28 |

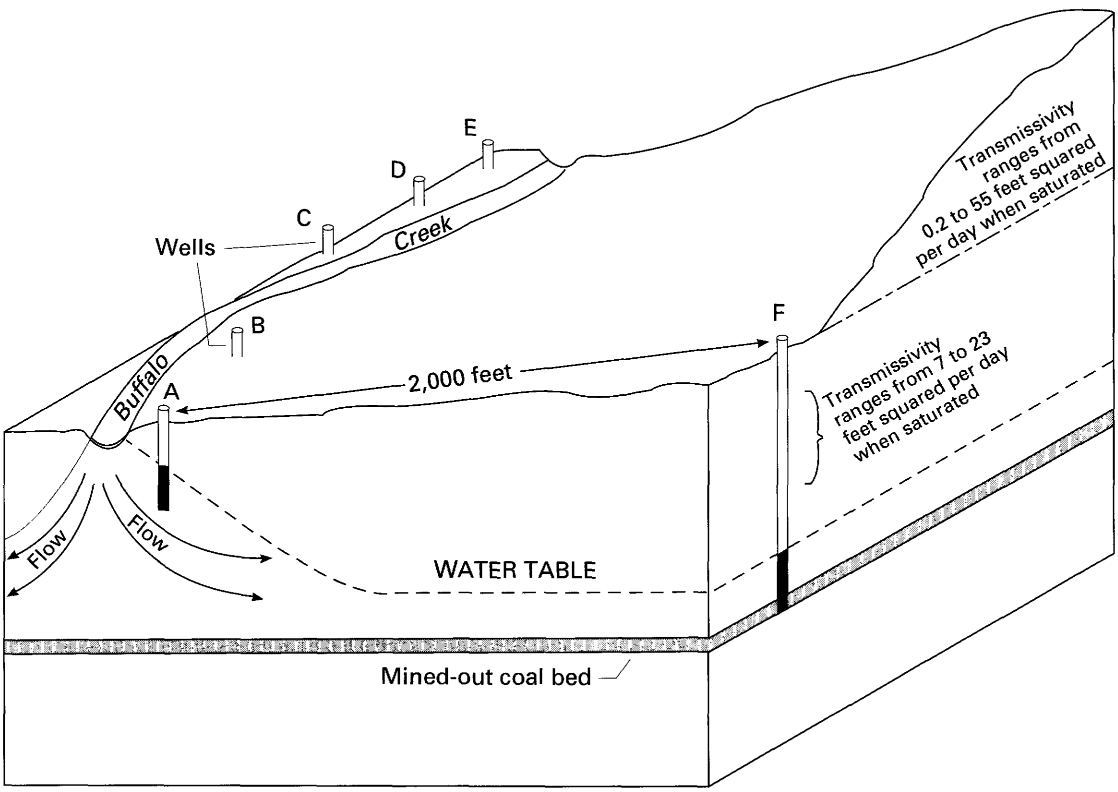



**Figure 3.5.1B.** Block diagram showing wells, water table, and computed ranges of transmissivity at Farmington, W. Va., where Buffalo Creek is losing about 1.4 $(ft^3/s)/mi$.

# Drainage Along Subsidence Cracks Eventually Lowers Water Levels, Even in Nearby Wells Penetrating Uncracked Rock

Computed transmissivity values range from 0.20 to 65 $ft^2/d$ in areas affected by mine subsidence.

Various tests were performed on wells in subsided and unsubsided areas to compare aquifer characteristics. Single-well drawdown and recovery tests were performed on wells A and C, both former public water-supply wells at Farmington, W. Va. (fig. 3.5.2A). These wells are located 10 to 30 ft from Buffalo Creek. Well A was pumped at 10.7 gal/min for 6 min, and drawdown and recovery rates were measured. Well C was pumped at about 35 gal/min for 12 min, and the recovery was measured. The recovery water levels were analyzed (Ferris and others, 1962, p. 101) to estimate aquifer transmissivity.

These transmissivity values may be inaccurate because of the large diameter of the wells and the short duration of the recovery test. As a check, the values of $T$ were also estimated in the vicinity of these wells using a flow-net analysis based on a modified form of Darcy's equation (Walton, 1962, p. 14):

$$T=\frac{Q/2}{I\,L}$$

where $Q/2$=streamflow loss over a measured reach ($ft^3/d$) divided by 2, $I$=average hydraulic gradient (ft/ft) from the stream surface to the water levels in the wells, and $L$=the length of stream reach (ft) over which the water loss occurs.

The flow loss measured over the 6,000-ft reach of Buffalo Creek between sites F and J (section 3.2.3), the gradient as estimated from stream level, and ground-water levels in wells A, B, D, and E, and distance from the stream to well were used in the computations. For computation purposes, the 6,000-ft reach of stream was divided into two reaches of 3,000 ft each. The stream level and the measured water levels in wells A and B were used to estimate the gradient along one 3,000-ft reach of the stream, and the stream level and the water levels in wells D and E were used to estimate the gradient along the other 3,000 ft reach of stream. It was assumed that 75 percent of the flow loss (345,000 $ft^3/d$) occurred along the reach of stream near wells A and B (having deep water levels) and that 25 percent (115,000 $ft^3/d$) occurred along the reach of stream near wells D and E (having shallow water levels). An average hydraulic gradient for each reach was determined from the water levels in the two wells. As shown in the chart in figure 3.5.2C, the transmissivity determined for the area in the vicinity of well A is essentially the same as that determined from the recovery test. Although the transmissivity for the area in the vicinity of well C is double that determined from the recovery test, it is still of the same order of magnitude and is less than the values determined by the permeability and specific-capacity tests.

As shown in figure 3.5.2C, the transmissivity computed from the recovery test is the same for both wells. However, water can enter about 115 ft of well C, whereas it can enter only 68 ft of well A. Thus, the rocks are more permeable at well A. This greater permeability is also suggested by the lower water level; that is, more water is leaking from well A into the mine below than from well C. Using a mirror and reflected sunlight, ripples can be seen on the water surface in well A, possibly caused by $H_2S$ gas bubbles or by water leaking into the well from above the water level.

The water levels in wells B, D, and E, located west of well A, ranged from 60 to 10 ft below creek level. These low water levels also indicate that Buffalo Creek is losing water in this area.

A test based on the recession of ground-water level and a water-injection test ("slug" test) were used to estimate transmissivity at the R. White observation well at Farmington. Aquifer diffusivity ($T/S$) can be estimated using a semilog plot of ground-water recession in a well, and the following equation (Rorabaugh, 1960, p. 317):

$$T/S=0.933\frac{a^2\log h_1/h_2}{t_2-t_1}$$

where $T/S$=transmissivity divided by storage coefficient, $a$=distance from stream to ground water divided along a line passing through the observation well, and $h_1$ and $h_2$=beginning and ending water levels in the well above stream level, at times $t_1$ and $t_2$, respectively.

(*Text continues on page 72.*)

| Well | Depth (feet) | Diameter (inches) | Depth cased (feet) | Water level | | |
|---|---|---|---|---|---|---|
| | | | | Below land surface (feet) | Below creek (feet) | Date measured in 1979 |
| A | 98 | 8 | 30 | 70.2 | 60 | June 28 |
| B | 80? | 8 | ? | 71.6 | 60 | April 3 |
| C | 145? | 8 | 20–30 | 14.0 | 3–4 | June 28 |
| D | 52 | 8 | ? | 22.5 | 10 | June 28 |
| E | 132 | 8 | ? | 25.3 | 12 | June 28 |
| F | 265 | 8 | 252 | 196.2 | 165 | June 28 |

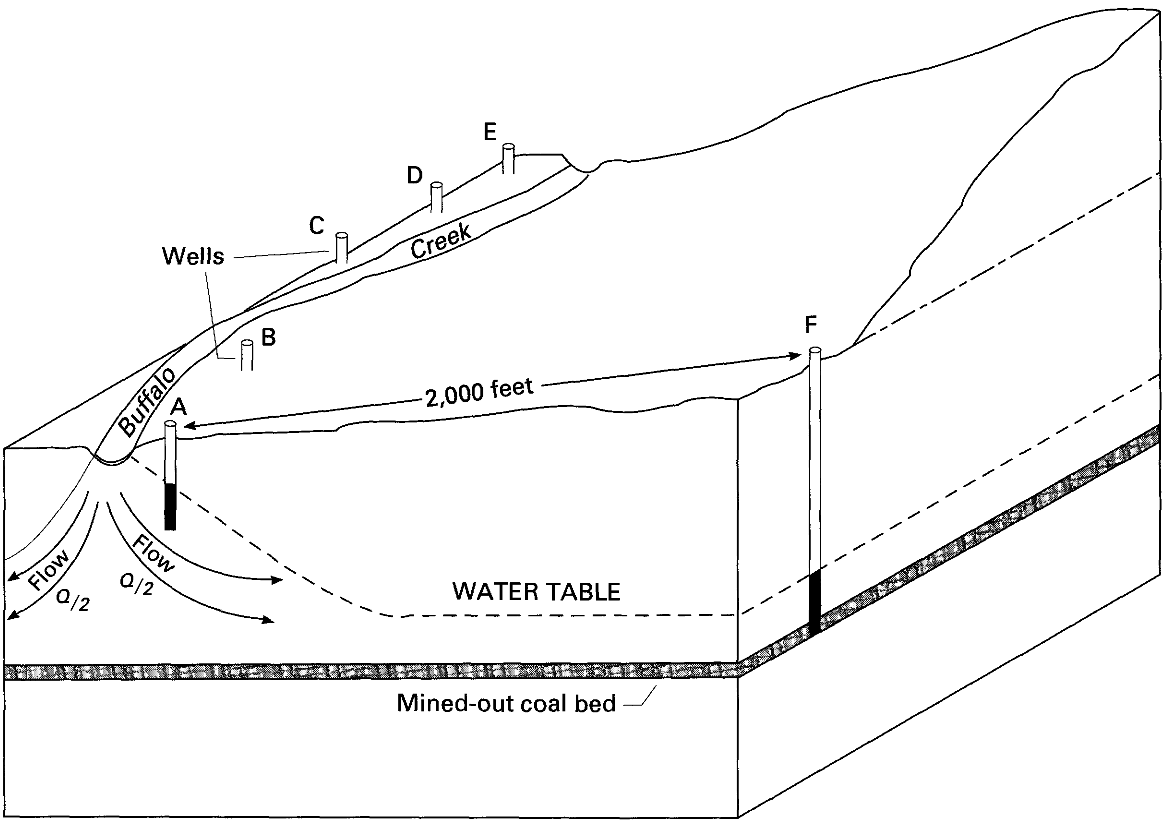



**Figure 3.5.2A.** Block diagram showing wells, water table, and mined coal bed at Farmington, W. Va., and chart of well data.

The technique assumes that the stream penetrates the full thickness of the aquifer, that the aquifer is homogeneous and isotropic, and that the observation well is on a straight profile extending from the ground-water divide to the stream. In applying the technique, it was assumed that the full thickness of the aquifer was from land surface to an elevation of 1,000 ft, where a minor coal bed with its underclay commonly acts to drain the overlying rocks, as evidenced by ground-water seeps on thermal imagery of the area (see fig. 3.4.3A in section 3.4.3). It was assumed that this level would generally act as "stream" level, that is, most of the water perched on the clay would flow horizontally and discharge at the outcrop.

The observation well, 74 ft deep and cased to about 6 ft, penetrates all but 54 ft of this aquifer, and the average distance of *a* is 800 ft (measured in an east-west direction, through the well, from the drainage divide to the 1,000-ft contour). By extending the recession curve of November 4–15 to December 31, 1978 (see hydrograph in fig. 3.5.2B), the computed diffusivity ($T/S$) was 647 $ft^2/d$. Assuming a storage coefficient of 0.1 (which is commonly representative of water table aquifers), a transmissivity of 65 $ft^2/d$ was calculated. However, this method of analysis would yield a higher than actual transmissivity value if vertical leakage of water through the underlying clay layer affects the shape of the water table.

At this same well, hydraulic conductivity values of 0.0045 and 0.0062 ft/d were computed, using variable-head permeability methods and data obtained from a slug injection test and from the water level recession hydrograph for October 27 to November 15, 1978. The values of hydraulic conductivity times the length of well tested in each instance yielded transmissivity values of 0.22 $ft^2/d$. This value indicates that the rocks are not very permeable, at least from 25 ft to the bottom of the well (the injected water slug filled the well to about 25 ft below land surface). However, the fact that a swampy area near the well dried up since subsidence occurred indicates that subsidence cracks are permitting local ground-water drainage.

The hydraulic conductivity is higher using the recession hydrograph than using the injection test, probably because the hydrograph data are longer term and reflect the influence of a larger volume of rock, some of which probably contains subsidence fractures. The rapid rise in water level in the well is attributed to water entering through fractures between 6 and 25 ft during wet periods. During dry periods, the water drains from the well through the less permeable rocks in the saturated part of the well, toward the more permeable subsidence cracks or joints some distance away.

The U.S. Soil Conservation Service has collected borehole hydraulic conductivity data at dam sites in Buffalo Creek and Middle Wheeling Creek basins (see section 3.1.2 for more information). These data were separated into two groups: sites underlain by mines (28 holes) and sites not underlain by mines (53 holes). Duration frequency curves show that average borehole hydraulic conductivity is slightly greater in mined areas than in unmined areas. When the data were further subdivided and analyzed, it was found that average hydraulic conductivity for valley wells in mined areas was greater than that of valley wells in unmined areas. Similarly, average hydraulic conductivity for hillside wells in mined areas was greater than that of hillside wells in unmined areas.

These findings (increased hydraulic conductivity of near-surface rock in mined areas) agree with findings from areal and well aquifer-testing methods. However, variations in geology, degree of pre-mining fracturing, and jointing also affect permeability and could partially mask the effects of mining and subsidence on local permeability.

Figure 3.5.2C summarizes the transmissivities computed by well methods for the subsided area at Farmington.

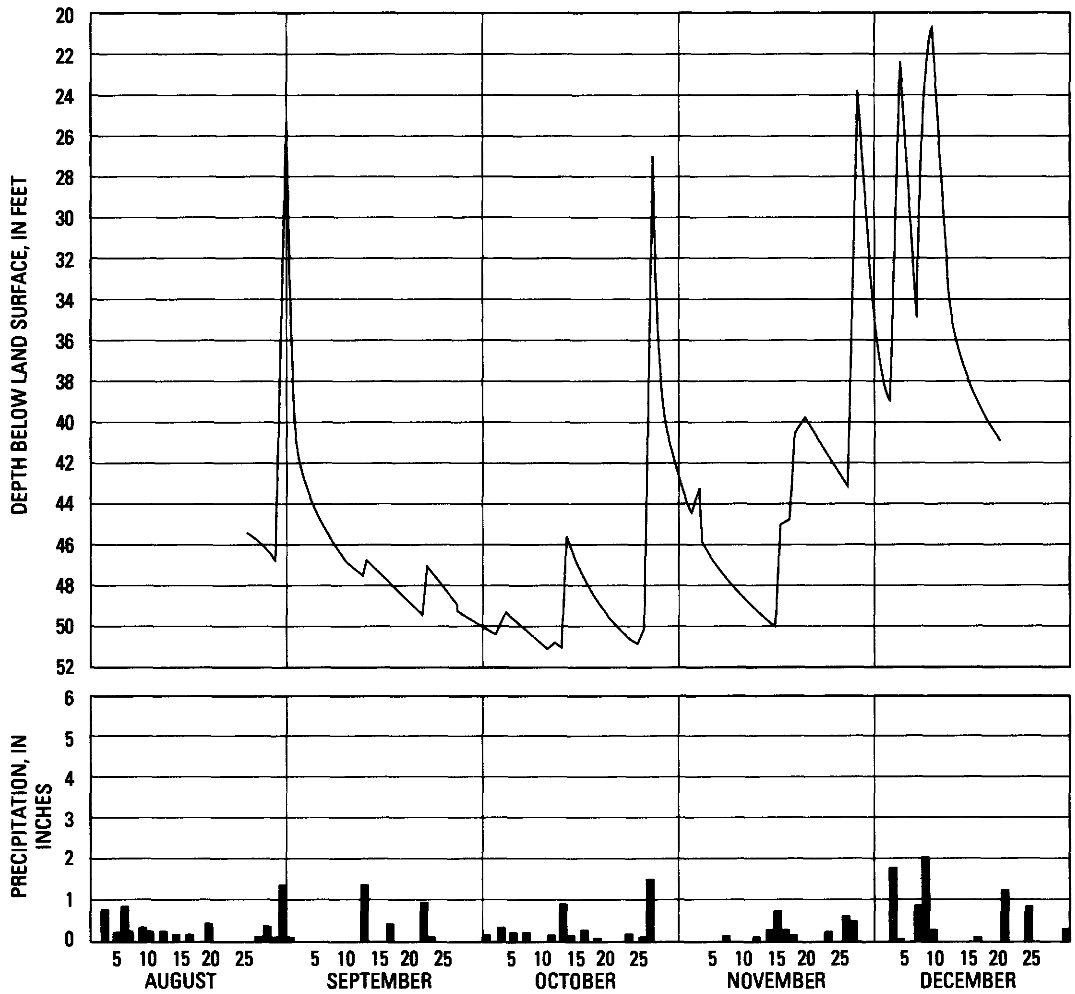



**Figure 3.5.2B.** Hydrograph of the R. White well near Farmington, W. Va., and precipitation at Mannington, W. Va., 1978.

| Site and method | Transmissivity, *T* (feet squared per day) | Hydraulic conductivity, *K* (feet per day) | Assumed aquifer thickness (feet) |
|---|---|---|---|
| FARMINGTON 5 (WELL A) | | | |
| Recovery test | 7 | 0.25 | 28 |
| Permeability test[1] | 10.9 | 0.39 | 28 |
| Permeability test[2] | 23 | 0.82 | 28 |
| Specific capacity[3] | 14 | 0.50 | 28 |
| Flow net analysis[5] | 6.6 | | |
| ROBERT DUDASH (WELL C) | | | |
| Recovery test | 7 | | |
| Permeability test[1] | 20 | 0.18 | 112 |
| Specific capacity[3] | 15 | | |
| Flow net analysis | 14 | | |
| R. WHITE OBSERVATION WELL | | | |
| Ground water recession[4] | 65 | 0.51 | 128 |
| Permeability tests[2] | 0.20 | 0.004 | 49.5 |
| | 0.21 | 0.006 | 35.5 |

[1]U.S. Department of the Navy (1962).
[2]U.S. Department of the Interior (1974, p. 576).
[3]Transmissivity estimated from 10-min specific capacity (Walton, 1962, p.12).
[4]Rorabaugh (1960).
[5]Walton (1962, p. 14).

**Figure 3.5.2C.** Transmissivity computations for mine-subsided area beneath Buffalo Creek at Farmington, W. Va.

# Underground Mining Modifies Hydrologic Budget in Buffalo Creek Basin

Underground mining and subsidence cause increased rock permeability, lower ground-water levels, interbasin transfer of water, and in general makes more water available because evapotranspiration is reduced.

The block diagrams in figure 3.6A show average water budgets for the 1978 and 1979 water years for mined and unmined parts of Buffalo Creek and Indian Creek basins. Annual evapotranspiration in the unmined basins of Laurel Run at Curtisville and Hibbs Run is estimated to be 49 percent of average annual precipitation for these water years, assuming no change in ground-water or surface-water storage. The graph in figure 3.6B shows yields per square mile (computed from instantaneous flow measurements) of these two unmined basins and two mined basins of Davy Run and Laurel Run at Farmington, W. Va. Yield of the mined basins is generally higher than that of the unmined basins. The rocks beneath Laurel Run basin at Farmington are known to be badly broken by subsidence, and it has the highest yield.

Stewart Run and Davy Run (fig. 3.6A) are both undermined. They lose about 52 percent of incoming precipitation to evapotranspiration and to adjacent basins via flow underground to active mine pumps. It is surprising that Davy Run basin has a high water loss (underflow + evapotranspiration) because it consistently has a high yield per square mile at base flow, and in winter the gaging site is seldom frozen. Both factors indicate considerable ground-water discharge. However, Davy Run has the highest water loss of the sites gaged in Buffalo Creek and Indian Creek basins.

Reasons for the low annual output of Davy Run basin may be that

1. underflow from the basin to Buffalo Creek bypasses the gage site, and (or)
2. underground transfer of water is occurring from the basin to active mine pumps in adjacent basins to the north, or
3. estimates of precipitation in the basin, which are based on data from rain gages in nearby basins, are too high. (Complete precipitation data were not available in Davy Run basin.)

The hydrograph for Davy Run was compared to those of other streams in Buffalo Creek basin. After adjustment for size of drainage area, peak flows in Davy Run were often lower than those for other basins in summer and fall, but were generally comparable during wet times of the year. This occurrence suggests that, during summer and fall, peak flows are reduced by recharge to the water table.

Buffalo Creek is one-half to two-thirds undermined. Of the basins monitored, it had the lowest average water loss for the 1978–79 water years. The water loss of 45 percent is somewhat reduced because mine water pumped from storage and public-supply water piped into the basin from Fairmont, W. Va., are measured as streamflow as the water flows back out of the basin. However, mine pumpage in the basin amounts to about 1,200 gal/min (0.35 in./yr), and public-supply water less than 100 gal/min (0.027 in./yr). Combined, this flow amounts to less than 0.4 in./yr and, if subtracted from the flow of Buffalo Creek, the water loss would only increase by 0.4 percent.

Thus the data indicate that the water loss in Buffalo Creek basin in the 1978–79 water years is less than that for unmined basins in the headwaters of Buffalo Creek basin. This lower water loss is attributed to mine subsidence and other effects of mining on hydrology within the basin.

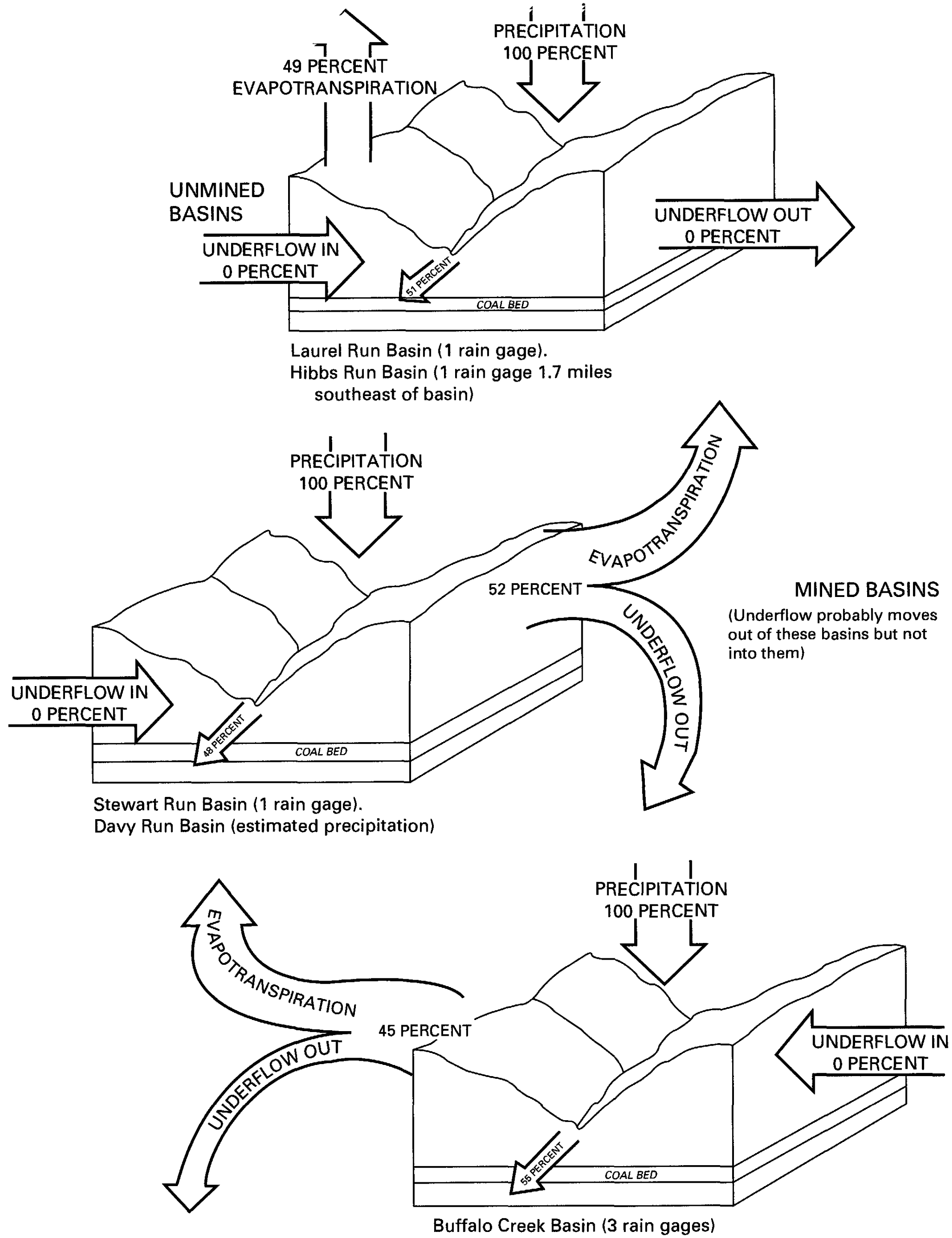



**Figure 3.6A.** Approximate percentages of water in parts of the hydrologic cycle in mined and unmined small basins within Buffalo Creek and Indian Creek basins (average for 1978–79 water years).

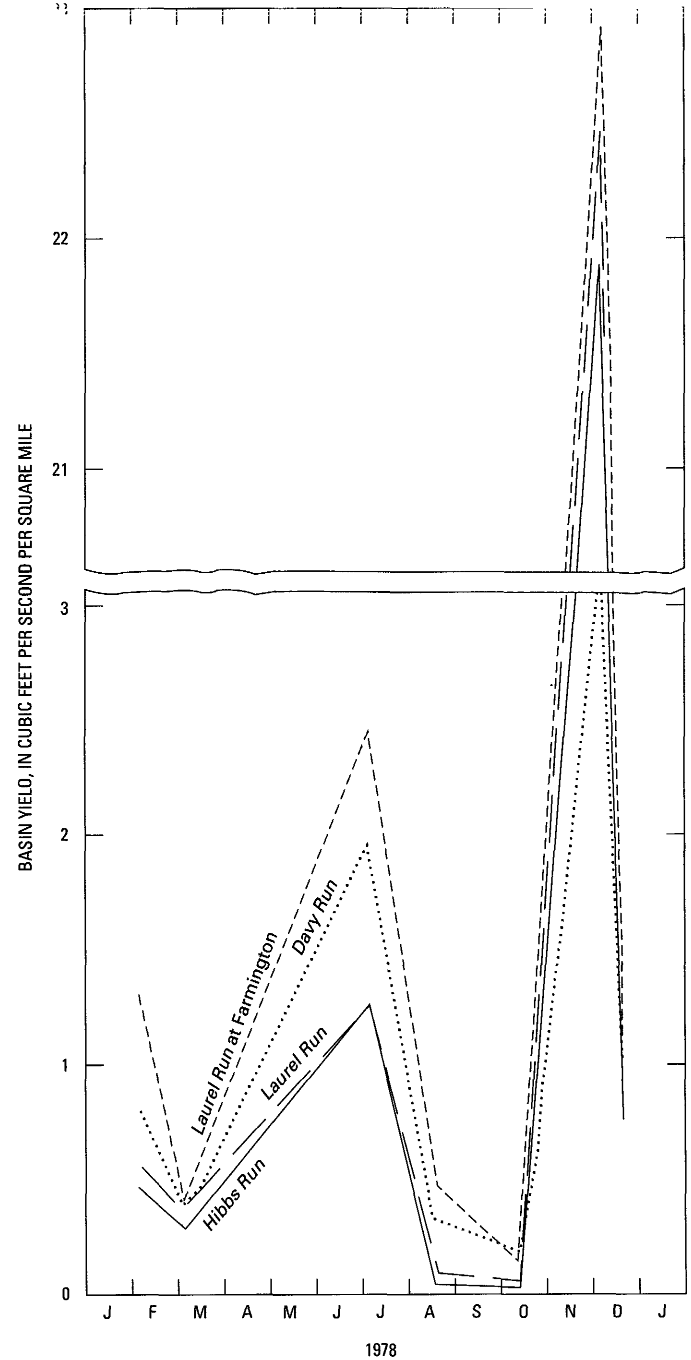



**Figure 3.6B.** Yield of water from mined and unmined basins within Buffalo Creek basin.

# Mining and Subsidence Increase Amount of Water Available for Development

Mining and mine subsidence reduce evapotranspiration by permitting increased infiltration, and hence increased amounts of water are available for development.

The block diagrams in figures 4.0A and B show probable water conditions in unmined, mined, and mined-subsided areas where the mine is (fig. 4.0A) above stream level and (fig. 4.0B) below stream level. The table summarizes, for both block diagrams, the general effect of mining and subsidence on surface water and ground water in zones A, B, C, and D, assuming "normal" water levels and yields of wells and streams before mining.

Mining and mine subsidence increase the total amount of water available for development by permitting increased infiltration and reduced evapotranspiration. However, total dissolved solids usually increase in ground water and surface water. The water in flooded mines below major streams may contain high concentrations of iron sulfate and have a low (acidic) pH. The same applies to streams receiving untreated water draining from mines above major streams.

General effect of underground mining and subsidence on surface water and ground water in zones shown in figures 4.0A and 4.0B.

| Zone | Surface-Water Flow and Pond Retention | Ground-Water Yields and Levels |
|---|---|---|
| A. Rock strata from land surface to top of zone D (fig. A), or to the bottom of the upper coal bed (fig. B). | Below normal near mine shafts, lineaments, and subsidence features. Otherwise near normal. | Below normal near mine shafts, normal fractures, and subsidence features; otherwise near normal. Some water may be perched on clay or shale layers. |
| B. Land surface area below upper bed of coal. | Fig. A. Above normal where coal beds dip toward valley and below normal where coal beds dip away from valley. | Fig. A. Above normal spring flow and mine discharge where coal beds dip toward valley; below normal where coal beds dip away from valley. Normal at most wells. |
| | Fig. B. Base flow generally above normal where mines are inactive or subsided. Generally below normal where mines are active. | Fig. B. Spring discharge and seepage generally above normal near streams in subsided areas. |
| C. Rock strata below mined coal bed (fig. A) or between upper coal bed and top of zone D (fig. B). | Fig. A. Not applicable. | Fig. A. Below normal yields under hills, normal or above normal yields under valleys (but below normal water levels). |
| | Fig. B. Not applicable. | Fig. B. Below normal near mine shafts, lineaments, and subsidence features; near normal otherwise. Deeper wells most often below normal. May be above normal if mine abandoned and flooded. |
| D. Rock strata 100 to 150 ft above the mined coal bed. | Fig. A. Below normal near lineaments, subsidence features, and where mined coal bed is at shallow depth. | Fig. A. Below normal most places; some perched water or unfractured rocks may occur above coal bed. |
| | Fig. B. Not applicable. | Fig. B. Below normal near mine shafts, lineaments, subsidence features, and active mine pumps. Above normal if mine is abandoned and flooded. |

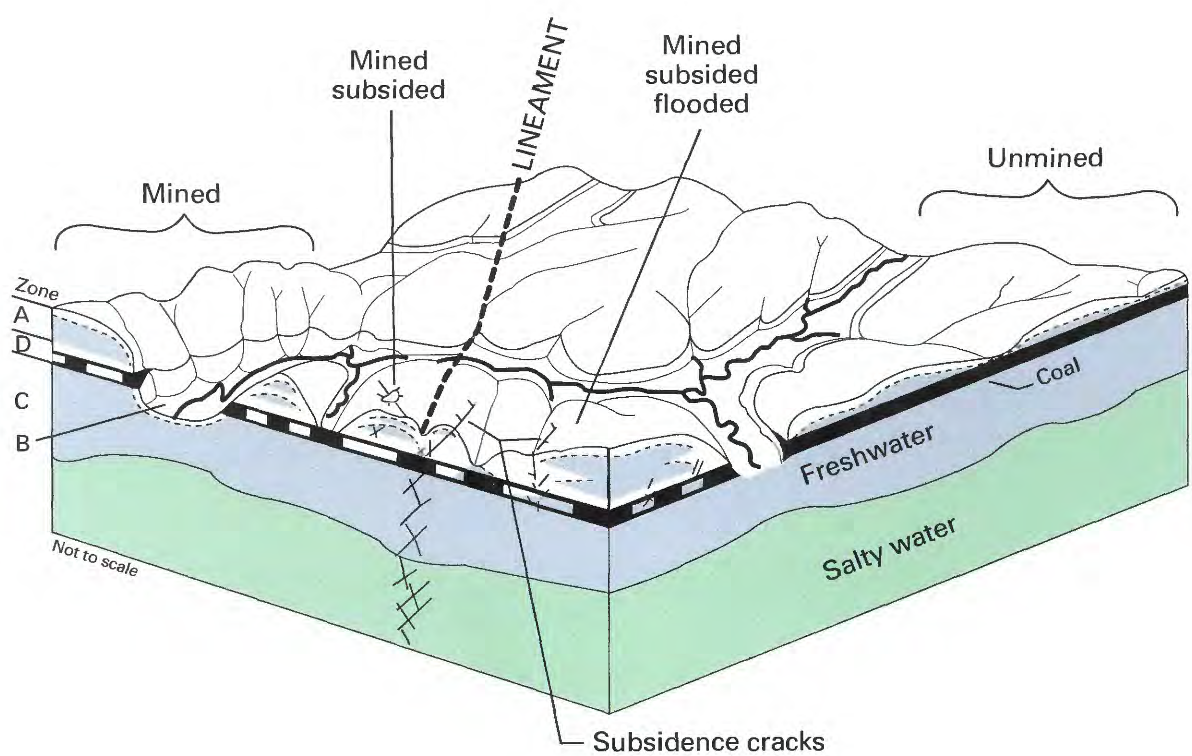



**Figure 4.0A.** General concept of ground-water conditions in unmined, mined, and mined-subsided areas where the mined bed is above major streams.

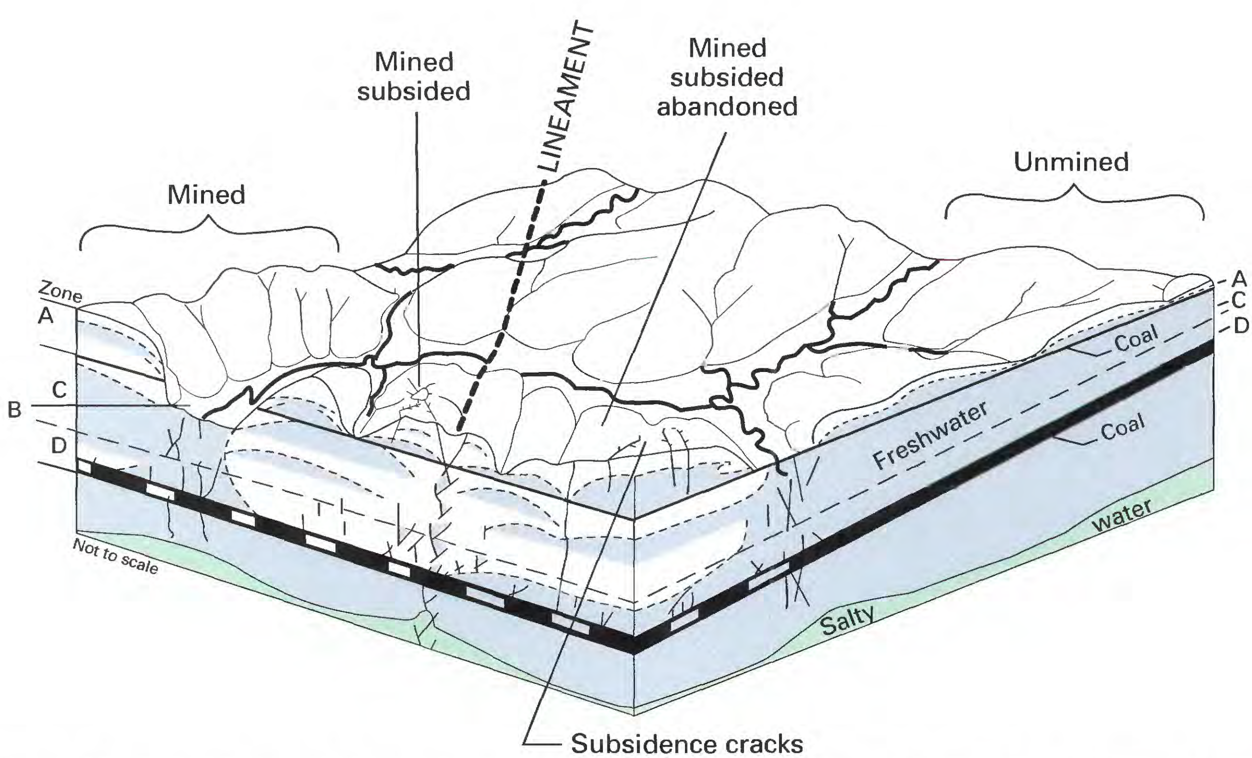



**Figure 4.0B.** General concept of ground-water conditions in unmined, mined, and mined-subsided areas where the mined bed is below major streams.

# Mining and Mine Subsidence Generally Reduce Evapotranspiration Losses and Make More Water Available for Other Uses

Greater infiltration of precipitation caused by mine-subsidence cracks leads to greater base flow discharge from some streams or mines.

## GENERAL HYDROLOGIC EFFECTS OF MINING AND MINE COLLAPSE, MINE ABOVE OR BELOW MAJOR DRAINAGE

1. Most subsidence fractures develop along, or parallel to, existing joints.
2. The water table above underground mines is generally lowered by the mining, most drastically where subsidence has occurred and where overburden is thin.
3. Infiltration of precipitation is increased, causing reduced evapotranspiration, which results in higher base flows or increased leakage into mines.
4. Subsidence may occur principally along weak zones, such as joints and fractures.
5. Mining generally causes interbasin transfer of ground water, due to mine pumpage or drainage.
6. The effect of subsidence on hydrology is apparently greatest near land surface.

## HYDROLOGIC EFFECTS OF MINING AND MINE COLLAPSE, MINE ABOVE MAJOR DRAINAGE

1. Causes losing streams.
2. Causes increased total dissolved solids in wells and streams, and generally low pH.
3. Causes water levels in some wells to fluctuate as much as 100 ft annually.
4. Causes most noticeable breakage of land surface where overburden is less than 150 ft thick.
5. Causes water levels to be much lower in deep wells located over mines than in nearby shallow wells.
6. Causes some streams receiving mine drainage to carry 100 times more dissolved minerals than streams draining unmined areas.
7. Causes pH from 2.6 to 6.3 for streams receiving mine drainage at low flow (those not receiving mine drainage range from 5.0 to 6.7).
8. Causes specific conductance from 50 to 1,750 μS in streams receiving mine drainage at low flow (those not receiving mine drainage range from 20 to 80 μS).

## HYDROLOGIC EFFECTS OF MINING AND MINE COLLAPSE, MINE BELOW MAJOR DRAINAGE

1. Causes both losing and gaining streams.
2. Causes increased total dissolved solids in some wells and streams, and above-normal pH where treated mine water enters streams.
3. Causes water levels in some wells to fluctuate as much as 50 ft annually.
4. Causes surface subsidence where overburden is more than 600 ft thick.
5. Causes little drainage from wells and streams in unsubsided areas.
6. Causes streams receiving mine pumpage at low flow to carry as much as 20 times more dissolved minerals than other streams.
7. Causes pH from 6.2 to 8.5 in streams receiving mine pumpage or drainage at low flow (those not receiving mine pumpage range from 6.7 to 7.6).
8. Causes specific conductance from 150 to 3,600 μS in streams receiving mine pumpage at low flow (those not receiving mine pumpage range from 95 to 155 μS).
9. Causes high base flow in some subsided upland basins.
10. Causes underground voids that can store large volumes of water.

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