GEOLOGIC SETTING AND WATER QUALITY OF SELECTED BASINS IN THE ACTIVE COAL-MINING AREAS OF OHIO, 1987-88

By Alan C. Sedam

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Temperature is given in degrees Celsius ($^{\circ}C$), which can be converted to degrees Fahrenheit ($^{\circ}F$) by the following equation:

$$F = 1.8(^{\circ}C) + 32$$

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."

IDENTIFICATION OF SAMPLE-COLLECTION SITE

In water-quality data tables, collection sites are identified as follows:

Surface-water site	Station number	Basin code	Station name	Latitude	Longitude
	03116950	G-2	NEWMAN C NR MASSILLON OH	(LAT 40 49 22N	LONG 081 33 06W)

Ground-water site	Station number	Local number	Owner	Location	Latitude	Longitude
	403830081220700	TU-53	US POST OFFICE	AT SANDYVILLE OH	(LAT 40 38 30N	LONG 081 22 07W)

STANDARD ABBREVIATIONS USED IN STATION NAMES

AB	Above	C	Creek	L	Little	NR	Near	TR	Tributary
B	Branch	E	East	LK	Lake	R	River	W	West
BK	Brook	F	Fork	M	Middle	RN	Run		
BL	Below	G	Great	N	North	S	South		

GEOLOGIC SETTING AND WATER QUALITY OF SELECTED BASINS IN THE ACTIVE COAL-MINING AREAS OF OHIO, 1987-88

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ABSTRACT

This report presents hydrologic data from selected drainage basins in the active coal-mining areas of Ohio from July 1987 through October 1988. The study area is mostly within the unglaciated part of eastern Ohio along the western edge of the Appalachian Plateaus physiographic province. The 1987-88 work is the second phase of a 7-year study to assess baseline water quality in Ohio's coal region.

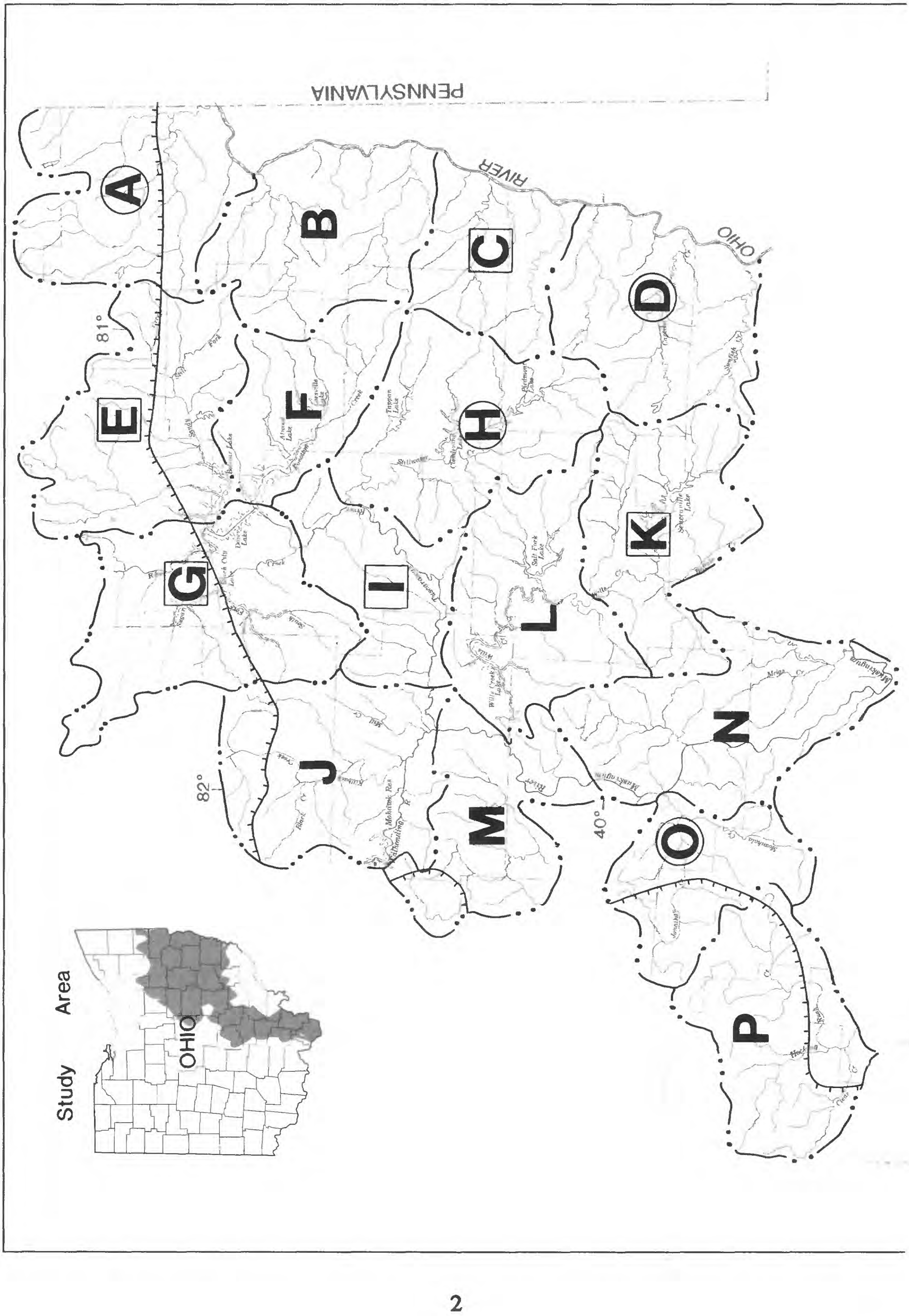
The data-collection network consisted of 41 long-term surface-water sites in 21 basins. The sites were measured and sampled twice yearly at low flow. In addition, six individual basins (three each year) were selected for a more detailed representation of surface-water and ground-water quality. In 1987, the Sandy Creek, Middle Tuscarawas River and Sugar Creek, and Lower Tuscarawas River basins were chosen. In 1988, the Short and Wheeling Creeks, Upper Wills Creek, and Upper Raccoon Creek basins were chosen.

Because of their proximity to the glaciated region and outwash drainage, the basins studied intensively in 1987 contain more shallow productive aquifers than do the basins studied in detail for 1988, in which shallow ground-water sources are very localized.

Chemical analyses for 202 surface-water and 24 ground-water samples are presented. For field measurements made at surface-water sites, the specific conductance ranged from 295 to 3,150 µS/cm (microsiemens per centimeter at 25 degrees Celsius). For pH, the range was 2.8 to 8.6. Alkalinity ranged from 5 to 305 mg/L (milligrams per liter) as $CaCO_3$. For similar measurements at ground-water sites, the specific conductance ranged from 120 to 1,590 µS/cm. For pH, the range was 5.4 to 8.9. Alkalinity ranged from 8 to 461 mg/L as $CaCO_3$.

INTRODUCTION

Surface mining of coal, which has been used for over 75 years in Ohio, accounts for most of the coal mined in the State. In 1987, 65.5 percent of Ohio coal was surface mined, and in 1988, 64.0 percent was surface mined (S.W. Lopez, Ohio Department of Natural Resources, Division of Geological Survey, oral commun., 1989).


PENNSYLVANIA
RIVER
OHIO
81°
82°
40°
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Study Area
OHIO

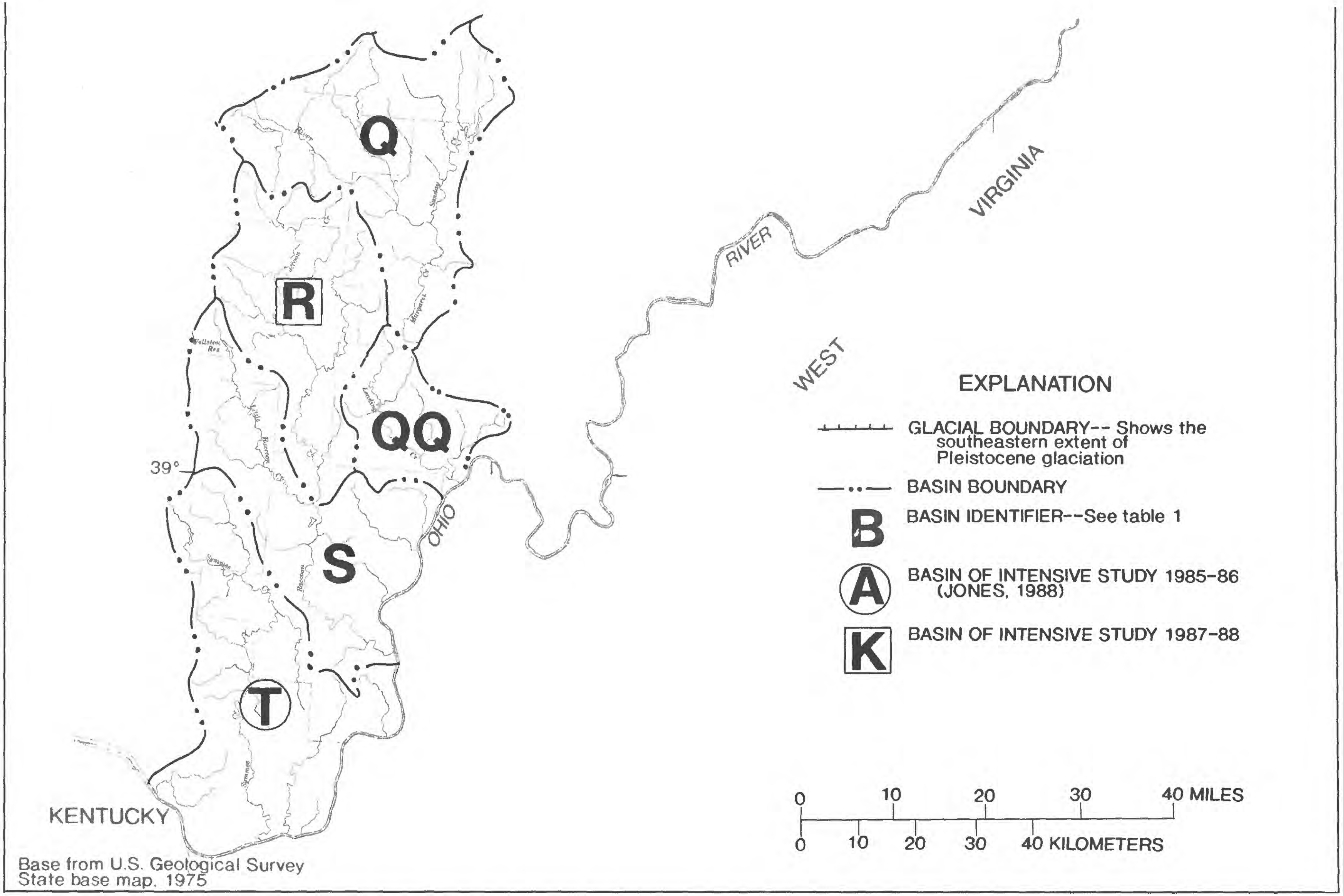


Figure 1.--Location of study areas.

Adverse effects on the hydrologic environment caused by surface mining have led to the enactment of stringent regulations designed to prevent or reduce further damage to ground and surface waters within and adjacent to mining areas and to promote reclamation of affected areas. Although considerable hydrologic data have been collected, much of the data have been limited to relatively small areas of abandoned mines. There remains a need to evaluate the long-term cumulative effects of surface mining on surface- and ground-water resources throughout the coal-bearing region of eastern Ohio. These data could be used by State agencies responsible for evaluating applications for surface-mining permits and enforcement of regulations.

In 1985, the U.S. Geological Survey, in cooperation with the Ohio Department of Natural Resources (ODNR), Division of Reclamation, began a study to collect baseline hydrologic data to describe the physical setting and quality of water in areas of active surface mining of coal. The study was planned as a three-phase, 7-year investigation during which a long-term stream-site sampling network was established. The study plan also included short-term collections of surface- and ground-water data from basins which were selected for intensive study.

Results of the first phase of the 7-year study, as well as considerable background information for the study area as a whole, are given in Jones (1988). A planned final report is to include data from the final phase, 1989-1991, along with interpretations based on the entire 7-year study.

Purpose and Scope

This report presents results of data collected during the second phase (July 1987 through October 1988) of the 7-year study. Specifically, the report (1) presents surface-water-quality data for 21 drainage basins in eastern Ohio where coal mining is currently active, (2) describes the physiographic and geologic settings of six selected basins, and (3) presents, within the same six basins, current water-quality data for several ground-water and surface-water sites selected to represent hydrologic conditions in the basins.

Description of Study Area

The study area includes all or part of 29 counties in the coal-bearing region of eastern Ohio (fig. 1). The area has been divided into 21 drainage basins, which are listed in downstream order in table 1 and shown by their respective basin identifiers (A, B, etc.) in figure 1. Sandy Creek, Middle Tuscarawas River and Sugar Creek, and Lower Tuscarawas River basins (E, G, and I, fig. 1) were selected for intensive study in 1987. Short and

Table 1.--Study basins, in downstream order, and assigned identification code

Basin code	Basin name
A	Little Beaver Creek
B	Yellow/Cross Creeks
C	Short/Wheeling Creeks
D	McMahon/Captina/Sunfish Creeks
E	Sandy Creek
F	Conotton Creek
G	Middle Tuscarawas River/Sugar Creek
H	Stillwater Creek
I	Lower Tuscarawas River
J	Walhonding River
K	Upper Wills Creek
L	Lower Wills Creek
M	Upper Muskingum River
N	Middle Muskingum River
O	Moxahala Creek
P	Upper Hocking River
Q	Middle Hocking River
QQ	Leading Creek
R	Upper Raccoon Creek
S	Lower Raccoon Creek
T	Symmes/Ice/Indian Guyan Creek

Wheeling Creeks, Upper Wills Creek, and Upper Raccoon Creek basins (C, K, and R, fig. 1) were selected for intensive study in 1988.

The boundary between Pleistocene glaciation on the northwest and the unglaciated terrain on the southeast is shown in figure 1. Most of the study area lies in the unglaciated Allegheny Plateau section of the Appalachian Plateaus physiographic province (Fenneman, 1938, p. 283). The Ohio Department of Natural Resources, Division of Geological Survey, designates the region as Glaciated Plateau and Unglaciated Plateau. Local relief is gentle (100 to 200 ft) along the glaciated western and northern fringes of the study area but is as much as 500 ft in places near the Ohio River Valley.

Four generalized land-use categories in eastern Ohio are shown in figure 2. Most of the areas depicted as "mining" within the study area represent surface mining of coal, although there is undoubtedly some local extraction of sand, gravel, or rock. Some areas of coal mining lie outside the study area, as shown in figure 2, but these are in drainage basins where coal extraction by surface mining is less active than it is in the 21-basin study area.

The climate of the eastern Ohio region was summarized by Jones (1988, p. 6). Average annual precipitation ranges from about 37 inches (in.) in the northern part of the study area to about 42 in. in the southern part (Ohio Department of Natural Resources, Division of Water, 1962). The period covered by this report, 1987-88, is somewhat unusual in that precipitation throughout Ohio was markedly below normal, especially in the study area.

The following excerpts with pertinent illustrations from Jones (1988, p. 6 and 10) furnish additional descriptions of the study area.

> Coal beds are found in a 32-county area of eastern Ohio (Brant and Delong, 1960). The area is underlain by rocks of Mississippian, Pennsylvanian, and Permian age. Rock types are usually present in sequences of (with increasing depth) coal, limestone, calcareous shale, sandstone, and limestone (Brant and Moulton, 1960).
>
> The outcrop pattern [fig. 3] from west to east progresses from older to younger units, which trend north-northeast and dip regionally to the southeast at approximately 30 feet per mile toward the Appalachian basin. The regional trend of the Pennsylvanian System is modified locally by numerous low structural features (Lamborn, 1951).

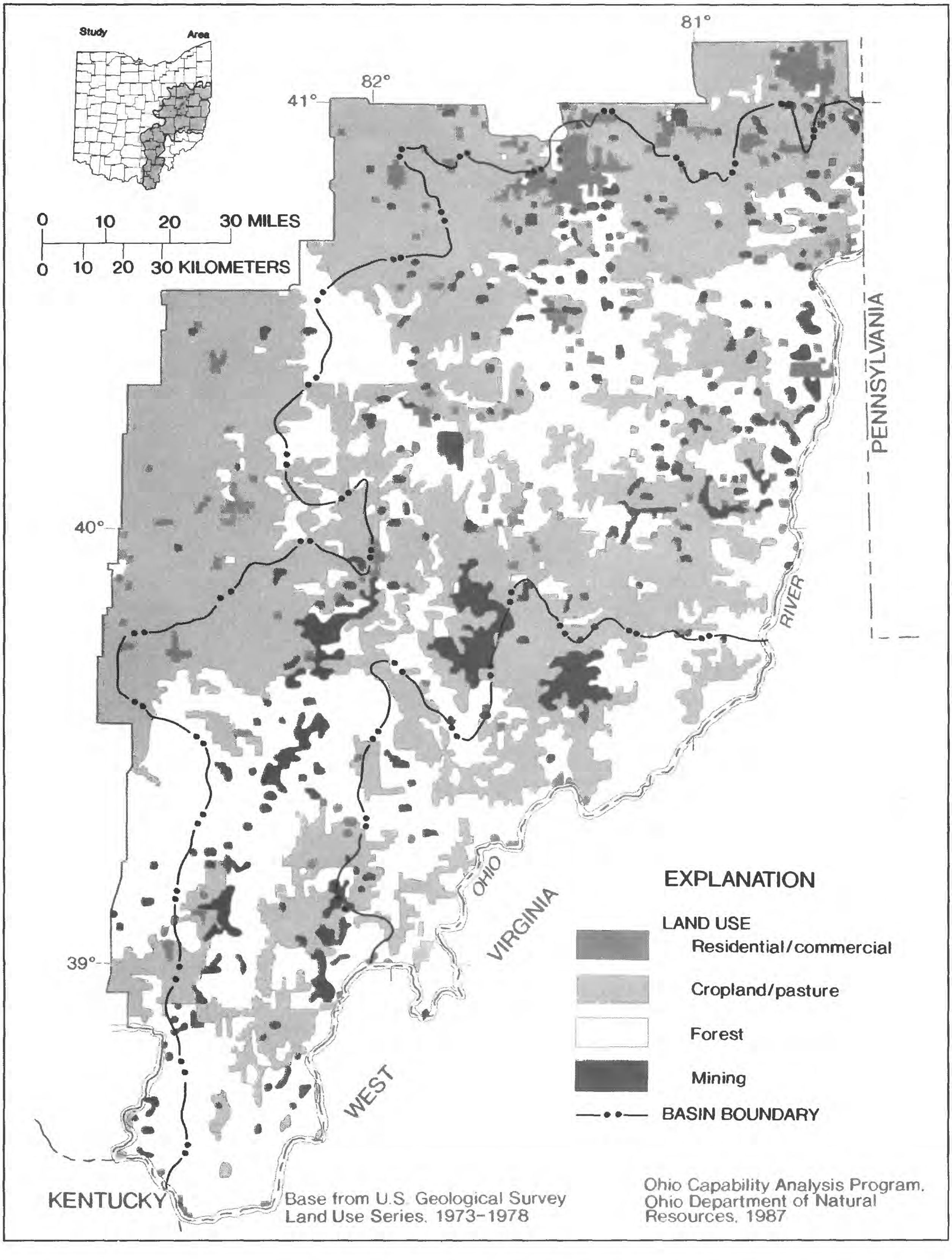


Figure 2.--Land use of eastern Ohio.

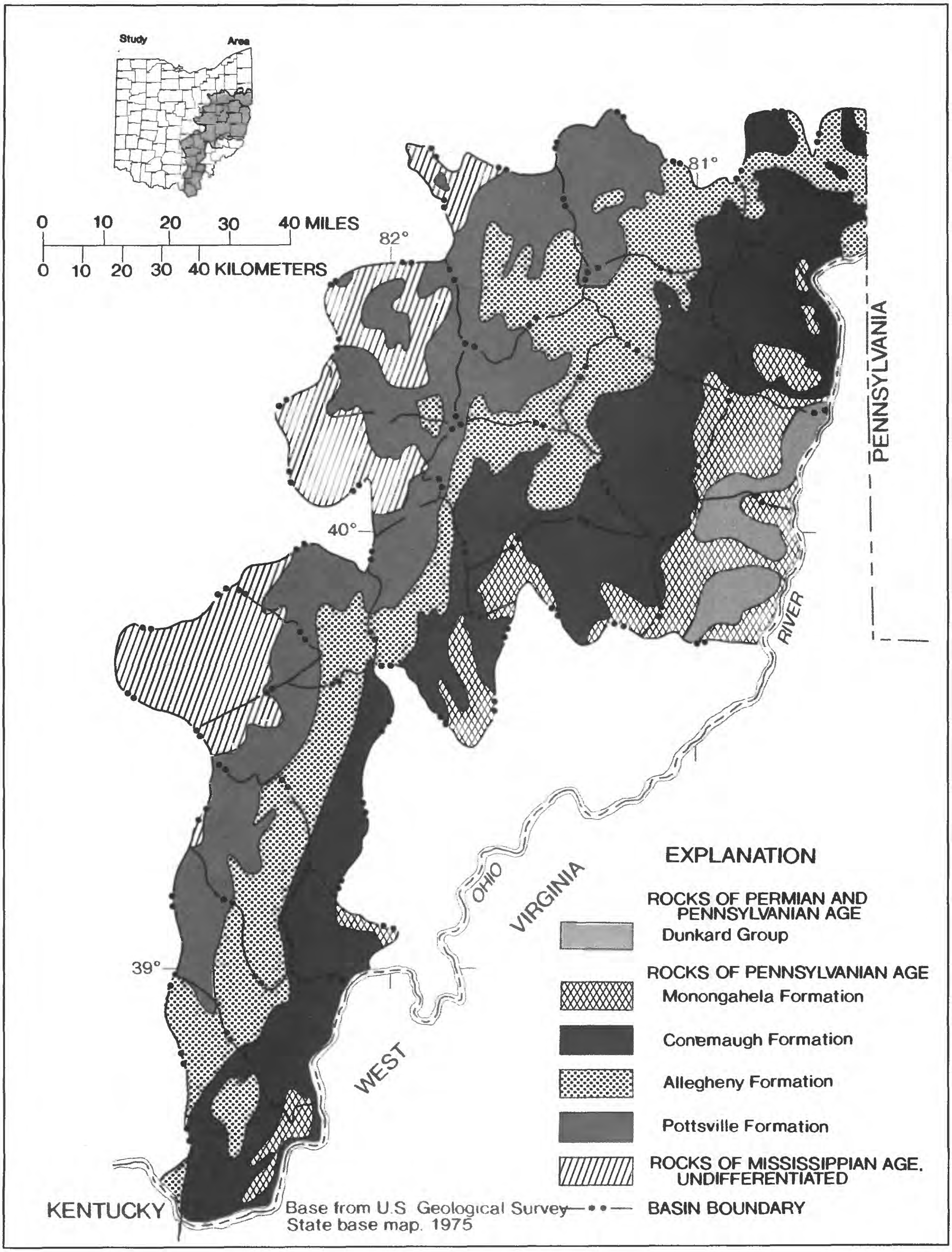


Figure 3.--Generalized geology of study area (modified from Collins, 1979).

The oldest formation of Pennsylvanian age is the Pottsville Formation [fig. 4], in which conglomeratic sandstones are dominant. Above this are the Allegheny, Conemaugh, and Monongahela Formations, all of Pennsylvanian age, which comprise alternating beds of shale, sandstone, coal, and thin limestones. The Dunkard Group of Pennsylvanian and basal Permian age is a variable series of rocks composed of beds of red shale (which is the most abundant rock type), limestone, sandstone, and coal. In the south, the limestone and coal are scarce, and the series consists chiefly of shale and sandstone (Collins, 1979).

The proportion of sandstone strata increases with age. The Allegheny Formation is 40 percent sandstone, and the remainder is composed of shale and clay. The Conemaugh Formation is not more than 30 percent sandstone, and the Monongahela Formation consists of shale, limestone, and not more than 15 percent sandstone (Stout and others, 1943). The carbonate content decreases with age in the Pennsylvanian rocks; therefore, the Monongahela Formation contains more carbonate rocks than the Allegheny and Conemaugh Formations (Razem and Sedam, 1985). Deposits of unconsolidated silts, nearly 100 feet thick in some places, are found chiefly in the bottoms of old valleys that now have no major drainage, and in the lower parts of many smaller valleys. In the main valleys, these silts have largely been removed, and the valleys now are filled with sands and gravels, which have been terraced by the present streams. In the valleys that have carried glacial waters (but have not been glaciated), these coarse, fluvial deposits are common and are composed chiefly of glacial outwash (Happ, 1934).

Fifty-two coal beds are recognized and named in Ohio, most of which are thin and discontinuous. Most minable coals are in the Allegheny and Monongahela Formations, and all are highly volatile and bituminous, falling in the medium (1.1 to 3.0 percent) to high (greater than 3.0 percent) sulfur range (Collins, 1978). Mining has traditionally concentrated on the "numbered" coals--Sharon ("No. 1") through Waynesburg ("No. 11")--which still supply most coal mined in Ohio. The Allegheny and Monongahela Formations are especially productive because of their more uniform thickness and distribution; therefore, most mines in Ohio are in parallel bands following the outcrop of these two formations (Pfaff and others, 1981). The lithologic character of the principal units and the relative positions of the important coals are shown in figure 4.

System	Group, Formation		Description	Important coal beds
Permian	Dunkard Group	Greene	Mostly red shales and thin limestones, localized coals and sandstone bodies. Present only in small areas.	No. 12 Washington
Pennsylvanian and Permian	Dunkard Group	Washington	Sandstones, shales, and minor coals. Sandstones are typically micaceous, fine to medium grained, and have thin conglomeratic zones. Locally, sandstones may be massively developed.	
Pennsylvanian	Monongahela		Important coal-bearing strata and associated beds of clay, shale, sandstone, and limestone. Sandstones tend to be fine to medium grained, micaceous, and patchy in development. Compared to other Pennsylvanian units, the Monongahela has a smaller proportion of sandstone and a larger proportion of limestone. Limestones tend to be marly, freshwater types. Secondary porosity along fractured surfaces is well developed locally.	No. 11 Waynesburg No. 10 Uniontown No. 9 Meigs Creek No. 8 Pittsburgh
Pennsylvanian	Conemaugh		Thick repetitious succession of shales and patchy sandstones interspersed with thin, discontinuous coals and clays and widespread limestones. The lower limestones are of marine origin, whereas those in the upper part are marly, freshwater types. Secondary porosity along fractured surfaces is well developed locally.	
Pennsylvanian	Allegheny		Repetitious succession of important coal-bearing strata interspersed with several fine to coarse-grained massive, cross-bedded sandstones and thin, persistent limestones. Sandstones, though widespread, have considerable local lateral variation. Solution cavities are developed locally in the limestones.	No. 7 Upper Freeport No. 6A Lower Freeport No 6 Middle Kittanning No. 5 Lower Kittanning No. 4A Clarion No. 4 Brookville
Pennsylvanian	Pottsville		Succession of sandstone, shales, clays, coals, and thin limestones. Locally, sandstones are open-textured, conglomeratic, massive, cross-bedded, and commonly are found as deposits filling old channels in eroded terrains. Lateral gradations include shale and coal. Non-deposition during the Early Pennsylvanian precluded the development of the basal conglomerate of the Sharon Member in most of southeastern Ohio.	No. 3 Lower Mercer No. 2 Quakertown No. 1 Sharon
Pennsylvanian	Pottsville		Thin, discontinuous zone of impure nodular iron ore and ferruginous sandstone. The unit marks the disconformity between Mississippian and Pennsylvanian strata. Age of the deposit is conjectural, but generally it is included at the base of the Pottsville Formation.	
Mississippian	Undifferentiated		Variable sequence of sandstones and shales; Maxville Limestone is present in patches at the top. In places, various units are conglomeratic and sandstones are massive. Lateral and vertical gradation to siltstone and shale is common. Ground-water potential is limited to extreme western areas. Eastward, the section contains salt water. To the north, post-Mississippian erosion has removed part of the section.	

Figure 4.--Generalized geologic column for southeastern Ohio, including relative position of important coal beds (from Razem and Sedam, 1985).

Acknowledgments

The author acknowledges the cooperation of the Ohio Department of Natural Resources, Division of Reclamation, for information concerning location of coal-mining activity, and to the Division of Water, for access to their data files. The author also appreciates the cooperation of various commercial and municipal entities as well as individual property owners who allowed access to their wells or other data-collection sites.

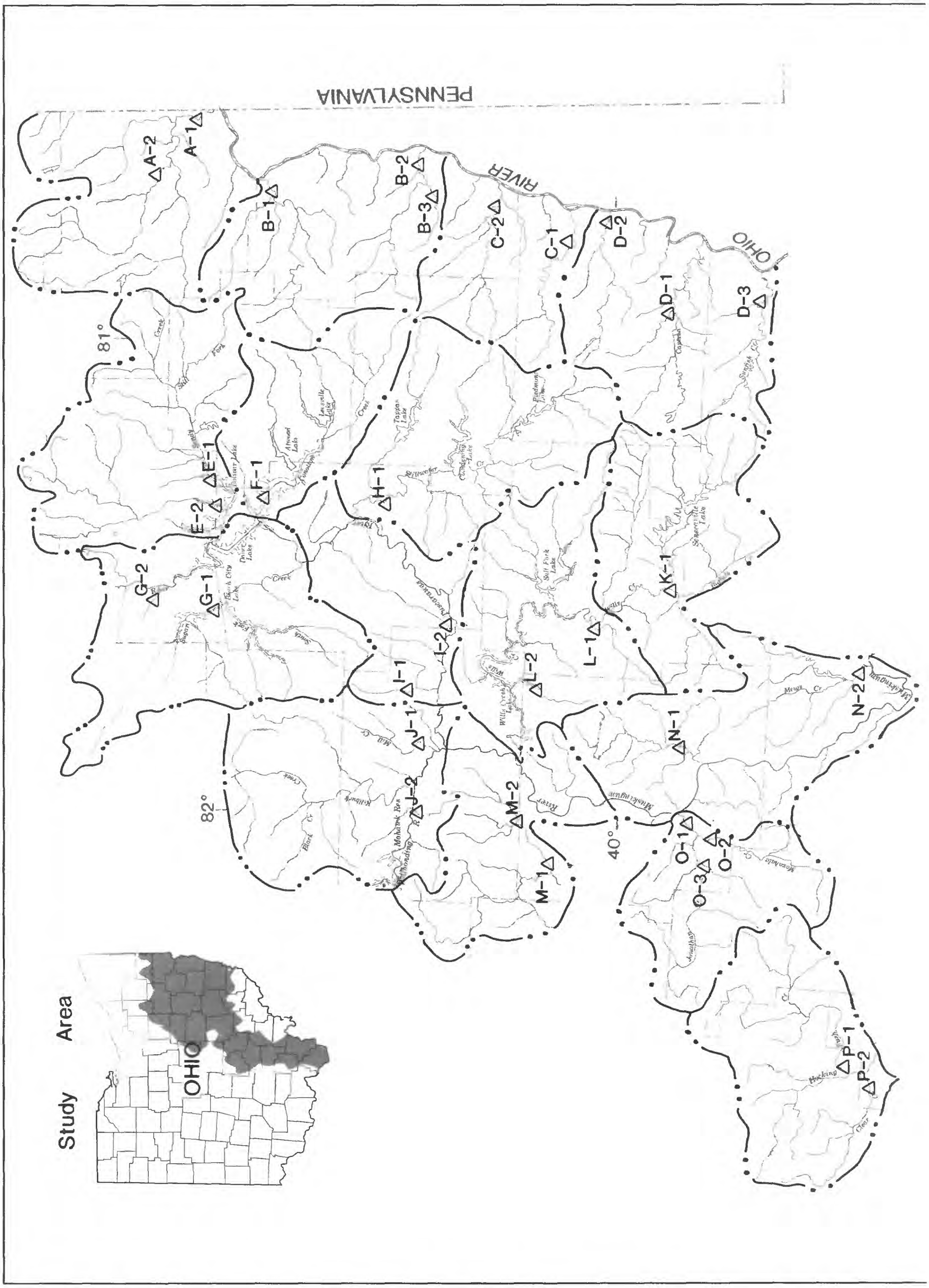
METHODS OF STUDY

Locations of the long-term surface-water sites by use of their basin identifier and sequential number are shown in figure 5. The original (1985-86) network of long-term surface-water sites consisted of one to three sites in each of 20 basins, totaling 40 sites. In 1987, Leading Creek basin (QQ, fig. 1), was added to the study area. With the addition of site QQ-1 (fig. 5), the network was expanded to 41 long-term surface-water sites.

Discharge measurements were made, and water samples were collected at all sites twice annually, in late spring or early summer and in early fall under low-flow conditions. (For this study, low-flow condition was a rate of flow exceeded 70 percent or more of the time). Consideration of rainfall as a factor in anticipation of streamflow conditions was essential to insure that results of stream sampling were not biased by unusually high or low flows. Identical low-flow conditions seldom prevailed throughout the study during the sampling periods, but the flow variations for a given site between sampling periods were of the same magnitude as in the first-phase study.

Discharge measurements were made and water samples were collected once at 40 short-term surface-water sites during the fall sampling periods. In 1987, 10 such sites were measured and sampled in each study basin (E, G, I, fig. 1), and, in 1988, five sites each were measured and sampled in basins C and K (fig. 1). Because of the completion of two recent studies in Raccoon Creek (Wilson, 1985 and 1988), no short-term surface-water sites were measured or sampled in Upper Raccoon Creek basin (R, fig. 1).

Identical procedures were followed at all surface-water sites (Jones, 1988). Field measurements of discharge, specific conductance, pH, temperature, alkalinity, and acidity were made at each site. Discharge was measured by the methods described in Rantz and others (1982). Specific conductance, pH, temperature, and alkalinity were determined by the methods discussed in Skougstad and others (1979).


Study Area
OHIO
PENNSYLVANIA
OHIO RIVER
81°
82°
40°
A-1
A-2
B-1
B-2
B-3
C-1
C-2
D-1
D-2
D-3
E-1
E-2
F-1
G-1
G-2
H-1
I-1
I-2
J-1
J-2
K-1
L-1
L-2
M-1
M-2
N-1
N-2
O-1
O-2
O-3
P-1
P-2

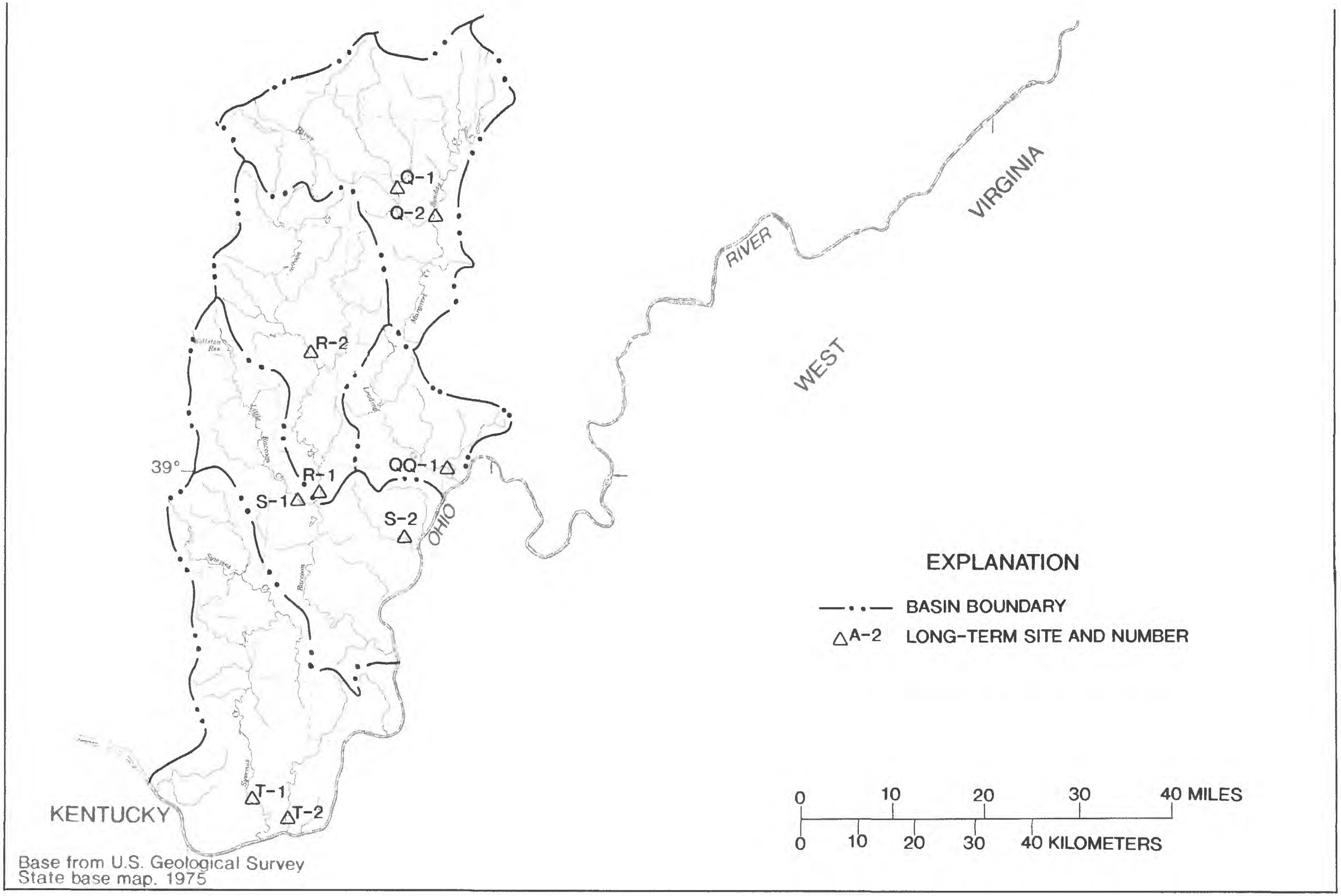


Figure 5.--Locations of long-term surface-water sites.

Alkalinity and (or) acidity were measured at each site. If the pH of the stream was in the range 5.0 to 6.5, both were determined. Acidity was determined by use of the hot-peroxide-treatment method (American Public Health Association, 1975). Water samples for chemical analysis were collected according to the equal-transit-rate/equal-width-increment method (U.S. Geological Survey, Office of Water Data Coordination, 1977) for all streams with water depths greater than 0.5 ft. These were composited in a churn splitter from which subsamples were then drawn for field and laboratory analysis. Samples that were sent to the U.S. Geological Survey's National Water Quality Laboratory in Denver, Co., were analyzed for concentrations of dissolved sulfate, total and dissolved iron, total and dissolved manganese, and total and dissolved aluminum.

All six of the basins selected for intensive study were examined for the existence of shallow productive aquifers that might be receiving recharge affected by surface-mine drainage. Ground-water resource maps and drillers' logs on file at the Ohio Department of Natural Resources, Division of Water, were used to locate prospective areas of shallow ground-water use and wells that could be used for sampling. The unconsolidated aquifer along the Ohio River was excluded from the study. Four ground-water sites in each of the six basins were selected for sampling. The 24 ground-water samples were analyzed at the U.S. Geological Survey's National Water Quality Laboratory. Sampling procedures usually consisted of selecting wells in current use, inspecting the system to avoid treatment devices, and allowing the well to pump long enough to insure that the water sample was representative of the formation. Field measurements were made for specific conductance, pH, dissolved-oxygen concentration, temperature, and alkalinity. Water levels also were measured when possible.

Laboratory analyses included concentrations of--

Total and dissolved aluminum;
Dissolved sulfate;
Total and dissolved iron;
Total and dissolved manganese;
Dissolved silica;
Dissolved calcium;
Dissolved magnesium;
Dissolved sodium;
Dissolved chloride;
Dissolved potassium;
Dissolved organic carbon; and
Total dissolved solids (residue on evaporation at 180 °C).

GENERAL WATER QUALITY

Surface Water

Local geology and the extent to which the area has been mined are two important factors that affect water quality of streams within the 21-basin study area. Acidified drainage has caused severe degradation of stream water quality in some areas and remains a potential threat elsewhere in unmined areas. In addition to acidic drainage, increased levels of constituents that can adversely affect aquatic biota of the stream can also be present.

The principal cause of the acidic drainage is the widespread presence of sulfur-bearing minerals, such as pyrite and marcasite, in coal-bearing strata. Exposure of these minerals to air and water by mining leads to complex chemical changes, such as the oxidation of sulfides to sulfates. This commonly results in an increased level of acidity to surface runoff. In some places, limestone is present and can serve as a buffer by helping to neutralize acidic drainage.

Several easily measured physical properties and chemical constituents were used to assess the general water quality of major streams in the study area. These were specific conductance, pH, field alkalinity and (or) acidity, and concentrations of dissolved sulfate, iron, manganese, and aluminum, and concentrations of total recoverable iron, manganese, and aluminum. Ranges and median values of these same properties and constituents are summarized in table 2 for the 41 long-term surface-water sites. Site identifiers for each extreme value correspond to the long-term-site sampling locations shown in figure 5. The table is based on data from four periods of sampling at the 41 sites: late July 1987, late October 1987, early June 1988, and early October 1987. Ranges, percentiles, and median values of constituents are presented graphically in figure 6, and detailed analyses are given in table 21 at the back of the report.

Table 2.--Ranges and medians for selected water-quality characteristics for long-term surface-water sites 1987-88

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 5)	Median
Specific conductance, in µS/cm----------------	290(T-1) to 2,700(C-1)	795
pH------------------------	2.8(Q-2) to 8.6(B-2,3; C-2;P-2)	7.8
Alkalinity, in mg/L as $CaCO_3$-------------------	0(sev. sites) to 263(C-1)	115
Sulfate, dissolved, in mg/L as SO_4---------	23(M-1) to 1,500(C-2)	195
Aluminum, total, in ug/L as Al----------	<10(J-1, P-2) to 17,000(Q-1)	190
Aluminum, dissolved, in µg/L as Al----------	<10(sev. sites) to 17,000(Q-1)	20
Iron, total, in µg/L as Fe----------	70(D-3, QQ-1) to 62,000(Q-2)	570
Iron, dissolved, in µg/L as Fe----------	<10(sev. sites) to 51,000(Q-2)	50
Manganese, total, in ug/L as Mn----------	10(D-1) to 50,000(O-2)	315
Manganese, dissolved, in ug/L as Mn----------	<10(D-1,D-3) to 47,000(O-2)	275

Specific conductance provides a quick approximation of the dissolved-solids content in water samples. According to Hem (1985), the dissolved-solids concentration, in milligrams per liter, is about 0.55 to 0.75 times the specific conductance, in microsiemens per centimeter at 25 °C. The dissolved-solids concentration, although not determined for the surface-water samples, was determined for the water samples from the 24 ground-water sites. In most of these samples, the dissolved-solids concentration (in milligrams per liter) was 0.58 to 0.67 times the specific conductance (in microsiemens per centimeter).

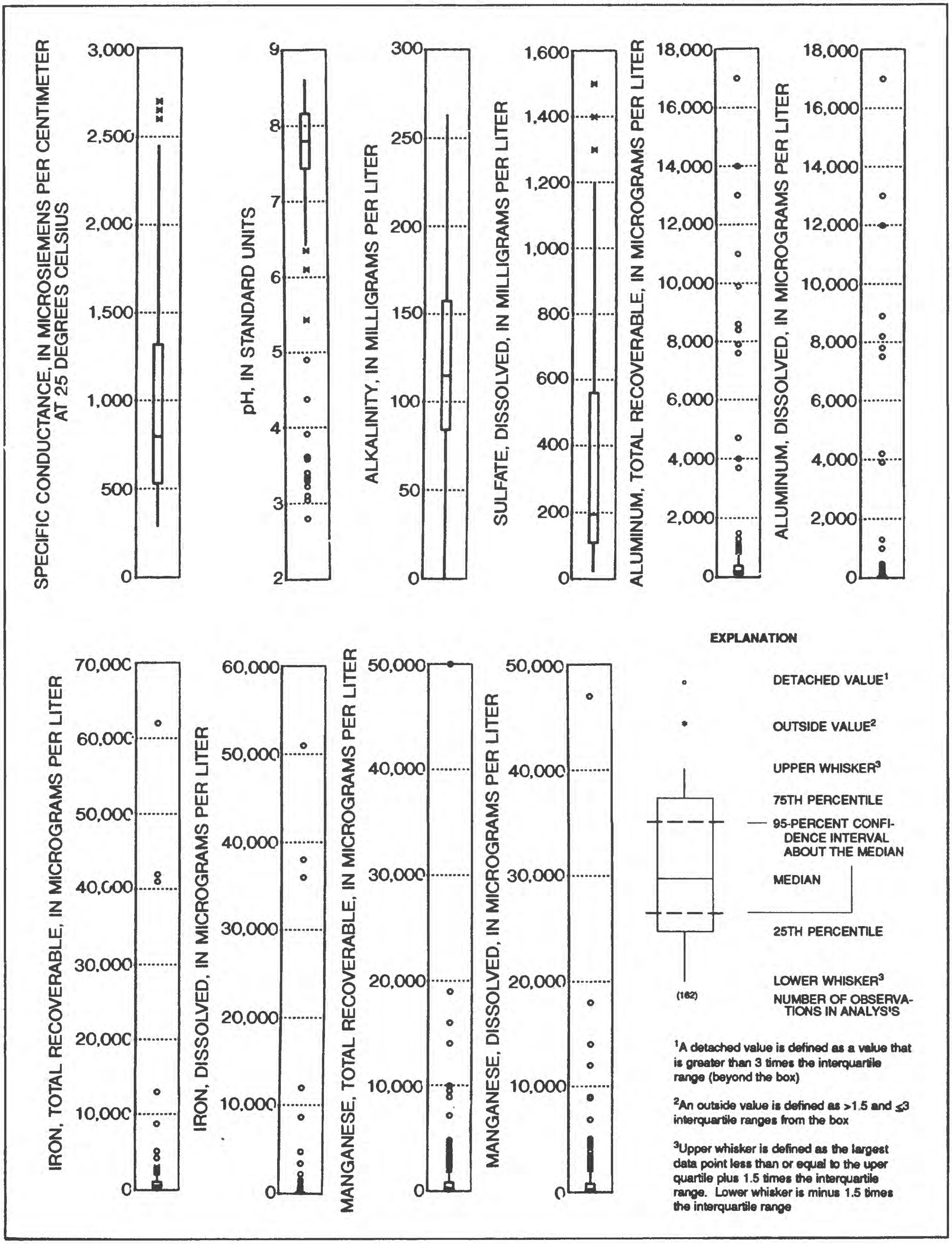


Figure 6.--Box plots showing the range, percentiles, and median values of constituents at long-term surface-water sites.

Sites where high specific conductance and low pH values were measured were generally the same sites where elevated[1] levels of dissolved sulfate, iron, manganese, and aluminum were found--typical of streams draining actively mined or unreclaimed abandoned-mine lands.

The long-term surface-water sites with the highest concentrations of dissolved aluminum, iron, and manganese were O-1, O-2, Q-1, and Q-2 (fig. 5). On most of the sampling occasions, the pH at these sites was less than 5.0. Although the concentration of dissolved sulfate was generally high at the acidic sites, the two highest sulfate levels were at sites C-1 and C-2 where the waters were alkaline. A number of long-term surface-water sites which were located near the mouth of a coal-producing basin exceeded the median values for these constituents listed in table 2.

In the first phase of this study (Jones, 1988, p. 16), it was noted that a neutral value of pH in streams that drain parts of the coal-mining region was not uncommon. In the current study, for most of the long-term surface-water samples, the pH exceeded a value of 7.0. The acid drainage could have been diluted by waters buffered from contact with limestone. "Buffering capacity," the ability to neutralize additions of acids or bases without a change in pH, is controlled by the concentration of alkalinity and acidity present in water (U.S. Environmental Protection Agency, 1986).

In earlier studies, it has been shown that levels of some of these constituents can be restored by reclamation to premining levels, although specific conductance and concentration of dissolved sulfate are likely to remain at elevated levels (Pfaff and others, 1981; Hren and others, 1984).

Ground Water

Ground-water systems within areas of coal-mining operations can be affected either by disruption of ground-water flow or by environmental changes that cause degradation of water quality. In this investigation, shallow, productive aquifers that could be affected by surface mining were targeted to be used for an assessment of ground-water quality. Shallow sources of ground water are present in many places throughout the coal-bearing region of eastern Ohio; however, those that are capable of furnishing enough water for commercial or small industrial

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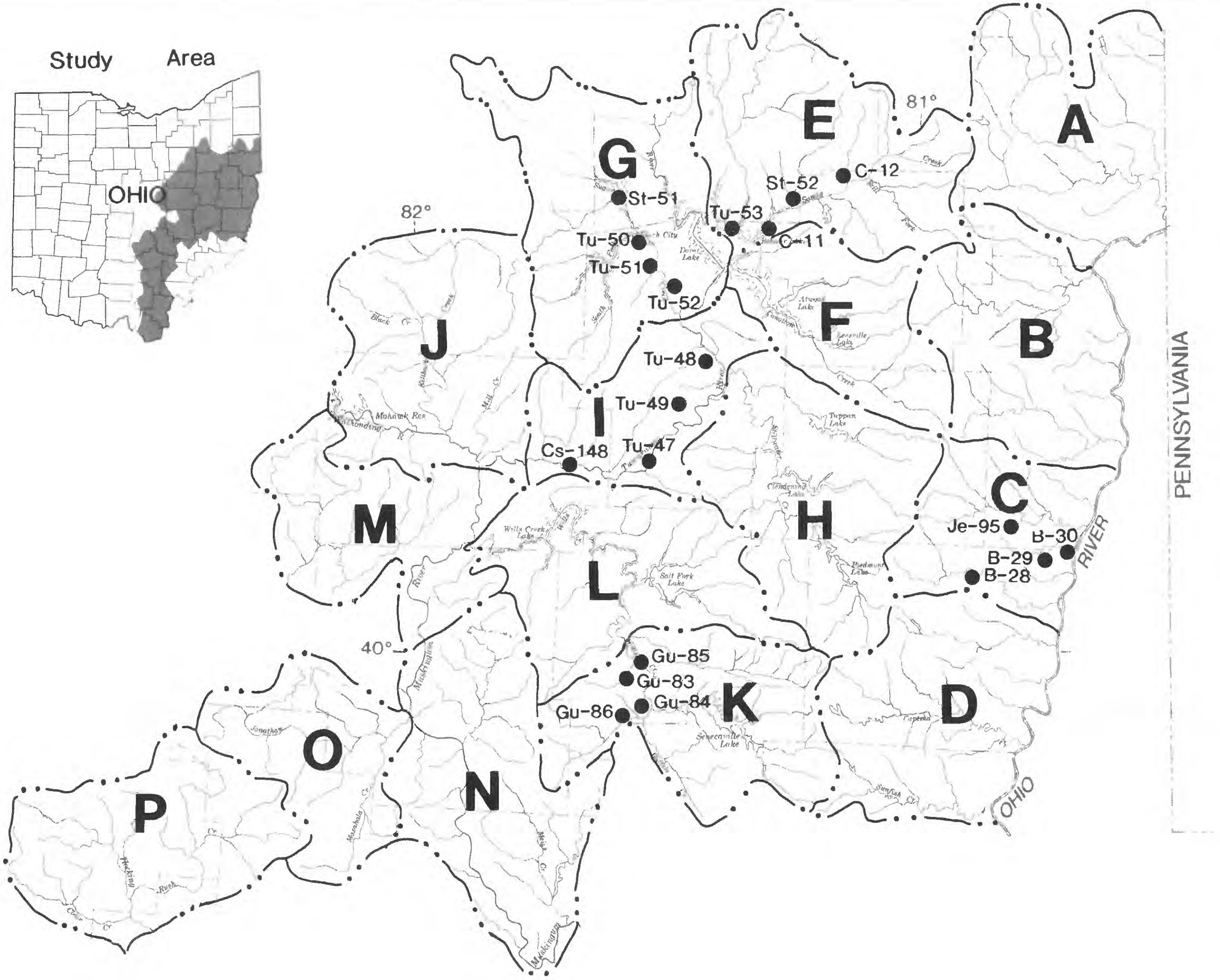
[1] "Elevated" in this context refers to constituent concentrations that are significantly above background levels.

purposes are mostly restricted to a few major valleys. The unconsolidated alluvial deposits along the Ohio River Valley, perhaps the most productive of these sources, are not included in the scope of this study. The next most productive source is the sand and gravel outwash and valley fill of sediments deposited as a result of Pleistocene glaciation, which covered the western and northern fringes of the study area. One of the more productive sources is along the Tuscarawas drainage system in the Sandy Creek, Middle Tuscarawas River and Sugar Creek, and Lower Tuscarawas River basins (E, G, and I, respectively, fig. 1). These three basins were chosen for intensive study in 1987.

Farther south and exclusive of the Ohio River Valley, shallow, productive sources of ground water are limited to the Muskingum River and Hocking River valleys. Elsewhere, shallow ground-water sources, whether in bedrock or unconsolidated material, are localized and, compared with the types just described, yield relatively small quantities of water to wells. This situation is characteristic of ground-water availability in Short and Wheeling Creek, Upper Wills Creek, and Upper Raccoon Creek basins (C, K, and R, respectively, fig. 1), which were chosen for intensive study in 1988.

Ground-water samples were collected at 24 sites scattered throughout the six basins chosen for intensive study in 1987-88 (fig. 7). A Piper diagram (fig. 8) shows the chemical character of the ground water from the 24 sites with respect to water type. The ranges and median values of selected constituents and physical properties are listed in table 3.


Study Area
OHIO
PENNSYLVANIA
OHIO
RIVER
81°
82°
40°
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
C-12
St-52
Tu-53
C-11
St-51
Tu-50
Tu-51
Tu-52
Tu-48
Tu-49
Tu-47
Cs-148
Je-95
B-30
B-29
B-28
Gu-85
Gu-83
Gu-84
Gu-86

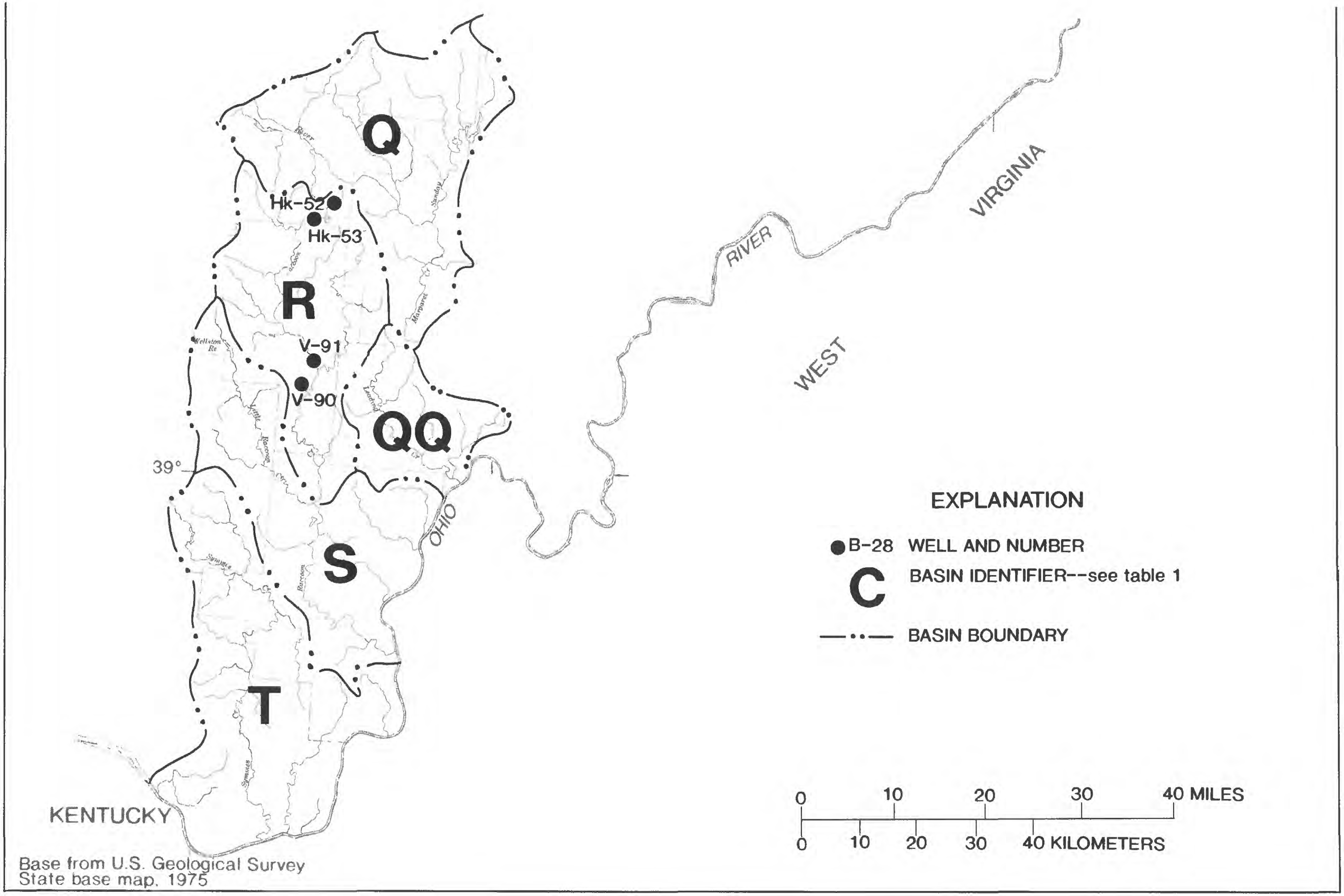
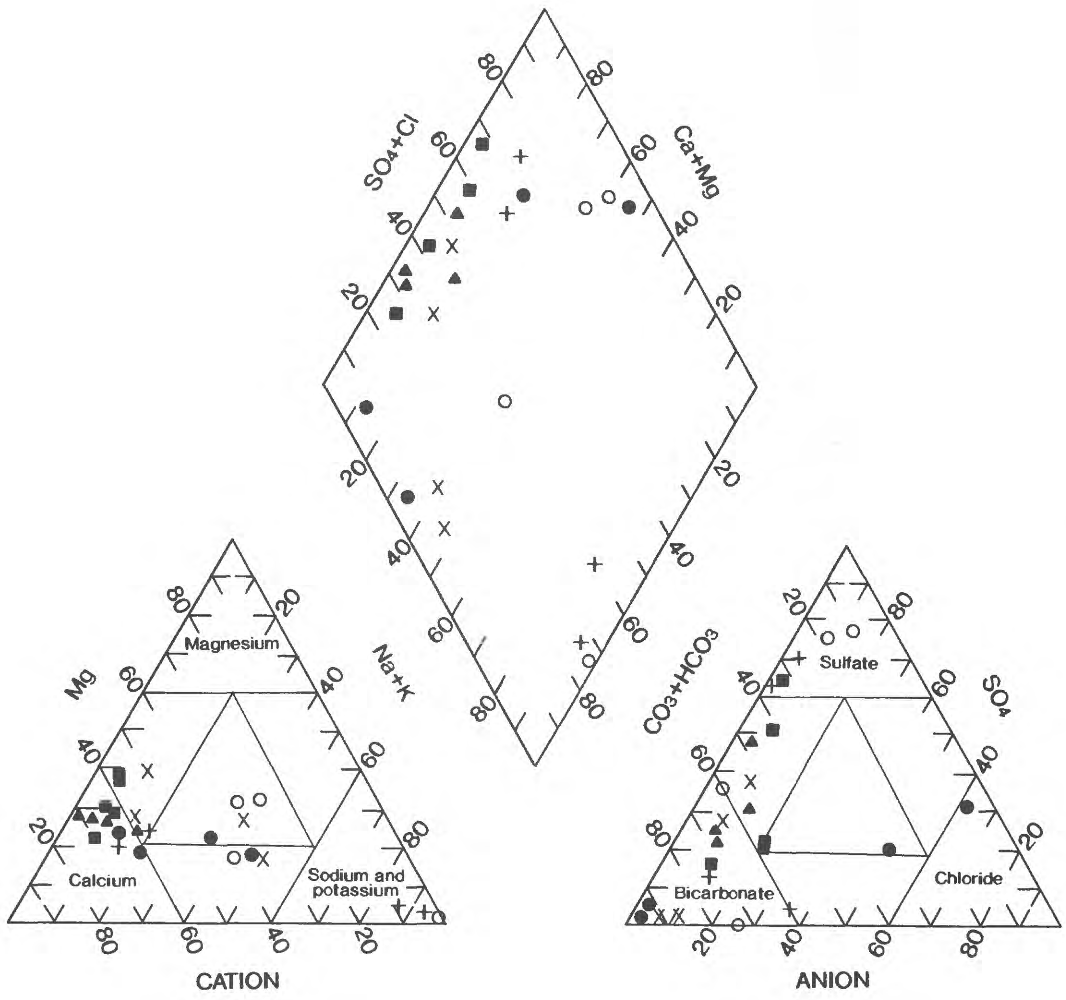


Figure 7.--Location of ground-water sampling sites.



EXPLANATION

CATION-ANION PERCENTAGES BASED ON MILLIEQUIVALENCE FOR GROUND-WATER SAMPLES IN:

- ● SANDY CREEK BASIN
- ■ MIDDLE TUSCARAWAS RIVER AND SANDY CREEK BASIN
- ▲ LOWER TUSCARAWAS RIVER BASIN
- + SHORT CREEK AND WHEELING CREEK BASIN
- X UPPER WILLS CREEK BASIN
- O UPPER RACCOON CREEK BASIN

Figure 8.--Piper diagram showing distribution of constituents in ground-water within the study area.

Table 3.--Ranges and medians for selected water-quality characteristics for ground-water sites, 1987-88

[mg/L, milligrams per liter; µg/L, micrograms per liter; uS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 7)	Median
Specific conductance, in µS/cm	120(V-90) to 1,590(B-30)	662
pH	5.4(C-11) to 8.9(B-28)	7.4
Oxygen, dissolved, in mg/L	0(sev. sites) to 7.8(TU-47)	1.4
Hardness, in mg/L as $CaCO_3$	13(HK-53) to 750 (B-30)	275
Noncarbonate hardness, in mg/L as $CaCO_3$	0(sev. sites) to 530(B-30)	85
Calcium, dissolved, in mg/L as Ca	6.4(V-90) to 230(B-30)	66
Magnesium, dissolved, in mg/L as Mg	1.1 (HK-53) to 43(B-30, TU-51)	19
Sodium, dissolved, in mg/L as Na	3.7(CS-148) to 280(B-28)	24
Potassium, dissolved, in mg/L as K	0.6(GU-83,GU-85) to 6.8(TU-50)	1.8
Alkalinity, in mg/L as $CaCO_3$	8(V-90) to 461(B-28)	200
Sulfate, dissolved, in mg/L as SO_4	1.1(HK-53) to 630(B-30)	78
Chloride, dissolved, in mg/L as Cl	3.0(V-90) to 200(TU-53)	21
Silica, dissolved, in mg/L as SiO_2	1.7(ST-51) to 38(V-90)	12
Solids, dissolved, sum of constituents, in mg/L	100(V-90) to 1,140(B-30)	374
Aluminum, total, in ug/L as Al	10(sev. sites) to 310(V-90)	20
Aluminum, dissolved, in ug/L as Al	<10(sev. sites) to 70(C-11)	<10
Iron, total, in ug/L as Fe	20(TU-50) to 6,700(TU-53)	425
Iron, dissolved, in ug/L as Fe	3(sev. sites) to 5,700(GU-83)	190
Manganese, total, in ug/L as Mn	<10(TU-48,TU-50) to 950(TU-49)	95
Manganese, dissolved, in ug/L as Mn	<1(TU-50) to 890(TU-49)	74
Carbon, organic, dissolved, in mg/L as C	0.5(sev. sites) to 3.0(GU-84)	0.8

Some of the values shown in table 3 may be compared with State water-quality standards for public water supply listed below. All concentrations are expressed as total concentrations unless otherwise noted (Ohio Environmental Protection Agency (OEPA), 1978):

Chloride----------------------	250 mg/L
Dissolved solids-------------	500 mg/L[2]
Iron (dissolved)-------------	300 ug/L
Manganese (total)------------	50 µg/L
Sulfates---------------------	250 mg/L

The hardness of water is based on the following classification (U.S. Environmental Protection Agency, 1986):

Classification of Water by Hardness

[Concentration in mg/L as $CaCO_3$]

0- 75---------------------	Soft
75-150---------------------	Moderately hard
150-300---------------------	Hard
Greater than 300------------	Very hard

GEOLOGIC SETTING AND WATER QUALITY OF SELECTED BASINS

Each of the six drainage basins is described with respect to its physical setting and geologic framework. Results of the ground- and surface-water sampling are described and supported by data tables and graphic figures.

Sandy Creek Basin

Sandy Creek basin has a drainage area of 504 mi^2. Much of the basin lies in the eastern half of Stark County (fig. 9). About a quarter of the basin is in the northern part of Carroll County, and the remainder is in small areas of Columbiana and Tuscarawas Counties. The glacial boundary divides the area about equally between the Glaciated Allegheny Plateau on the north from the unglaciated Allegheny Plateau on the south, both sections of the Appalachian Plateaus Province (Fenneman, 1938) (fig. 1, basin E).

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[2] Not exceeding 500 mg/L as a monthly average or 750 ug/L at any time (equivalent specific-conductance values at 25 degrees Celsius are 800 and 1,200 uS/cm, respectively).

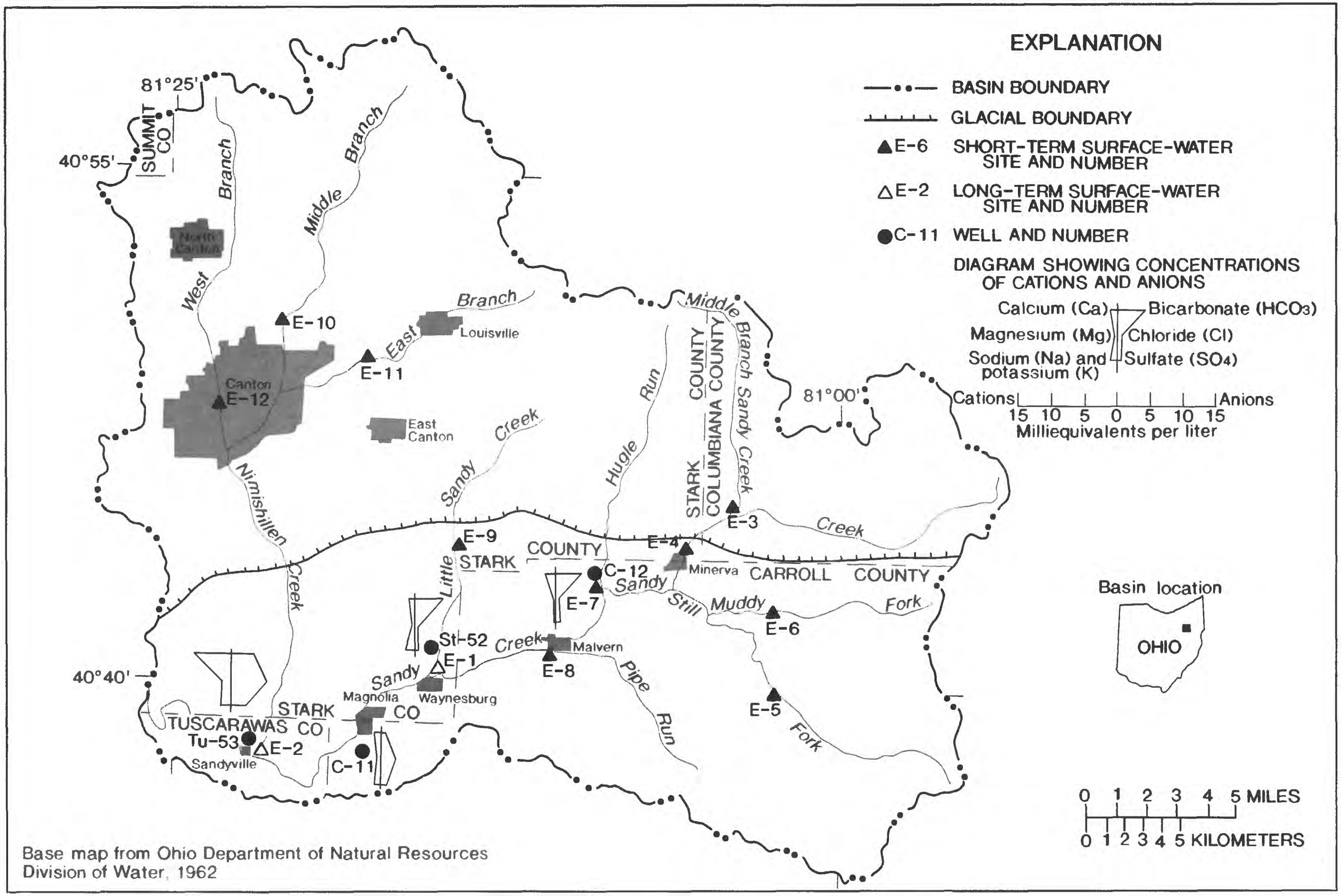

Figure 9.--Sandy Creek basin (E), showing surface-water sites, ground-water sites and stiff diagrams for ground-water sites.

Sandy Creek, the basin's principal stream, lies mostly south of the glaciated area and flows southwestward across the southern third of the basin toward its confluence with the Tuscarawas-Muskingum drainage system near Bolivar, Ohio. A principal tributary to Sandy Creek, Nimishillen Creek, drains much of the glaciated area in the Canton area.

What was probably a rugged, maturely dissected land surface has been subdued by glaciation in the north. Much of the topographically subdued area is characterized by urban growth in the Canton area (fig. 9). Elsewhere, principally toward the southeast, the land surface is more rugged, and local relief is about 300 ft. The main valley of Sandy Creek is broader than those of its tributaries and in places is relatively flat.

Geologic Setting

Major bedrock units, from west to east in ascending order, are the Pottsville, Allegheny, and Conemaugh Formations, of Pennsylvanian age. The Pottsville crops out in the Canton area but is generally covered with glacial drift. The Allegheny, which is present in most of the Sandy Creek basin, is the principal coal-bearing formation. As shown in figure 4, the Pennsylvanian System, in general, is a cyclic sequence of sandstones and shales interbedded with coal, clay, and limestone (fig. 4). The Conemaugh Formation, which is present as erosional hilltop remnants in the southeastern part of Stark County, is more extensive south of Sandy Creek in Carroll County.

Areas of active surface mining for the most part are across the middle third of the Sandy Creek basin, where the Allegheny Formation is at or near land surface. Part of this area is thinly covered with glacial drift. One or more of the Allegheny coals (fig. 4), primarily the Upper Freeport No. 7 and the Middle Kittanning No. 6, are being surface mined in this area. Two small areas are permitted for extraction of the Mahoning coal, which is found discontinuously in the Conemaugh Formation. Coal production from the Conemaugh Formation within the study area is generally minor.

Aquifers in the Sandy Creek basin include unconsolidated alluvial and glacial deposits and bedrock of sandstone, coal, and fractured limestone. In places, yields of more than 1,000 gal/min (gallons per minute) can be developed in the unconsolidated aquifers (Pree, 1962a). The most productive and extensively used shallow unconsolidated aquifers are in the northwestern part of the basin near Canton. The water quality of several public-supply systems in the area is already documented in the files of the Ohio Department of Health. Unconsolidated materials along Sandy Creek also are capable of relatively high yields to wells. Elsewhere in the southern two-thirds of the basin yields of 5 to 25 gal/min can be developed from wells tapping bedrock. In the southeastern corner of the area, on the other hand, less than 5 gal/min can be expected (Pree, 1962a).

Water Quality

For an assessment of baseline water quality in Sandy Creek Basin, synoptic collections of water samples were made at selected stream and ground-water sites. Most of the stream and ground-water sampling sites were along Sandy Creek and tributaries that drain the largest area of active mining. A few sites were located on branches of Nimishillen Creek in the Canton area. All of the ground-water sites were within the Sandy Creek valley.

Surface water

The following surface-water sites were sampled in late October 1987.

Map index number	Site type	Site name	Drainage area (square miles)
E-1	Long-term	Sandy C at Waynesburg-----------	253
E-2	do.	Nimishillen C at Sandyville-----	187.9
E-3	Short-term	Middle B Sandy C nr Minerva-----	20.3
E-4	do.	Sandy C at Minerva--------------	61.9
E-5	do.	Still F nr Minerva--------------	36.2
E-6	do.	Muddy F nr Minerva--------------	11.8
E-7	do.	Hugle Rn nr Malvern-------------	21.3
E-8	do.	Pipe Rn at Malvern--------------	27.7
E-9	do.	L Sandy C at Robertsville-------	29.7
E-10	do.	Middle B Nimishillen at Canton--	43.1
E-11	do.	E B Nimishillen C nr Canton-----	33.4
E-12	do.	W B Nimishillen C at Canton-----	43.9

Figure 10 is based on the 12 sites sampled. Results of the analyses of water samples from the 12 sites are listed in table 4. Water-quality analyses for the two long-term sites also are listed in table 21. Table 5 presents a summary of water-quality characteristics for the surface-water sites.

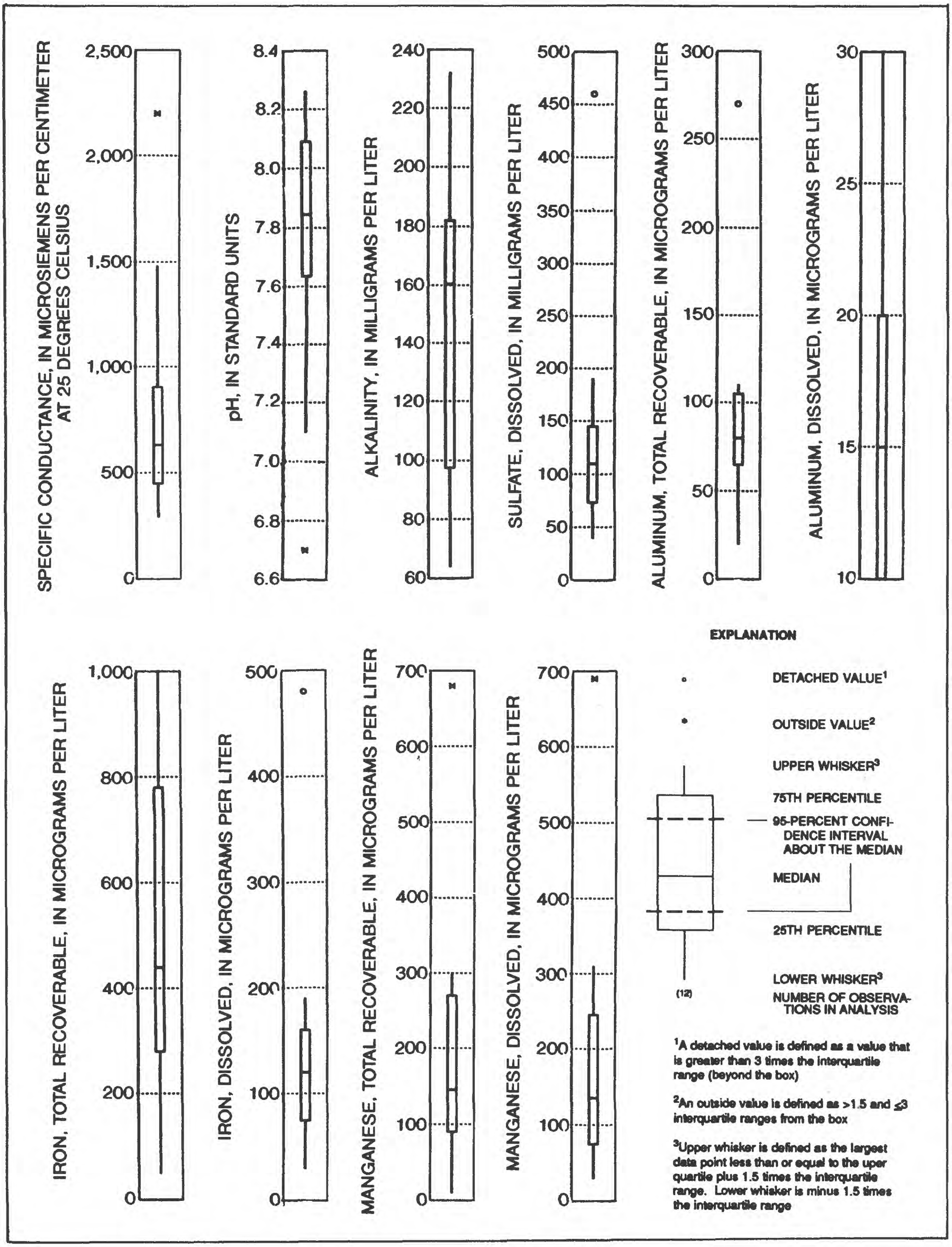

Figure 10.--Box plots showing the range, percentiles, and median values of constituents at surface-water sites in Sandy Creek basin.

Table 4.--Water-quality data for surface-water sites in Sandy Creek basin, October 1987

[°C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03117160 E-5 STILL F NR MINERVA OH (LAT 40 39 49N LONG 081 02 24W)							
OCT 1987							
27...	1.1	330	7.6	9.0	--	93	40
03117280 E-7 HUGLE RN NR MALVERN OH (LAT 40 42 49N LONG 081 09 03W)							
OCT 1987							
27...	2.5	620	7.9	9.5	--	159	110
03117310 E-8 PIPE RN AT MALVERN OH (LAT 40 41 16N LONG 081 11 02W)							
OCT 1987							
27...	0.50	295	7.7	8.0	--	64	49
404210081023700 E-6 MUDDY F NR MINERVA OH (LAT 40 42 10N LONG 081 02 37W)							
OCT 1987							
27...	1.3	370	7.7	8.0	--	93	75
404505081041100 E-3 M B SANDY C NR MINERVA OH (LAT 40 45 05N LONG 081 04 11W)							
OCT 1987							
27...	1.8	640	8.1	8.0	--	215	72
03117150 E-4 SANDY C AT MINERVA OH (LAT 40 43 53N LONG 081 05 57W)							
OCT 1987							
27...	12	550	8.3	9.0	--	168	87
03117450 E-9 L SANDY C NR ROBERTSVILLE OH (LAT 40 44 03N LONG 081 14 40W)							
OCT 1987							
26...	6.4	800	7.8	11.0	--	153	170
03118000 E-10 M B NIMISHILLEN C AT CANTON OH (LAT 40 50 29N LONG 081 21 14W)							
OCT 1987							
26...	4.2	850	7.1	12.0	--	172	120
03118100 E-11 E B NIMISHILLEN C NR CANTON OH (LAT 40 49 24N LONG 081 17 55W)							
OCT 1987							
26...	7.9	2,200	6.7	12.5	--	162	460
03117500 E-1 SANDY C AT WAYNESBURG OH (LAT 40 40 21N LONG 081 15 36W)							
OCT 1987							
26...	80	530	8.1	10.0	--	102	110
403823081213700 E-2 NIMISHILLEN CR AT SANDYVILLE OH (LAT 40 38 23N LONG 081 21 37W)							
OCT 1987							
26...	68	1,480	8.1	10.0	--	192	190
03118300 E-12 W B NIMISHILLEN C AT CANTON OH (LAT 40 47 48N LONG 081 23 26W)							
OCT 1987							
26...	7.3	955	8.0	11.0	--	232	120

Table 4.--Water-quality data for surface-water sites in Sandy Creek basin, October 1987--Continued

Date	Alu-minum, total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)
03117160 E-5 STILL F NR MINERVA OH (LAT 40 39 49N LONG 081 02 24W)						
OCT 1987						
27...	270	20	1,000	160	220	230
03117280 E-7 HUGLE RN NR MALVERN OH (LAT 40 42 49N LONG 081 09 03W)						
OCT 1987						
27...	80	<10	760	160	260	250
03117310 E-8 PIPE RN AT MALVERN OH (LAT 40 41 16N LONG 081 11 02W)						
OCT 1987						
27...	110	30	800	480	130	110
404210081023700 E-6 MUDDY F NR MINERVA OH (LAT 40 42 10N LONG 081 02 37W)						
OCT 1987						
27...	110	20	660	190	300	310
404505081041100 E-3 M B SANDY C NR MINERVA OH (LAT 40 45 05N LONG 081 04 11W)						
OCT 1987						
27...	70	<10	420	140	90	100
03117150 E-4 SANDY C AT MINERVA OH (LAT 40 43 53N LONG 081 05 57W)						
OCT 1987						
27...	30	<10	290	100	60	40
03117450 E-9 L SANDY C NR ROBERTSVILLE OH (LAT 40 44 03N LONG 081 14 40W)						
OCT 1987						
26...	60	10	950	140	680	690
03118000 E-10 M B NIMISHILLEN C AT CANTON OH (LAT 40 50 29N LONG 081 21 14W)						
OCT 1987						
26...	20	<10	50	30	10	30
03118100 E-11 E B NIMISHILLEN C NR CANTON OH (LAT 40 49 24N LONG 081 17 55W)						
OCT 1987						
26...	80	20	230	100	160	160
03117500 E-1 SANDY C AT WAYNESBURG OH (LAT 40 40 21N LONG 081 15 36W)						
OCT 1987						
26...	80	20	430	90	280	240
403823081213700 E-2 NIMISHILLEN CR AT SANDYVILLE OH (LAT 40 38 23N LONG 081 21 37W)						
OCT 1987						
26...	70	30	450	60	100	80
03118300 E-12 W B NIMISHILLEN C AT CANTON OH (LAT 40 47 48N LONG 081 23 26W)						
OCT 1987						
26...	100	<10	270	50	90	70

Table 5.--Ranges and medians for selected water-quality characteristics for surface-water sites in Sandy Creek basin

[mg/L, milligrams per liter; ug/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 9)	Median
Specific conductance, in μS/cm	295(E-8) to 2,200(E-11)	630
pH	6.7(E-11) to 8.3(E-4)	7.8
Alkalinity, in mg/L as $CaCO_3$	64(E-8) to 232(E-12)	160
Sulfate, dissolved, in mg/L as SO_4	40(E-5) to 460(E-11)	110
Aluminum, total, in ug/L as Al	20(E-10) to 270(E-5)	80
Aluminum, dissolved, in μg/L as Al	<10(E-3,4,10) to 30(E-8)	15
Iron, total, in μg/L as Fe	50(E-10) to 1,000(E-5)	440
Iron, dissolved, in μg/L as Fe	30(E-10) to 480(E-8)	120
Manganese, total, in μg/L as Mn	10(E-10) to 680(E-9)	145
Manganese, dissolved, in ug/L as Mn	30(E-10) to 690(E-9)	135

Some variations in the analyses resulting from the synoptic sampling of the streams may seem unusual. Sites closest to areas of active mining might be expected to show above-average levels (or greater than the median) for constituents listed in table 5, except for pH and alkalinity. For sites E-7 and E-9, which are close to active surface mining, this is true for iron, manganese, and sulfate but not for aluminum. At the same sites, alkalinity, specific conductance, and pH were close to the median value indicated in table 5. Dissolved sulfate and specific conductance were highest and pH the lowest at site E-11, which is not close to active mining but can be affected by drainage from areas of abandoned mines.

Sites E-5, E-6, and E-8, on tributaries to Sandy Creek, are not heavily impacted by mining activity. With respect to the median values in table 5, these sites were relatively high in iron and manganese and, except for E-8, aluminum as well. Conversely, levels of sulfate, alkalinity, and specific conductance at the same three sites were lowest in the basin.

Ground water

Four wells that tap unconsolidated deposits of sand and gravel were sampled in the study basin. Locations of the sampled wells are shown in figure 9. For each site, a Stiff diagram[3] geometrically depicts principal ionic constituents of the samples. Analyses of ground-water samples collected in Sandy Creek basin are given in table 6.

In terms of ground-water types, calcium was a principal cation in samples from all four sites, but the sites differed considerably in anionic character. The waters at wells TU-53, ST-52, and C-12 were in a neutral pH range, whereas at C-11 the water was slightly acidic. The wells are located along drainage systems downstream from areas where coal is being mined. With respect to the median values for all 24 ground-water sites sampled in 1987-88 (table 3), wells ST-52, C-12, and C-11 were relatively low in dissolved sulfate and dissolved solids. At well TU-53, however, the concentration of several constituents was greater than the median value.

With respect to OEPA standards for public supply, the limit for dissolved-solids (500 mg/L) was exceeded at TU-53, and the limits for dissolved iron (300 µg/L) and manganese (50 µg/L) were exceeded at TU-53, C-12, and ST-52. At a pH of 5.43, C-11 was the most acidic of the four wells. Significantly, with respect to the constituents listed earlier in the OEPA standard and for public water supply, well C-11 was within the standards. The well is not used as a potable water supply, however.

Middle Tuscarawas River and Sugar Creek Basin

The area selected for intensive study is a combination of two subbasins. The Sugar Creek subbasin lies partly in Wayne, Stark, Tuscarawas, and Holmes Counties. The Middle Tuscarawas River subbasin lies partly in Stark and Tuscarawas Counties. The drainage divide between the two basins is east of and closely parallel to Sugar Creek (fig. 11). Both streams flow essentially southward and join at Dover, Ohio.

Slightly more than the northern half of the combined area of the two subbasins was covered by glaciation. The glacial boundary also separates the Glaciated Allegheny Plateau and Unglaciated Allegheny Plateau sections of the Appalachian Plateaus Province (Fenneman, 1938).

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[3] A geometric configuration that represents the concentration, expressed as milliequivalence, of the common ionic constituents analyzed at the site represented by the figure.

Table 6.--Water-quality data for ground-water sites in Sandy Creek basin, August 1987

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Depth to water below land-surface datum (feet)	Specific conductance (µS/cm)	pH	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
403830081220700 TU-53 US POST OFFICE AT SANDYVILLE OH (LAT 40 38 30N LONG 081 22 07W)									
AUG 1987									
26...	--	1,280	7.5	12.5	1.1	420	250	130	22
403816081175100 C-11 BELDEN AND BLAKE NR MAGNOLIA OH (LAT 40 38 16N LONG 081 17 51W)									
AUG 1987									
26...	28.40	400	5.4	14.0	5.4	89	79	24	7.1
404115081152000 ST-52 D GREEN AT WAYNESBURG OH (LAT 40 41 15N LONG 081 15 20W)									
AUG 1987									
26...	--	380	6.7	12.5	1.9	120	0	33	10
404317081091500 C-12 R BECKER NR MINERVA OH (LAT 40 43 17N LONG 081 09 15W)									
AUG 1987									
26...	--	360	6.5	11.5	1.5	160	0	47	10

Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity total, field (mg/L as $CaCO_3$)	Alkalinity, carbonate, field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)
403830081220700 TU-53 US POST OFFICE AT SANDYVILLE OH (LAT 40 38 30N LONG 081 22 07W)								
AUG 1987								
26...	48	2.3	168	169	110	200	12	663
403816081175100 C-11 BELDEN AND BLAKE NR MAGNOLIA OH (LAT 40 38 16N LONG 081 17 51W)								
AUG 1987								
26...	34	1.8	10	10	47	68	13	238
404115081152000 ST-52 D GREEN AT WAYNESBURG OH (LAT 40 41 15N LONG 081 15 20W)								
AUG 1987								
26...	28	3.2	191	202	6.0	2.6	9.5	192
404317081091500 C-12 R BECKER NR MINERVA OH (LAT 40 43 17N LONG 081 09 15W)								
AUG 1987								
26...	9.9	1.2	174	182	9.0	2.1	12	190

Table 6.--Water-quality data for ground-water sites in Sandy Creek basin, August 1987--Continued

Date	Solids, sum of constit- uents, dis- solved (mg/L)	Alu- minum total recov- erable (µg/L as Al)	Alu- minum, dis- solved (µg/L as Al)	Iron, total recov- erable (µg/L as Fe)	Iron, dis- solved (µg/L as Fe)	Manga- nese, total recov- erable (µg/L as Mn)	Manga- nese, dis- solved (µg/L as Mn)	Carbon, organic dis- solved (mg/L as C)
403830081220700 TU-53 US POST OFFICE AT SANDYVILLE OH (LAT 40 38 30N LONG 081 22 07W)								
AUG 1987								
26...	630	10	<10	6,700	4,200	810	800	1.0
403816081175100 C-11 BELDEN AND BLAKE NR MAGNOLIA OH (LAT 40 38 16N LONG 081 17 51W)								
AUG 1987								
26...	201	90	70	80	26	40	38	0.6
404115081152000 ST-52 D GREEN AT WAYNESBURG OH (LAT 40 41 15N LONG 081 15 20W)								
AUG 1987								
26...	209	10	<10	1,700	1,700	190	190	0.5
404317081091500 C-12 R BECKER NR MINERVA OH (LAT 40 43 17N LONG 081 09 15W)								
AUG 1987								
26...	197	20	<10	750	780	730	730	0.7

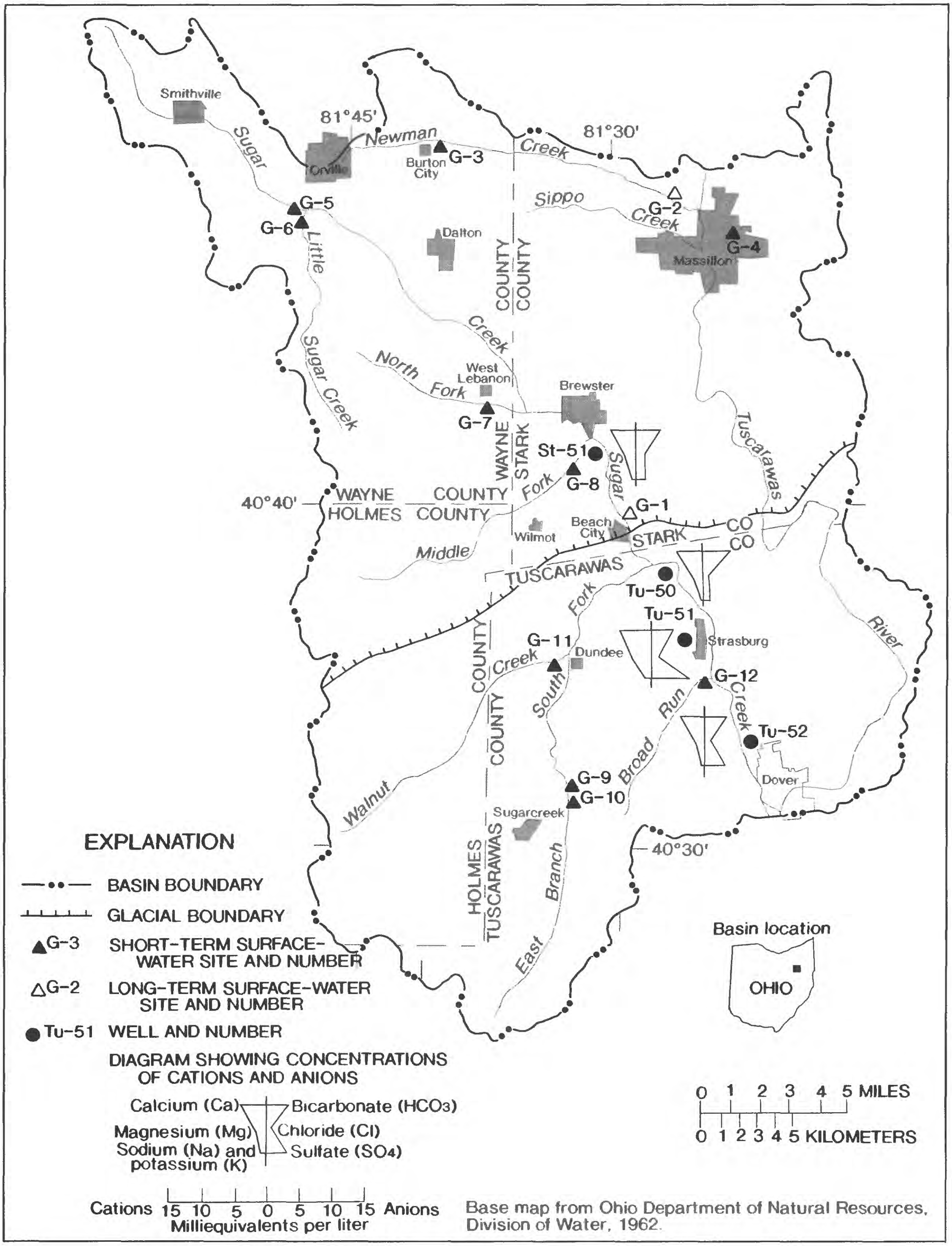

Figure 11.--Middle Tuscarawas River and Sugar Creek basin (G), showing surface-water sites, ground-water sites and stiff diagrams for ground-water sites.

The southern third of the study basin area is a maturely dissected upland with local relief on the order of 300 ft. Glaciation has greatly subdued the northern half of the area. Locally, the terrain ranges from relatively featureless broad valleys to gently rolling upland. For most of its length, the valley in which Sugar Creek flows is relatively broad. Several of its tributaries that drain the southwestern part of the study area, in contrast, have fairly narrow valleys. Upstream from Dover to the Stark County line, the Tuscarawas Valley is relatively narrow and steep-sided.

Geologic Setting

Major bedrock units underlying the basin, in ascending order of age, consist of shales of Mississippian age and sandstones and coal-bearing strata of Pennsylvanian age. The oldest units are the Cuyahoga and Logan Formations, of Mississippian age[4] (Multer, 1967), which lie below a covering of glacial drift in the valley floors of the northwestern part of the basin in Wayne County. To the south and east, these are followed by the Pottsville, Allegheny, and Conemaugh Formations of Pennsylvanian age (fig. 4). The Conemaugh is limited to ridge-tops along the eastern and southern extremities of the area. Structurally, the stratigraphic section exhibits a gentle eastward regional dip.

Most of the coal produced in the basin is from the Allegheny Formation (individual coal units are identified in figure 4). The Allegheny is present in patches over much of the area. Most surface-mining activity is in the southern third of the basin. The Lower Kittanning (No. 5) and the Middle Kittanning (No. 6) coals are the principal units being mined. Other Allegheny units being mined include the Brookville (No. 4) and the Strasburg (No. 5A). The Upper Freeport (No. 7) coal at the top of the Allegheny is missing over much of the area because of erosion. Three Pottsville coals, that are present not far below the base of the Allegheny, the Lower Mercer (No. 3), Upper Mercer (No. 3A), and the Tionesta (No. 3B), are mined locally.

Both unconsolidated and bedrock aquifers are important sources of water supply in the basin. The unconsolidated aquifer consists of thick deposits of sand and gravel that are present in much of the glaciated area and in the outwash valleys to the south. Well yields in these sources can exceed 1,000 gal/min (Schmidt, 1962). Of the bedrock aquifer, the Pottsville sandstones from which well yields of 500 gal/min have been reported, are the most important. Also available are shallow local supplies in sandstone, limestone, and coal units of the Allegheny Formation.

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[4] On figure 4, these formations are not broken out. Undifferentiated Mississippi is shown.

Productive shallow aquifers are limited to alluvial sand and gravel deposits. Most of these aquifers are in the northern half of the study area and are not greatly affected by surface-mining operations. However, the lower part of Sugar Creek passes through actively mined areas, and, in places, sand and gravel are well developed sources of ground water. Several tributaries of Sugar Creek also drain the active mining areas. Alluvial fill along these tributaries is thin, and shallow wells typically tap the bedrock for supply.

Water Quality

Current mining activity is greater in the area drained by Sugar Creek and its tributaries than in the Middle Tuscarawas River subbasin. Therefore, surface-water sampling sites were selected to give a composite of conditions in the study basin. The ground-water sites were within or near the Sugar Creek valley where shallow productive aquifers are more extensive.

Surface water

The following surface-water sites were sampled in late October 1987.

Map index number	Site type	Site name	Drainage area (square miles)
G-1	Long-term	Sugar C at Beach City Dam at Beach City--------------	160
G-2	do.	Newman C nr Massillon--------	38.2
G-3	Short-term	Newman C at Burton City------	11.5
G-4	do.	Sippo C at Massillon---------	16.2
G-5	do.	Sugar C nr Orrville----------	28.1
G-6	do.	L Sugar C nr Orrville--------	17.9
G-7	do.	N F Sugar C nr W Lebanon-----	17.0
G-8	do.	Middle F Sugar C nr Brewster-	45.5
G-9	do.	S F Sugar C nr Sugar C-------	63.3
G-10	do.	E B S F Sugar C nr Sugar C---	28.2
G-11	do.	Walnut C at Dundee-----------	48.0
G-12	do.	Broad Rn at Strasburg---------	19.5

Table 7.--Water-quality data for surface-water sites in Middle Tuscarawas River and Sugar Creek basin, October 1987

[°C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03122980 G-8 M F SUGAR C NR BREWSTER OH (LAT 40 41 10N LONG 081 36 40W)							
OCT 1987							
27...	9.5	570	7.0	10.0	--	171	94
404831081301000 G-4 SIPPO C AT MASSILLON OH (LAT 40 48 31N LONG 081 30 10W)							
OCT 1987							
27...	6.6	610	6.8	10.5	--	177	76
03123000 G-1 SUGAR C AB BEACH CITY DAM AT BEACH CITY OH (LAT 40 39 24N LONG 081 34 37W)							
OCT 1987							
27...	24	680	6.9	9.0	--	200	72
03116950 G-2 NEWMAN C NR MASSILLON OH (LAT 40 49 22N LONG 081 33 06W)							
OCT 1987							
27...	3.0	850	7.4	10.0	--	251	120
03123166 G-9 S F SUGAR C NR SUGARCREEK OH (LAT 40 31 25N LONG 081 36 52W)							
OCT 1987							
28...	9.8	1,200	6.6	8.5	--	115	350
03123299 G-11 WALNUT C AT DUNDEE OH (LAT 40 35 12N LONG 081 37 16W)							
OCT 1987							
28...	5.8	1,250	6.6	8.5	--	131	520
403445081313200 G-12 BROAD RN AT STRASBURG OH (LAT 40 34 45N LONG 081 31 32W)							
OCT 1987							
28...	2.6	1,300	6.8	6.0	--	80	720
403108081364900 G-10 EB SF SUGAR C AT SUGARCREEK OH (LAT 40 31 08N LONG 081 36 49W)							
OCT 1987							
28...	4.8	1,050	6.6	6.5	--	82	470
404858081464900 G-6 L SUGAR C NR ORRVILLE OH (LAT 40 48 58N LONG 081 46 49W)							
OCT 1987							
27...	1.9	765	7.4	10.0	--	216	68
404300081394900 G-7 NF SUGAR C NR WEST LEBANON OH (LAT 40 43 00N LONG 081 39 49W)							
OCT 1987							
27...	6.5	630	7.4	10.0	--	216	49
405037081420700 G-3 NEWMAN C AT BURTON CITY OH (LAT 40 50 37N LONG 081 42 07W)							
OCT 1987							
27...	0.81	1,350	7.5	10.0	--	305	75
404906081464600 G-5 SUGAR C NR ORRVILLE OH (LAT 40 49 06N LONG 081 46 46W)							
OCT 1987							
27...	4.9	760	7.0	9.5	--	208	80

Table 7.--Water-quality data for surface-water sites in Middle Tuscarawas River and Sugar Creek basin, October 1987--Continued

Date	Aluminum, total recoverable (µg/L as Al)	Aluminum, dissolved (µg/L as Al)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
03122980 G-8 M F SUGAR C NR BREWSTER OH (LAT 40 41 10N LONG 081 36 40W)						
OCT 1987 27...	160	10	730	130	140	150
404831081301000 G-4 SIPPO C AT MASSILLON OH (LAT 40 48 31N LONG 081 30 10W)						
OCT 1987 27...	360	30	1,300	270	210	190
03123000 G-1 SUGAR C AB BEACH CITY DAM AT BEACH CITY OH (LAT 40 39 24N LONG 081 34 37W)						
OCT 1987 27...	210	<10	700	170	110	90
03116950 G-2 NEWMAN C NR MASSILLON OH (LAT 40 49 22N LONG 081 33 06W)						
OCT 1987 27...	110	<10	660	180	160	130
03123166 G-9 S F SUGAR C NR SUGARCREEK OH (LAT 40 31 25N LONG 081 36 52W)						
OCT 1987 28...	400	30	1,000	50	2,900	3,000
03123299 G-11 WALNUT C AT DUNDEE OH (LAT 40 35 12N LONG 081 37 16W)						
OCT 1987 28...	380	20	1,100	60	3,400	3,500
403445081313200 G-12 BROAD RN AT STRASBURG OH (LAT 40 34 45N LONG 081 31 32W)						
OCT 1987 28...	870	60	330	20	11,000	11,000
403108081364900 G-10 EB SF SUGAR C AT SUGARCREEK OH (LAT 40 31 08N LONG 081 36 49W)						
OCT 1987 28...	510	10	1,200	40	4,000	4,100
404858081464900 G-6 L SUGAR C NR ORRVILLE OH (LAT 40 48 58N LONG 081 46 49W)						
OCT 1987 27...	120	20	380	90	110	100
404300081394900 G-7 NF SUGAR C NR WEST LEBANON OH (LAT 40 43 00N LONG 081 39 49W)						
OCT 1987 27...	210	<10	650	70	220	200
405037081420700 G-3 NEWMAN C AT BURTON CITY OH (LAT 40 50 37N LONG 081 42 07W)						
OCT 1987 27...	70	<10	710	260	170	160
404906081464600 G-5 SUGAR C NR ORRVILLE OH (LAT 40 49 06N LONG 081 46 46W)						
OCT 1987 27...	210	20	550	100	120	130

Figure 12 is based on the 12 sites sampled. Results of the analyses of water samples from the 12 sites are listed in table 7. Water-quality analyses for the two long-term sites also are listed in table 21. Table 8 presents a summary of water-quality characteristics for the surface-water sites.

Table 8.--Ranges and medians for selected water-quality characteristics for surface-water sites in Middle Tuscarawas River and Sugar Creek basin

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 11)	Median
Specific conductance, in µS/cm	570(G-8) to 1,350(G-3)	808
pH	6.6(G-9,10,11) to 7.5(G-3)	6.9
Alkalinity, in mg/L as $CaCO_3$	80(G-12) to 305(G-5)	188
Sulfate, dissolved, in mg/L as SO_4	49(G-7) to 720(G-12)	87
Aluminum, total, in µg/L as Al	70(G-3) to 870(G-12)	210
Aluminum, dissolved, in µg/L as Al	<10(G-1,2,7) to 60(G-12)	15
Iron, total, in µg/L as Fe	330(G-12) to 1,300(G-4)	705
Iron, dissolved, in µg/L as Fe	20(G-12) to 270(G-4)	95
Manganese, total, in µg/L as Mn	110(G-1,6) to 11,000(G-12)	190
Manganese, dissolved, in µg/L as Mn	90(G-1) to 11,000(G-12)	175

In general, results of the synoptic sampling of the streams were consistent, considering location of each site with respect to currently active areas of surface mining. Sites G-9, G-10, G-11, and G-12 are all downstream not far from areas of active mining. At these sites, constituent values were mostly near the top of the ranges listed in table 8, except for pH and alkalinity, which were in the lower end of the range. One exception was below-median values for the amount of dissolved iron at these sites. Constituent levels at the two long-term sites, G-1 and G-2, were generally near the median values for the basin (table 8). The lowest pH value was 6.6 at three sites--not far below 6.9, the median for all sites in the basin.

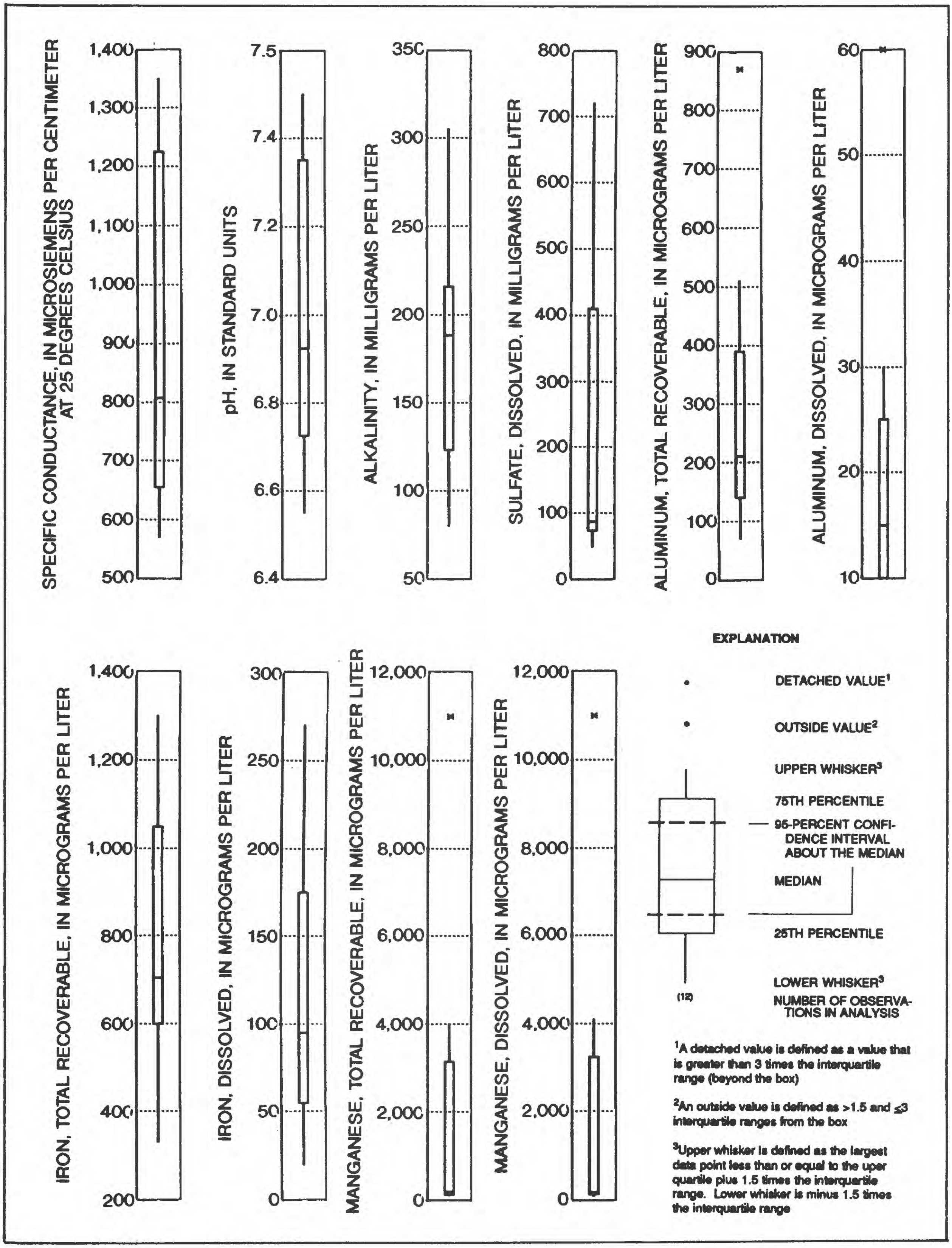

Figure 12.--Box plots showing the range, percentiles, and median values of constituents at surface-water sites in Middle Tuscarawas River and Sugar Creek basin.

Ground water

Four wells were sampled in the study basin. The wells tap unconsolidated deposits of sand and gravel in alluvial or glacial outwash deposits. Well ST-51 is located in the glaciated part of the region, and the others are in an outwash area south of the glacial limit (fig. 11).

For each site shown in figure 11, a Stiff diagram geometrically depicts the principal ionic constituents of each sample. Results of analyses are listed in table 9.

As to water type, calcium was the principal cation, and bicarbonate and sulfate were the principal anions. The waters which range from pH 7.35 to 7.59 are slightly basic but very hard. In general, there were no unusual variations in the constituents analyzed in water from these wells. With respect to OEPA standards for public supply, well TU-51 had excessive levels of sulfate, dissolved solids, iron, and manganese. Well ST-51 was excessive in the amount of dissolved iron, and well TU-52 in the amount of manganese.

Lower Tuscarawas River Basin

The Lower Tuscarawas River basin covers the eastern third of Coshocton County and the southwestern half of Tuscarawas County (fig. 13). The Tuscarawas River, which flows southward from New Philadelphia, Ohio, gradually turns westward near Newcomerstown and continues to Coshocton, where the Walhonding River from the west and the Tuscarawas River join to form the Muskingum River. At Dover, Ohio, the subject basin receives the combined drainage of Sugar Creek and Middle Tuscarawas basins and other upstream tributary basins.

The path traversed by the Lower Tuscarawas River is fairly close to the eastern and southern boundaries of the basin. In the northeastern part of the basin the larger tributaries generally flow northward. In the remainder of the basin, the larger tributaries flow southward.

The Lower Tuscarawas River basin is within the Unglaciated Allegheny Plateau section of the Appalachian Plateaus Province (Fenneman, 1938). The topographic character of the region is essentially that of a thoroughly dissected upland through which the main stem of the Tuscarawas drainage system, in terms of its flood plain development, has cut a fairly wide swath. In contrast, the tributaries feeding the main stream are relatively short with narrow steep-sided valleys. Local relief in the main valley is negligible, but along the upland edges can be as much as 300 ft.

Table 9.--Water-quality data for ground-water sites in Middle Tuscarawas River and Sugar Creek basin, August 1987

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Depth to water below land-surface datum (feet)	Specific conductance (µS/cm)	pH	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
404130081354200 ST-51 D HOSTETLER NR BREWSTER OH (LAT 40 41 30N LONG 081 35 42W)									
AUG 1987									
25...	36.80	640	7.6	10.5	1.2	310	120	87	23
403742081331800 TU-50 BECKERS FALLS FARMS NR STRASBURG OH (LAT 40 37 42N LONG 081 33 18W)									
AUG 1987									
25...	19.58	685	7.4	11.0	3.8	330	96	99	19
403543081321800 TU-51 L ELLIOTT AT STRASBURG OH (LAT 40 35 43N LONG 081 32 18W)									
AUG 1987									
25...	34.85	850	7.5	11.0	1.7	450	290	110	43
403255081295800 TU-52 ZIMMER PATIENT CARE NR DOVER OH (LAT 40 32 55N LONG 081 29 58W)									
AUG 1987									
26...	--	685	7.4	10.5	0.9	330	180	94	24

Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity total, field (mg/L as $CaCO_3$	Alkalinity, carbonate, field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)
404130081354200 ST-51 D HOSTETLER NR BREWSTER OH (LAT 40 41 30N LONG 081 35 42W)								
AUG 1987								
25...	7.9	1.4	193	196	70	47	1.7	377
403742081331800 TU-50 BECKERS FALLS FARMS NR STRASBURG OH (LAT 40 37 42N LONG 081 33 18W)								
AUG 1987								
25...	7.2	6.8	230	236	44	24	13	399
403543081321800 TU-51 L ELLIOTT AT STRASBURG OH (LAT 40 35 43N LONG 081 32 18W)								
AUG 1987								
25...	7.9	2.0	159	160	300	10	13	616
403255081295800 TU-52 ZIMMER PATIENT CARE NR DOVER OH (LAT 40 32 55N LONG 081 29 58W)								
AUG 1987								
26...	10	1.9	153	154	180	19	11	444

Table 9.--Water-quality data for ground-water sites in Middle Tuscarawas River and Sugar Creek basin, August 1987--Continued

Date	Solids, sum of constit- uents, dis- solved (mg/L)	Alu- minum total recov- erable (µg/L as Al)	Alu- minum, dis- solved (µg/L as Al)	Iron, total recov- erable (µg/L as Fe)	Iron, dis- solved (µg/L as Fe)	Manga- nese, total recov- erable (µg/L as Mn)	Manga- nese, dis- solved (µg/L as Mn)	Carbon, organic dis- solved (mg/L as C)
404130081354200 ST-51 D HOSTETLER NR BREWSTER OH (LAT 40 41 30N LONG 081 35 42W)								
AUG 1987								
25...	355	20	<10	680	710	180	24	0.6
403742081331800 TU-50 BECKERS FALLS FARMS NR STRASBURG OH (LAT 40 37 42N LONG 081 33 18W)								
AUG 1987								
25...	351	20	<10	20	3	<10	<1	0.7
403543081321800 TU-51 L ELLIOTT AT STRASBURG OH (LAT 40 35 43N LONG 081 32 18W)								
AUG 1987								
25...	582	20	<10	500	580	100	93	0.5
403255081295800 TU-52 ZIMMER PATIENT CARE NR DOVER OH (LAT 40 32 55N LONG 081 29 58W)								
AUG 1987								
26...	432	20	<10	200	220	130	130	0.5

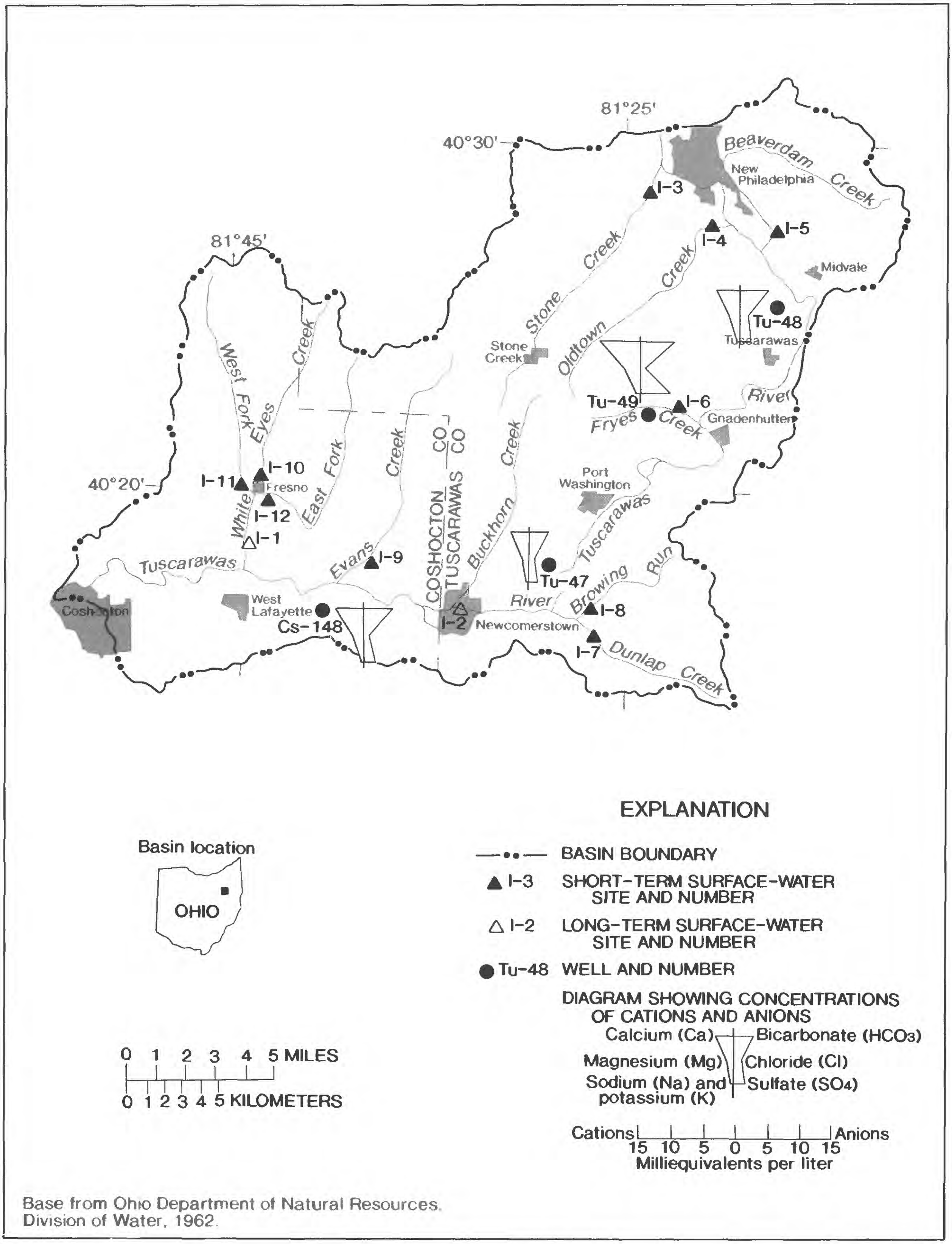

Figure 13.--Lower Tuscarawas River basin (I), showing surface-water sites, ground-water sites and stiff diagrams for ground-water sites.

Geologic Setting

The stratigraphic section consists of gently eastward- and southeastward-dipping units of Pennsylvanian age. The units, in ascending order of age, are: the Pottsville, Allegheny, and Conemaugh Formations. The Pottsville exists extensively in hillsides and valley bottoms in Coshocton County and is mostly confined to valley bottoms in Tuscarawas County. The Allegheny Formation, which forms most of the ridges, is patchy in Coshocton County but becomes more extensive to the east in Tuscarawas County. It forms the floor of the Tuscarawas Valley south of New Philadelphia to Gnadenhutten. Many scattered remnants of the Conemaugh Formation are present in Coshocton County, but they become more extensive in Tuscarawas County, especially southeast of the Tuscarawas River.

Several coals are present in the Pottsville and Allegheny Formations, but, of these, the Lower Kittanning No. 5, Middle Kittanning No. 6, and Upper Freeport No. 7 coals within the subject area have shown the greatest production and reserves (Brant and Delong, 1960). Most of the surface coal-mining activity is north and west of the Tuscarawas Valley in the upland section of the area.

Aquifers in the Lower Tuscarawas River basin include bedrock sources in sandstones of the Pottsville Formation. Yields to wells generally are adequate for domestic purposes. Similar but more localized sources are present in the Allegheny Formation. In contrast, the assemblage of sands and gravels that constitute the unconsolidated aquifer in the Tuscarawas valley is the principal ground-water source in the area. In places, these materials can yield as much as 1,000 gal/min to wells (Walker, 1962a). Water levels, which are affected by the stage of the Tuscarawas River for the most part, fluctuate about 1 to 3 ft throughout the year.

Water Quality

The two long-term surface-water sites were located near the mouth of important tributary systems that drain coal-mining areas. The short-term sites were located to include the effects of drainage from both actively mined areas as well as abandoned-mine areas. Four wells were sampled to provide some representation of baseline ground-water quality in shallow-productive aquifers.

Surface water

The following streams at the indicated locations were sampled in late October 1987.

Map index number	Site type	Site name	Drainage-area (square miles)
I-1	Long-term	White Eyes C nr Fresno-----------	52.1
I-2	do.	Buckhorn C at Newcomerstown------	22.9
I-3	Short-term	Stone C nr New Philadelphia------	25.2
I-4	do.	Oldtown C at New Philadelphia----	18.6
I-5	do.	Beaverdam C nr New Philadelphia--	20.8
I-6	do.	Frys C nr Gnadenhutten-----------	5.7
I-7	do.	Dunlap C nr Newcomerstown--------	18.1
I-8	do.	Browning Rn nr Newcomerstown-----	7.1
I-9	do.	Evans C nr West Lafayette--------	21.0
I-10	do.	White Eyes C at Fresno-----------	14.8
I-11	do.	W F White Eyes C nr Fresno-------	20.0
I-12	do.	E F White Eyes C nr Fresno-------	12.4

Figure 14 is based on the 12 sites sampled at this time. Results of analyses of water samples from the 12 sites are listed in table 10. Water-quality analyses for the two long-term sites also are listed in table 21. Table 11 presents a summary of water-quality characteristics for the surface-water sites.

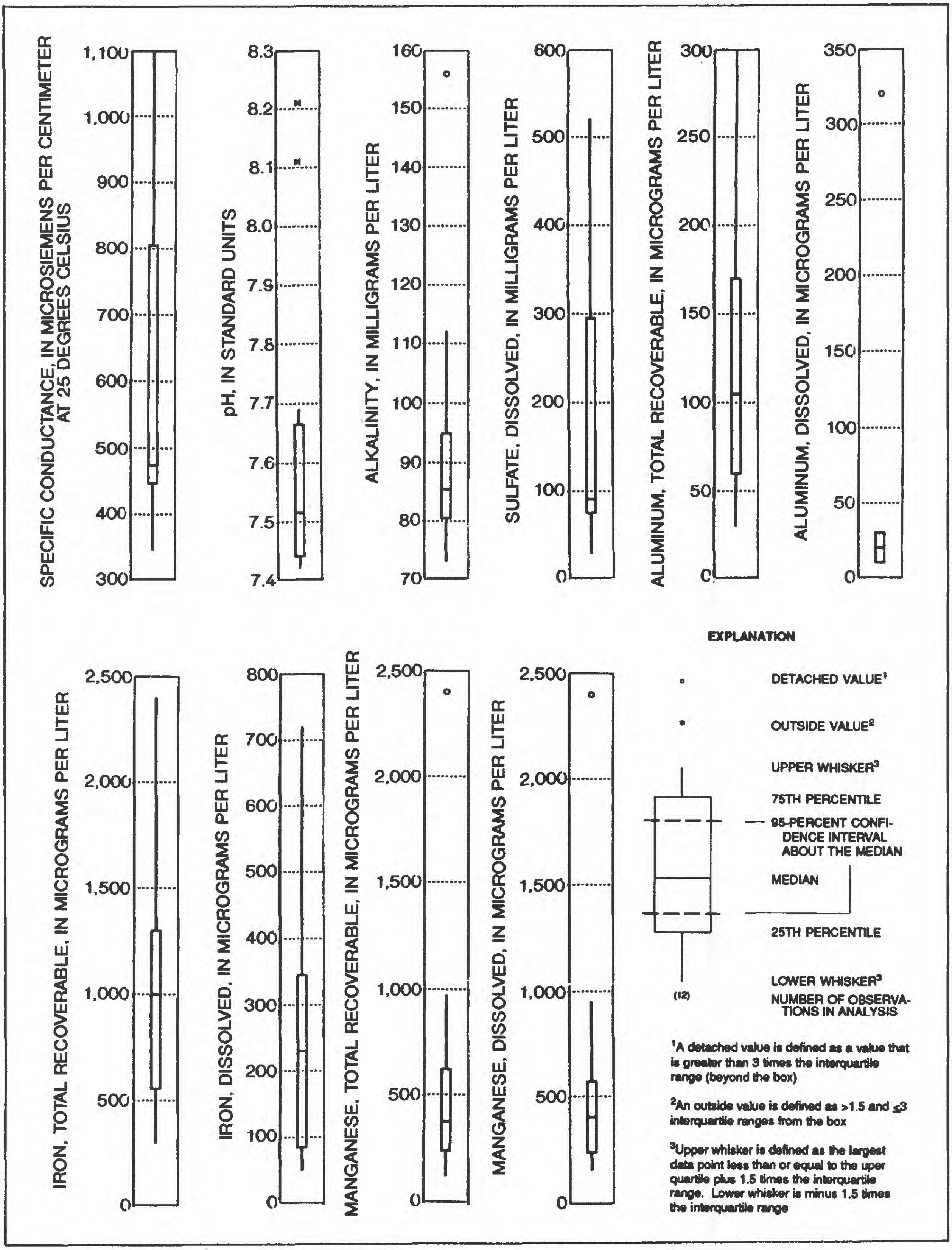

Figure 14.--Box plots showing the range, percentiles, and median values of constituents at surface-water sites in Lower Tuscarawas River basin.

Table 10.--Water-quality data for surface-water sites in Lower Tuscarawas River basin, October 1987

[°C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
401805081394500 I-9 EVANS C NR W LAFAYETTE OH (LAT 40 18 05N LONG 081 39 45W)							
OCT 1987							
27...	3.2	450	7.5	9.5	--	83	71
401940081441400 I-12 E F WHITE EYES C NR FRESNO OH (LAT 40 19 40N LONG 081 44 14W)							
OCT 1987							
27...	1.1	455	7.7	7.0	--	86	79
03129100 I-1 WHITE EYES C NR FRESNO OH (LAT 40 18 17N LONG 081 45 01W)							
OCT 1987							
26...	5.0	460	7.4	9.0	--	92	79
401959081443300 I-10 WHITE EYES C AT FRESNO OH (LAT 40 19 59N LONG 081 44 33W)							
OCT 1987							
26...	1.5	445	8.2	8.5	--	98	65
402738081262300 I-4 OLD TOWN C AT NEW PHILADELPHIA OH (LAT 40 27 38N LONG 081 26 23W)							
OCT 1987							
28...	2.8	1,050	7.4	5.0	--	74	510
402841081285900 I-3 STONE C (59-11) NR NEW PHILADELPHIA OH (LAT 40 28 41N LONG 081 28 59W)							
OCT 1987							
28...	5.7	610	7.4	5.0	--	73	150
402226081280300 I-6 FRYS C NR GNADENHUTTEN OH (LAT 40 22 26N LONG 081 28 03W)							
OCT 1987							
28...	0.80	1,100	8.1	8.0	--	156	520
401616081313900 I-8 BROWNING RN NR NEWCOMERSTOWN OH (LAT 40 16 16N LONG 081 31 39W)							
OCT 1987							
27...	0.49	510	7.4	8.5	--	82	150
401548081311700 I-7 DUNLAP C NR NEWCOMERSTOWN OH (LAT 40 15 48N LONG 081 31 17W)							
OCT 1987							
27...	1.0	345	7.6	8.5	--	112	28
402011081450500 I-11 W F WHITE EYES C NR FRESNO OH (LAT 40 20 11N LONG 081 45 05W)							
OCT 1987							
26...	1.8	430	7.6	8.0	--	90	82
401624081363400 I-2 BUCKHORN C AT NEWCOMERSTOWN OH (LAT 40 16 24N LONG 081 36 34W)							
OCT 1987							
27...	3.4	490	7.5	8.5	--	79	100
402733081240400 I-5 BEAVERDAM C NR NEW PHILADELPHIA OH (LAT 40 27 33N LONG 081 24 04W)							
OCT 1987							
28...	3.7	1,000	7.5	6.5	--	85	440

Table 10.--Water-quality data for surface-water sites in Lower Tuscarawas River basin, October 1987--Continued

Date	Alu-minum, total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)
401805081394500 I-9 EVANS C NR W LAFAYETTE OH (LAT 40 18 05N LONG 081 39 45W)						
OCT 1987						
27...	110	<10	2,100	330	630	570
401940081441400 I-12 E F WHITE EYES C NR FRESNO OH (LAT 40 19 40N LONG 081 44 14W)						
OCT 1987						
27...	80	10	1,400	270	240	240
03129100 I-1 WHITE EYES C NR FRESNO OH (LAT 40 18 17N LONG 081 45 01W)						
OCT 1987						
26...	180	20	2,400	720	430	420
401959081443300 I-10 WHITE EYES C AT FRESNO OH (LAT 40 19 59N LONG 081 44 33W)						
OCT 1987						
26...	50	20	1,200	90	240	240
402738081262300 I-4 OLD TOWN C AT NEW PHILADELPHIA OH (LAT 40 27 38N LONG 081 26 23W)						
OCT 1987						
28...	220	30	300	50	2,400	2,400
402841081285900 I-3 STONE C (59-11) NR NEW PHILADELPHIA OH (LAT 40 28 41N LONG 081 28 59W)						
OCT 1987						
28...	300	30	1,000	190	970	950
402226081280300 I-6 FRYS C NR GNADENHUTTEN OH (LAT 40 22 26N LONG 081 28 03W)						
OCT 1987						
28...	60	20	300	60	350	360
401616081313900 I-8 BROWNING RN NR NEWCOMERSTOWN OH (LAT 40 16 16N LONG 081 31 39W)						
OCT 1987						
27...	30	20	1,100	320	400	390
401548081311700 I-7 DUNLAP C NR NEWCOMERSTOWN OH (LAT 40 15 48N LONG 081 31 17W)						
OCT 1987						
27...	130	10	1,000	160	170	160
402011081450500 I-11 W F WHITE EYES C NR FRESNO OH (LAT 40 20 11N LONG 081 45 05W)						
OCT 1987						
26...	60	10	820	360	120	160
401624081363400 I-2 BUCKHORN C AT NEWCOMERSTOWN OH (LAT 40 16 24N LONG 081 36 34W)						
OCT 1987						
27...	100	320	730	410	610	570
402733081240400 I-5 BEAVERDAM C NR NEW PHILADELPHIA OH (LAT 40 27 33N LONG 081 24 04W)						
OCT 1987						
28...	160	30	380	80	300	490

Table 11.--Ranges and medians for selected water-quality characteristics for surface-water sites in Lower Tuscarawas River basin

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 13)	Median
Specific conductance, in µS/cm	345(I-12) to 1,100(I-6)	475
pH	7.4(I-2,4,5,8) to 8.2(I-10)	7.5
Alkalinity, in mg/L as $CaCO_3$	73(I-3) to 156(I-6)	85
Sulfate, dissolved, in mg/L as SO_4	28(I-7) to 520(I-6)	91
Aluminum, total, in µg/L as Al	30(I-8) to 300(I-3)	105
Aluminum, dissolved, in µg/L as Al	<10(I-9) to 320(I-2)	20
Iron, total, in µg/L as Fe	300(I-4,6) to 2,400(I-1)	1,000
Iron, dissolved, in µg/L as Fe	50(I-4) to 720(I-1)	230
Manganese, total, in µg/L as Mn	170(I-7) to 2,400(I-4)	415
Manganese, dissolved, in µg/L as Mn	160(I-7,11) to 2,400(I-4)	405

All of the surface-water sites from which the synoptic water-quality samples were collected are on tributary systems of the Tuscarawas River. Active areas of coal mining are more widely scattered throughout the basin than in Sandy Creek or Middle Tuscarawas River and Sugar Creek basins. Coal mining has taken place somewhere upstream from all sites, but, based on the analyses, the sites most affected by drainage from surface mining are I-3, I-4, and I-6 (fig. 13). The streams which range from 7.4 to 8.2 in pH are all mildly basic, which suggests that some attenuation of constituents carried from mining areas is probably taking place in the streams above the sampling sites.

Ground water

The four wells sampled in the study basin all tap unconsolidated deposits of sand and gravel. The sediments along the Tuscarawas River which are tapped by three of the wells are derived partly from glacial outwash. Well TU-49 taps the alluvial material along Frys Creek (fig. 13), a tributary to the Tuscarawas River. Most of the many domestic wells in the subject area outside the main valley of the Tuscarawas River are completed in bedrock. Analyses of ground-water samples for this basin are listed in table 12.

The water-quality analysis for well TU-49 suggests an influence from coal-mining activity nearby. Although the pH was in a neutral range, concentrations of dissolved solids, sulfate, iron, and manganese were much greater than in the other wells sampled in the basin. At TU-49, OEPA standards were exceeded for iron and manganese and for dissolved solids when averaged monthly (see footnote, p. 24). Sulfate was equal to the upper limit suggested by OEPA.

The dominant ions indicated by the Stiff diagrams (fig. 13) show that water samples were generally calcium bicarbonate in water type. In two samples, sulfate was an important constituent, also.

Short and Wheeling Creeks Basin

The Short and Wheeling Creeks basin is a combination of two subbasins that are tributaries to the Ohio River (fig. 15). The basin has a combined drainage area of 317 mi^2. The principal streams are Short Creek and Wheeling Creek, both of which generally flow eastward. About half of the study area lies in the Wheeling Creek drainage system. Both subbasins include several short streams that flow directly into the Ohio River.

Most of the Wheeling Creek subbasin is in the northern third of Belmont County and a small part of Harrison County. The area drained by Short Creek and other tributaries to the Ohio River is in the southeastern corner of Harrison County and the southern part of Jefferson County.

The study area is bordered on the west by the Flushing escarpment, which is also the drainage divide between the Muskingum drainage system on the west and several drainage systems on the east that empty into the Ohio River. The northern and southern boundaries that divide this basin from other study basins (fig. 1) are arbitrarily placed between the principal streams near their confluence with the Ohio River. Thus, each of the principal basins may include minor drainage areas that flow directly into the Ohio River.

Table 12.--Water-quality data for ground-water sites in Lower Tuscarawas River basin

[^{o}C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Depth to water below land-surface datum (feet)	Specific conductance (µS/cm)	pH	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
401620081415300 CS-148 KOEBEL NURSERY NR W LAFAYETTE OH (LAT 40 16 20N LONG 081 41 53W)									
AUG 1987									
24...	23.12	635	7.5	12.0	1.2	320	90	94	21
401800081324500 TU-47 ECHO POINT HARDWOODS NR PORT WASHINGTON OH (LAT 40 18 00N LONG 081 32 45W)									
AUG 1987									
24...	10.11	540	8.0	12.5	7.8	230	85	64	16
402532081241400 TU-48 L CONKEY NR TUSCARAWAS OH (LAT 40 25 32N LONG 081 24 14W)									
AUG 1987									
25...	40.63	695	7.6	11.5	5.8	330	120	95	22
402224081292400 TU-49 S JOHNSON NR GNADENHUTTEN OH (LAT 40 22 24N LONG 081 29 24W)									
AUG 1987									
25...	24.91	940	7.1	11.5	1.0	450	200	130	31

Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity total, field (mg/L as $CaCO_3$	Alkalinity, carbonate, field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)
401620081415300 CS-148 KOEBEL NURSERY NR W LAFAYETTE OH (LAT 40 16 20N LONG 081 41 53W)								
AUG 1987								
24...	3.7	1.3	232	234	82	19	12	400
401800081324500 TU-47 ECHO POINT HARDWOODS NR PORT WASHINGTON OH (LAT 40 18 00N LONG 081 32 45W)								
AUG 1987								
24...	19	1.2	141	143	75	23	10	328
402532081241400 TU-48 L CONKEY NR TUSCARAWAS OH (LAT 40 25 32N LONG 081 24 14W)								
AUG 1987								
25...	6.6	2.0	210	213	66	20	12	426
402224081292400 TU-49 S JOHNSON NR GNADENHUTTEN OH (LAT 40 22 24N LONG 081 29 24W)								
AUG 1987								
25...	16	2.7	257	263	250	17	10	632

Table 12.--Water-quality data for ground-water sites in Lower Tuscarawas River basin--Continued

Date	Solids, sum of constit-uents, dis-solved (mg/L)	Alu-minum total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)	Carbon, organic dis-solved (mg/L as C)
401620081415300 CS-148 KOEBEL NURSERY NR W LAFAYETTE OH (LAT 40 16 20N LONG 081 41 53W)								
AUG 1987								
24...	373	20	<10	280	290	390	370	--
401800081324500 TU-47 ECHO POINT HARDWOODS NR PORT WASHINGTON OH (LAT 40 18 00N LONG 081 32 45W)								
AUG 1987								
24...	293	20	10	740	6	10	5	--
402532081241400 TU-48 L CONKEY NR TUSCARAWAS OH (LAT 40 25 32N LONG 081 24 14W)								
AUG 1987								
25...	350	20	<10	60	6	<10	<1	0.8
402224081292400 TU-49 S JOHNSON NR GNADENHUTTEN OH (LAT 40 22 24N LONG 081 29 24W)								
AUG 1987								
25...	613	10	10	1,200	710	950	890	1.1

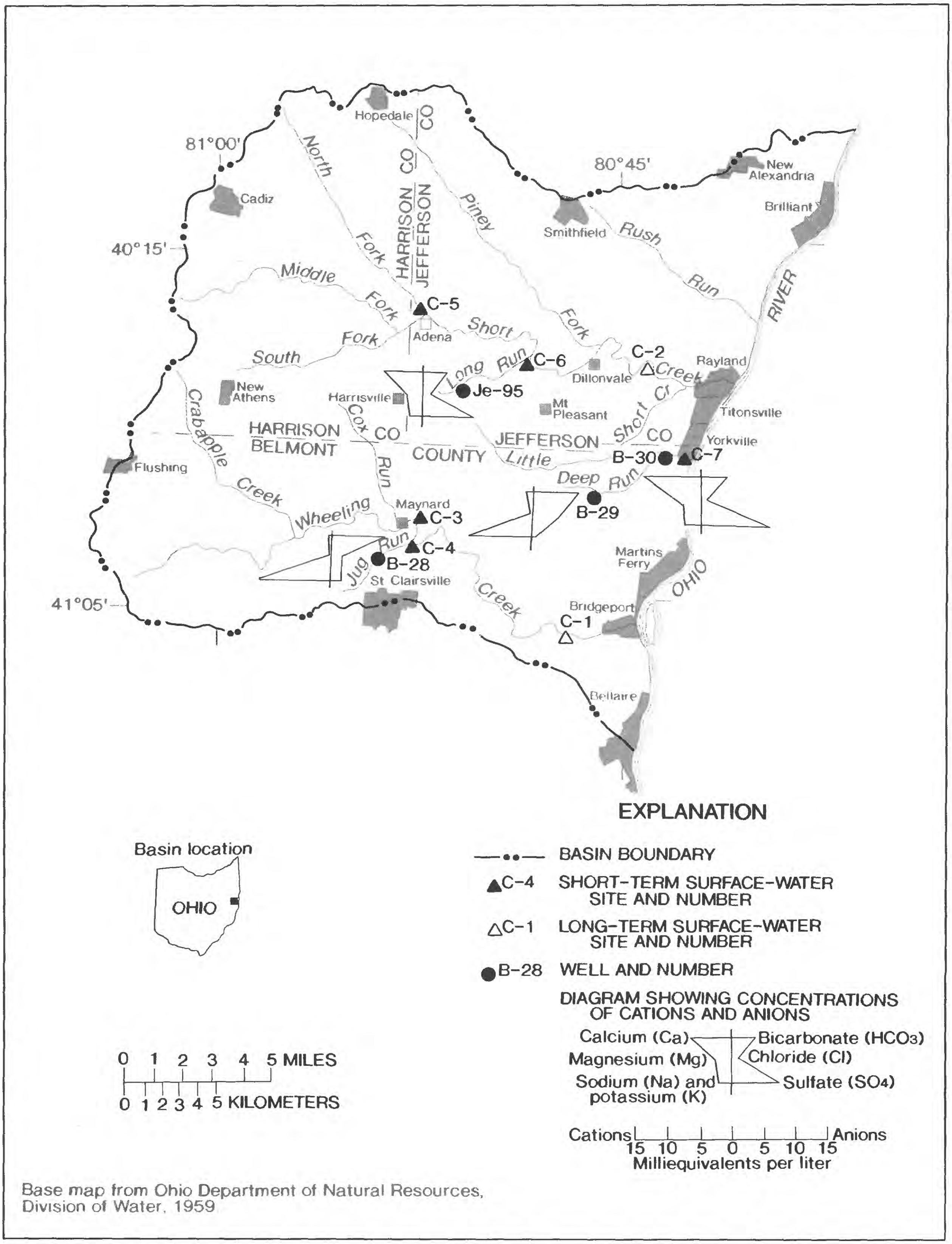

Figure 15.--Short and Wheeling Creeks basin (C), showing surface-water sites, ground-water sites and stiff diagrams for ground-water sites.

The basin lies entirely within the unglaciated Allegheny Plateau section of the Appalachian Plateaus Province. The terrain is characterized by a thoroughly dissected upland surface. In places, the upland is a broad, relatively flat surface that gives way abruptly to numerous steep-sided valleys with narrow bottoms. Local relief in the vicinity of the Ohio River Valley is as much as 500 ft.

Geologic Setting

Stratigraphic units present, in ascending order, are the Conemaugh and Monongahela Formations of Pennsylvanian age and the Waynesburg and Greene Formations that comprise the Dunkard Group of Pennsylvanian and Permian age (fig. 6). Structurally, the rocks have a southward to southeastward dip across the Short and Wheeling Creeks area. Throughout the study area, the Conemaugh is present in valley bottoms and hillsides.

In Harrison and Jefferson Counties, the Monongahela has a somewhat patchy distribution in upland areas along ridgetops in areas where erosion has cut deeply into the underlying Conemaugh Formation. In Belmont County, the Monongahela is present widely and, in places, is capped by units of Permian age. Along Wheeling Creek, erosion has cut down into the Conemaugh Formation, as is also the case in the Ohio River Valley.

In the Short and Wheeling Creeks basin, commercial coals are chiefly the Pittsburgh (No. 8), Meigs Creek (No. 9), Uniontown (No. 10), and Waynesburg (No. 11) coals in the Monongahela Formation and the Washington (No. 12) coal in the Greene Formation (fig. 6). A number of thin local coal beds present in the Conemaugh are of little commercial value in the Short and Wheeling Creeks area. The Allegheny Formation coals are extractable by underground mining only. In general, the coals of the Monongahela Formation are easily extractable by surface mining.

Coal beds that are being surface mined include the Pittsburgh, Redstone, Meigs Creek, Uniontown, Waynesburg, and Washington (Nos. 8, 8A, 9, 10, 11, and 12, respectively). Surface mining of the Pittsburgh and Redstone coals (Nos. 8 and 8A, respectively) is more prevalent in the northwestern and northern parts of the study area. Most surface mining for the Meigs Creek (No. 9) and Waynesburg (No. 11) coals is to the south, mostly in the Wheeling Creek subbasin. The Uniontown (No. 10) coal has a relatively low number of active mines. Surface mining of the Washington (No. 12) coal is prevalent in the southeastern part of the area, where the Permian section is thicker.

Ground-water resources are, at best, meager in bedrock areas exclusive of the Ohio River Valley (Schmidt, 1959). Nevertheless, many people still depend on the small local supplies that are available in the various sandstones, fractured limestones, and coal beds underlying the region. Because of population growth that has spread outward from the Ohio Valley, public water-supply lines have been laid in many areas. These systems draw much of their supply from the productive alluvial aquifer in the Ohio River Valley. Although unconsolidated alluvial sediments are present in many of the valleys, these sediments are relatively thin, and most water wells are completed in bedrock. These materials are important as a medium through which the shallow bedrock is recharged from precipitation, surface runoff, or streams through streambed infiltration.

Water Quality

Coal is surface mined in most of the Short and Wheeling Creeks basin. The largest areas not having any currently permitted locations are mainly areas where the Conemaugh Formation exists exclusively. Nevertheless, the lithologic makeup of any of the rock systems in the study area can affect both stream and ground-water quality such as an ability to buffer the pH of the system or by contribution of mineral constituents. Analytical results of both the surface-water and ground-water sampling show some of these influences.

Surface water

The following surface-water sites were sampled in early October 1988. Their locations are shown in figure 15.

Map index number	Site type	Site name	Drainage area (square miles)
C-1	Long-term	Wheeling C bl Blaine----------	97.7
C-2	do.	Short C nr Dillonvale---------	123
C-3	Short-term	Wheeling C at Maynard---------	68.8
C-4	do.	Jug Rn nr Maynard-------------	3.6
C-5	do.	Short C at Adena--------------	63.9
C-6	do.	Long Rn nr Dillonvale---------	6.3
C-7	do.	Deep Rn at Yorkville----------	3.7

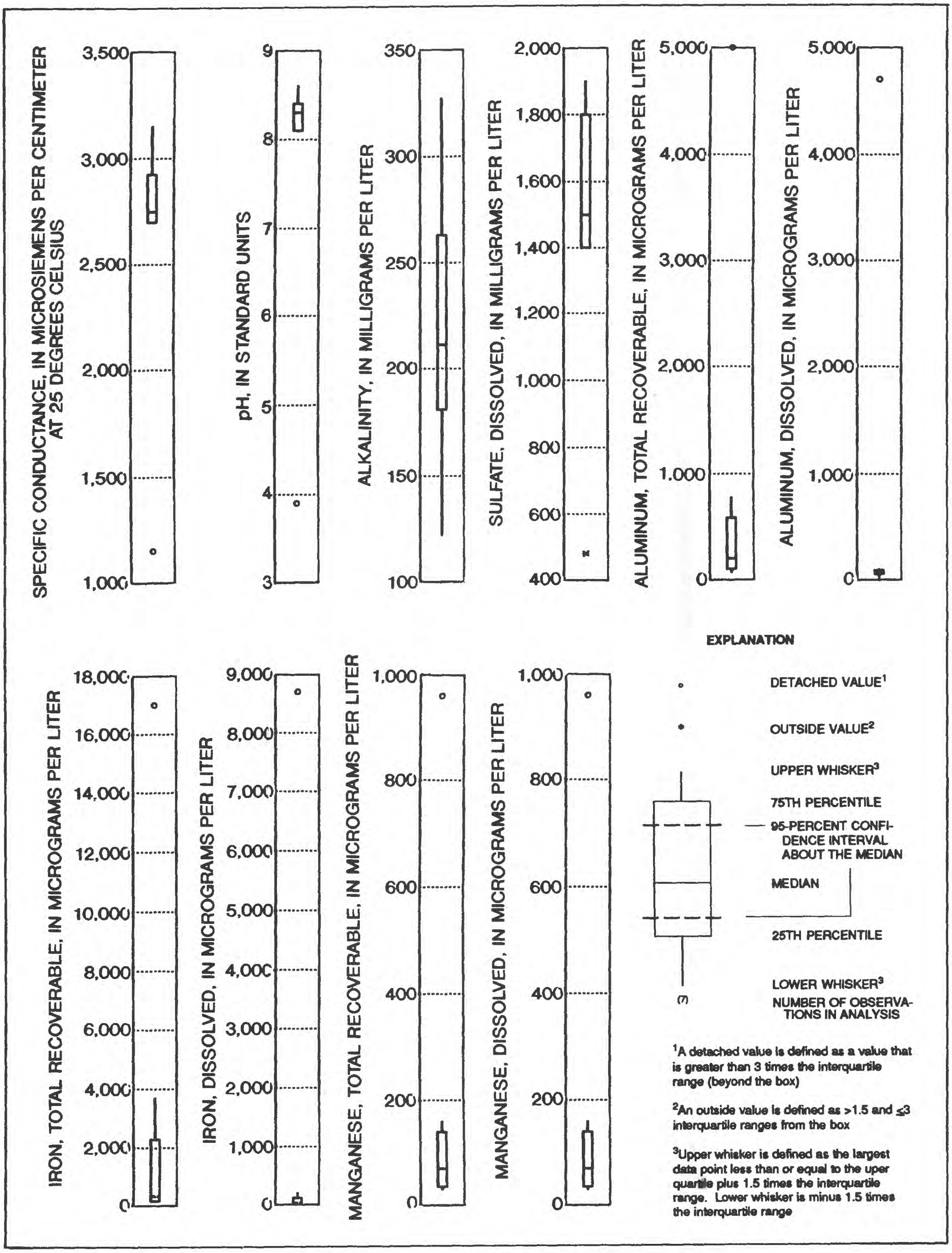

Figure 16.--Box plots showing the range, percentiles, and median values of constituents at surface-water sites in Short and Wheeling Creeks basin.

Table 13.--Water-quality data for surface-water sites in Short and Wheeling Creeks basin, October 1988

[°C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03111500 C-2 SHORT C NR DILLONVALE OH (LAT 40 11 36N LONG 080 44 04W)							
OCT 1988							
05...	23	2,700	8.6	10.5	--	212	1,500
03111465 C-5 SHORT C AT ADENA OH (LAT 40 13 09N LONG 080 52 22W)							
OCT 1988							
05...	7.3	3,150	8.5	12.5	--	210	1,900
401158080484000 C-6 LONG RN NR DILLONVALE OH (LAT 40 11 58N LONG 080 48 40W)							
OCT 1988							
06...	0.38	3,000	8.1	5.5	--	122	1,800
400859080424600 C-7 DEEP RN AT YORKVILLE OH (LAT 40 08 59N LONG 080 42 46W)							
OCT 1988							
06...	0.23	2,850	3.9	8.0	68	--	1,800
03111548 C-1 WHEELING C BL BLAINE OH (LAT 40 04 01N LONG 080 48 31W)							
OCT 1988							
06...	12	2,700	8.3	8.5	--	263	1,400
400639080524400 C-4 JUG RN NR MAYNARD OH (LAT 40 06 39N LONG 080 52 44W)							
OCT 1988							
06...	0.23	1,150	8.1	10.0	--	181	480
400728080524300 C-3 WHEELING C (55-10) AT MAYNARD OH (LAT 40 07 28N LONG 080 52 43W)							
OCT 1988							
06...	31	2,750	8.3	10.5	--	327	1,400

Table 13.--Water-quality data for surface-water sites in Short and Wheeling Creeks basin, October 1988--Continued

Date	Aluminum, total recoverable (µg/L as Al)	Aluminum, dissolved (µg/L as Al)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
03111500 C-2 SHORT C NR DILLONVALE OH (LAT 40 11 36N LONG 080 44 04W)						
OCT 1988						
05...	200	100	340	20	30	30
03111465 C-5 SHORT C AT ADENA OH (LAT 40 13 09N LONG 080 52 22W)						
OCT 1988						
05...	70	20	160	30	40	30
401158080484000 C-6 LONG RN NR DILLONVALE OH (LAT 40 11 58N LONG 080 48 40W)						
OCT 1988						
06...	780	50	3,700	200	160	170
400859080424600 C-7 DEEP RN AT YORKVILLE OH (LAT 40 08 59N LONG 080 42 46W)						
OCT 1988						
06...	5,000	4,700	17,000	8,700	960	1,200
03111548 C-1 WHEELING C BL BLAINE OH (LAT 40 04 01N LONG 080 48 31W)						
OCT 1988						
06...	390	80	870	30	120	120
400639080524400 C-4 JUG RN NR MAYNARD OH (LAT 40 06 39N LONG 080 52 44W)						
OCT 1988						
06...	100	60	150	30	70	60
400728080524300 C-3 WHEELING C (55-10) AT MAYNARD OH (LAT 40 07 28N LONG 080 52 43W)						
OCT 1988						
06...	100	60	170	20	30	20

Figure 16 is based on the seven sites sampled. Results of the analyses of water samples from the seven sites are listed in table 13. Water-quality analyses for the two long-term sites also are listed in table 21. Table 14 presents a summary of water-quality characteristics for the surface-water sites.

Table 14.--Ranges and medians for selected water-quality characteristics for surface-water sites in Short and Wheeling Creeks basin

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 15)	Median
Specific conductance, in uS/cm	1,150(C-4) to 3,150(C-5)	2,750
pH	3.90(C-7) to 8.60(C-2)	8.30
Alkalinity, in mg/L as $CaCO_3$	0(C-7) to 327(C-3)	211
Sulfate, dissolved, in mg/L as SO_4	480(C-4) to 1,900(C-5)	1,500
Aluminum, total, in µg/L as Al	70(C-5) to 5,000(C-7)	200
Aluminum, dissolved, in µg/L as Al	20(C-5) to 4,700(C-7)	60
Iron, total, in µg/L as Fe	150(C-4) to 17,000(C-7)	340
Iron, dissolved, in µg/L as Fe	20(C-2,3) to 8,700(C-7)	30
Manganese, total, in µg/L as Mn	30(C-3) to 960(C-7)	70
Manganese, dissolved, in µg/L as Mn	20(C-3) to 1,200(C-7)	70

Water-quality analyses of the seven surface-water sites show the effects of surface mining in the study basin, which is evidenced by high levels of specific conductance and dissolved sulfate (table 15). In some places, the amounts of iron, magnesium, and aluminum were especially high. However, water at only one of the seven sites (C-7) was strongly acidic. Samples from several sites were high in constituents commonly associated with acidic waters, but the pH values were, with the one exception, all neutral or alkaline, indicating considerable buffering of the stream waters. Samples from the two long-term sites (C-1 and C-2), though high in dissolved sulfates and specific conductance, were high in pH. Because of their downstream locations, there is probably an attenuation of iron,

Table 15.--Water-quality data for ground-water sites in Short and Wheeling Creeks basin

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Depth to water below land-surface datum (feet)	Specific conductance (µS/cm)	pH	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
400609080541800 B-28 J MATIS NR ST CLAIRSVILLE OH (LAT 40 06 09N LONG 080 54 18W)									
AUG 1988 24...	23.17	1,250	8.9	13.0	0	43	0	10	4.3
400806080453600 B-29 WM TALBOTT NR YORKVILLE OH (LAT 40 08 06N LONG 080 45 36W)									
AUG 1988 25...	19.10	1,320	7.9	15.0	1.3	100	0	27	8.0
400915080433100 B-30 GARY MILLER NR YORKVILLE OH (LAT 40 09 15N LONG 080 43 31W)									
AUG 1988 25...	7.52	1,590	7.4	12.5	0	750	510	230	43
401140080490200 JE-95 J BRANDI NR DILLONVALE OH (LAT 40 11 40N LONG 080 49 02W)									
AUG 1988 25...	8.22	1,170	7.5	11.5	2.4	520	290	150	35

Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity total, field (mg/L as $CaCO_3$)	Alkalinity, carbonate, field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)
400609080541800 B-28 J MATIS NR ST CLAIRSVILLE OH (LAT 40 06 09N LONG 080 54 18W)								
AUG 1988 24...	280	1.1	461	461	89	50	8.4	789
400806080453600 B-29 WM TALBOTT NR YORKVILLE OH (LAT 40 08 06N LONG 080 45 36W)								
AUG 1988 25...	270	1.3	363	364	25	150	7.1	738
400915080433100 B-30 GARY MILLER NR YORKVILLE OH (LAT 40 09 15N LONG 080 43 31W)								
AUG 1988 25...	57	2.6	242	242	630	26	8.1	1,220
401140080490200 JE-95 J BRANDI NR DILLONVALE OH (LAT 40 11 40N LONG 080 49 02W)								
AUG 1988 25...	56	1.4	227	226	390	7.7	7.2	863

Table 15.--Water-quality data for ground-water sites in Short and Wheeling Creeks basin--Continued

Date	Solids, sum of constit- uents, dis- solved (mg/L)	Alu- minum total recov- erable (µg/L as Al)	Alu- minum, dis- solved (µg/L as Al)	Iron, total recov- erable (µg/L as Fe)	Iron, dis- solved (µg/L as Fe)	Manga- nese, total recov- erable (µg/L as Mn)	Manga- nese, dis- solved (µg/L as Mn)	Carbon, organic dis- solved (mg/L as C)
400609080541800 B-28 J MATIS NR ST CLAIRSVILLE OH (LAT 40 06 09N LONG 080 54 18W)								
AUG 1988								
24...	795	50	<10	130	55	10	<1	0.8
400806080453600 B-29 WM TALBOTT NR YORKVILLE OH (LAT 40 08 06N LONG 080 45 36W)								
AUG 1988								
25...	706	130	<10	240	<3	30	10	1.1
400915080433100 B-30 GARY MILLER NR YORKVILLE OH (LAT 40 09 15N LONG 080 43 31W)								
AUG 1988								
25...	1,140	40	<10	40	<3	10	1	0.9
401140080490200 JE-95 J BRANDI NR DILLONVALE OH (LAT 40 11 40N LONG 080 49 02W)								
AUG 1988								
25...	783	30	<10	60	14	10	6	0.8

manganese, and aluminum due to dilution. In addition, the presence of carbonate rocks in the area could have provided buffering which raised the pH value of the stream. As stated in figure 4, there is a larger proportion of limestone in the Monongahela Formation than in the other Pennsylvanian units. These, along with several thin limestones in the Conemaugh, could provide a stronger buffering system in the Short and Wheeling Creeks basin than in most of the other study basins.

Ground water

Locations of the sampled wells, including Stiff diagrams which depict the ionic character of the ground-water samples, are shown in figure 15. Analyses of ground-water samples are listed in table 15. All of the sites were located close to perennial streams. In general, the wells penetrated probably less than 30 ft of unconsolidated material before tapping the underlying bedrock.

All of the wells were relatively high in mineral content. As for ground-water type, the water from two wells was dominantly strongly sodium bicarbonate, and the water from remaining wells was calcium sulfate. The pH ranged from 7.4 to 8.9; water at two sites, JE-95 and B-30, was very hard.

With regard to OEPA water-quality standards for public supply, at a range of 738 to 1,220 mg/L for dissolved solids, the standards for the monthly average (500 mg/L) were greatly exceeded. The OEPA standard allows a maximum of 750 mg/L dissolved solids for single-event samples. However, iron, manganese, and chloride concentrations were less than the OEPA limits. At wells B-30 and JE-95, the sulfate content was considerably greater than the OEPA limit of 250 mg/L. Samples from wells B-29 and B-30, located along Deep Run, had pH levels of 7.90 and 7.40, respectively, which contrasts sharply with a pH of 3.90 measured for Deep Run less than a mile downstream from well B-30.

Upper Wills Creek Basin

The Upper Wills Creek basin, which is about 406 mi^2 in area, lies mostly in the southern third of Guernsey County and in the northeastern part of Noble County (fig. 17). Small parts of the basin lie in the northwestern corner of Monroe County, the southwestern corner of Belmont County, and the southeastern corner of Muskingum County.

The southwestern part of the basin is drained by branches of Buffalo Creek that meet at Pleasant City to form Wills Creek, which in turn follows a generally meandering northward course.

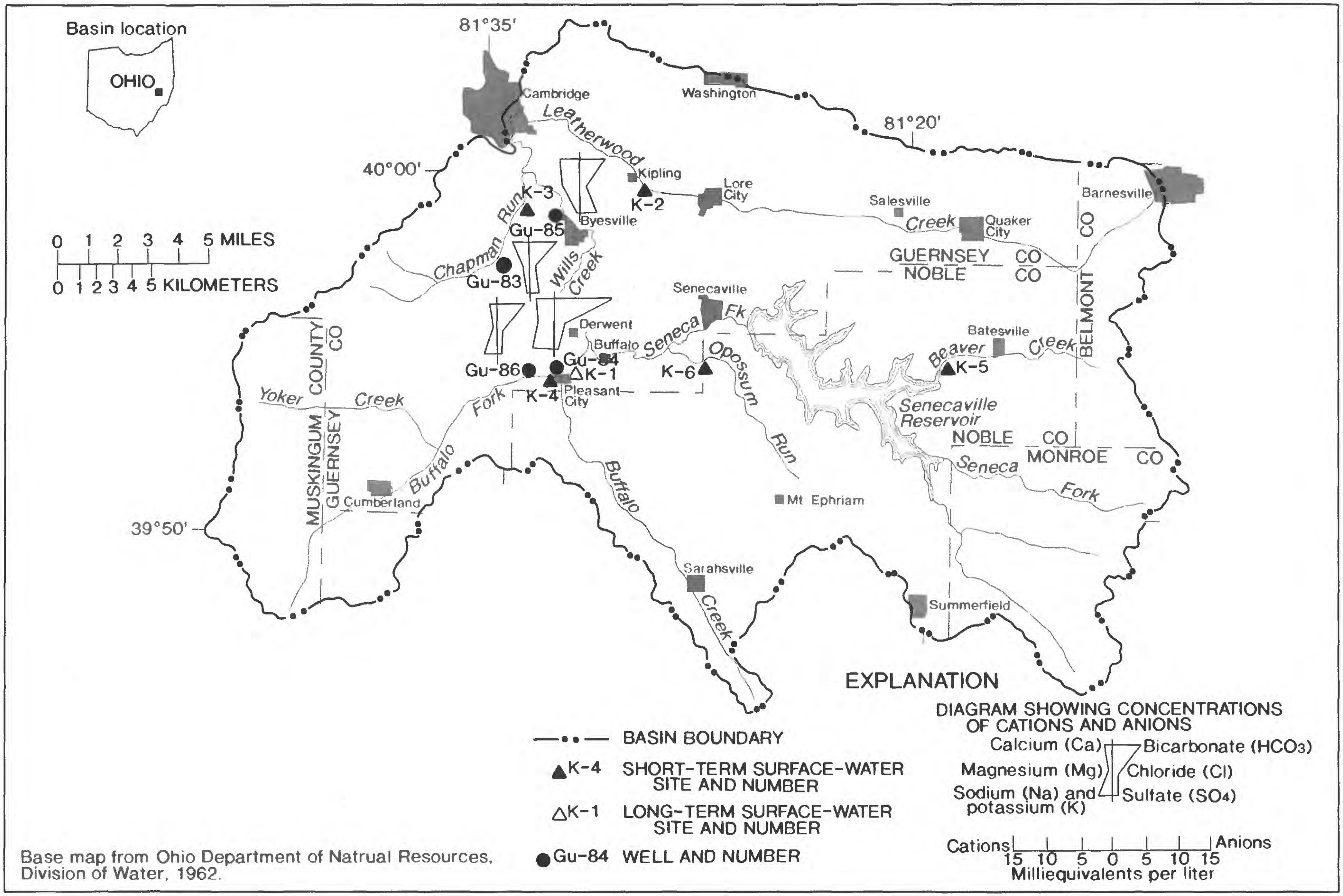

Figure 17.--Upper Wills Creek basin (K), showing surface water sites, ground-water sites and stiff diagrams for ground-water sites.

Two tributaries that separate Upper Wills Creek basin from Lower Wills Creek basin to the north are Leatherwood Creek, which enters Wills Creek from the east at Cambridge, and Chapman Creek, which enters from the west near Cambridge. A large part of the basin is drained by Seneca Fork, which enters Wills Creek near Buffalo.

The Upper Wills Creek basin is in the Unglaciated Allegheny Plateau section of the Appalachian Plateaus Province. Erosion of the land surface has produced a thoroughly dissected terrain, much of which is characterized by a relatively subdued surface with wide bottomlands and low hills. The more rugged parts are around the periphery of the basin, especially to the east, where the Flushing escarpment separates Muskingum-basin drainage from that of basins A, B, C, and D (fig. 1). Toward the center of the basin, streamflow is sluggish. Wetlands and poorly drained areas are not uncommon.

Geologic Setting

Stratigraphic units present in the Upper Wills Creek basin, in ascending order, are the Allegheny, Conemaugh, and Monongahela Formations of Pennsylvanian age and the Washington Formation of the Dunkard Group of Pennsylvanian and Permian age. Three areas of active surface mining include the upper watershed of Buffalo Fork near Cumberland, the vicinity of Pleasant City and Byesville, and mines scattered around the upper watershed of Leatherwood Creek near Quaker City (fig. 17).

Regionally, the rocks across the eastern half of Ohio dip southeastward about 30 ft/mi toward the Appalachian Basin. Locally, the system is modified by various minor structural features that produce reversals in the regional dip (Lamborn, 1951, p. 13). One such feature, the Cambridge Arch, causes the oldest units to appear at or near the surface in the vicinity of Wills Creek in the Cambridge area. As a result, the Upper Freeport (No. 7) coal at the top of the Allegheny Formation is at or near the surface.

The Conemaugh Formation is the most prevalent surficial unit in the Wills Creek basin. On the western and eastern edges of the basin, the Conemaugh is overlain by coal-bearing units of the Monongahela Formation. Surface mining of coal takes place in both areas. The Monongahela has a patchy distribution across Noble County along the southern part of the basin. Only scattered remnants of the Washington Formation in the Dunkard Group remain along the eastern edge of the basin.

Throughout the Upper Wills Creek basin, the underlying bedrock is not a high-yielding source of ground water, but, locally, it is an important source for domestic use. The area does not have any glacial outwash deposits, but, in some areas, valley fill deposits of sand and gravel can be as much as 50 ft thick. With proper development, these sand-and-gravel sources can supply the needs of small industry or small public systems (Walker, 1962b). Relatively few wells yield solely from the permeable unconsolidated sediments and, instead, are usually completed in the underlying bedrock, into which considerable recharge from the saturated unconsolidated section is passed. Most of the Byesville municipal-supply wells along Chapman Creek and the public-supply wells for Pleasant City along Wills Creek are completed in this manner. Because of the prevalence of wetlands along Wills Creek, the ground-water potential of the unconsolidated section is not fully developed.

Water Quality

Six surface-water sites were used to obtain water-quality samples to assess differences in stream-water quality which could have resulted from nearby surface mining. The four ground-water sites were concentrated in the area of the basin where the presence of alluvial sediments along perennial streams, in combination with permeable layers in the underlying bedrock, provides conditions most favorable for the existence of a shallow productive aquifer.

Surface water

The following streams at the indicated locations were sampled in early October 1988.

Map index number	Site type	Site name	Drainage area (square miles)
K-1	Long-term	Wills C at Pleasant City----------	406
K-2	Short-term	Leatherwood C nr Kipling----------	68.9
K-3	do.	Chapman Rn at SR 209 nr Byesville----------------------	13.7
K-4	do.	Buffalo F at Pleasant City--------	71.2
K-5	do.	Beaver C above Senecaville Reservoir nr Batesville---------	16.8
K-6	do.	Opossum Rn nr Senecaville---------	10.7

Figure 18 is based on the six sites sampled. Results of the analyses of water samples from the six sites are listed in table 16. Water-quality analyses for the long-term site also are listed in table 21. Table 17 presents a summary of water-quality characteristics for the surface-water sites.

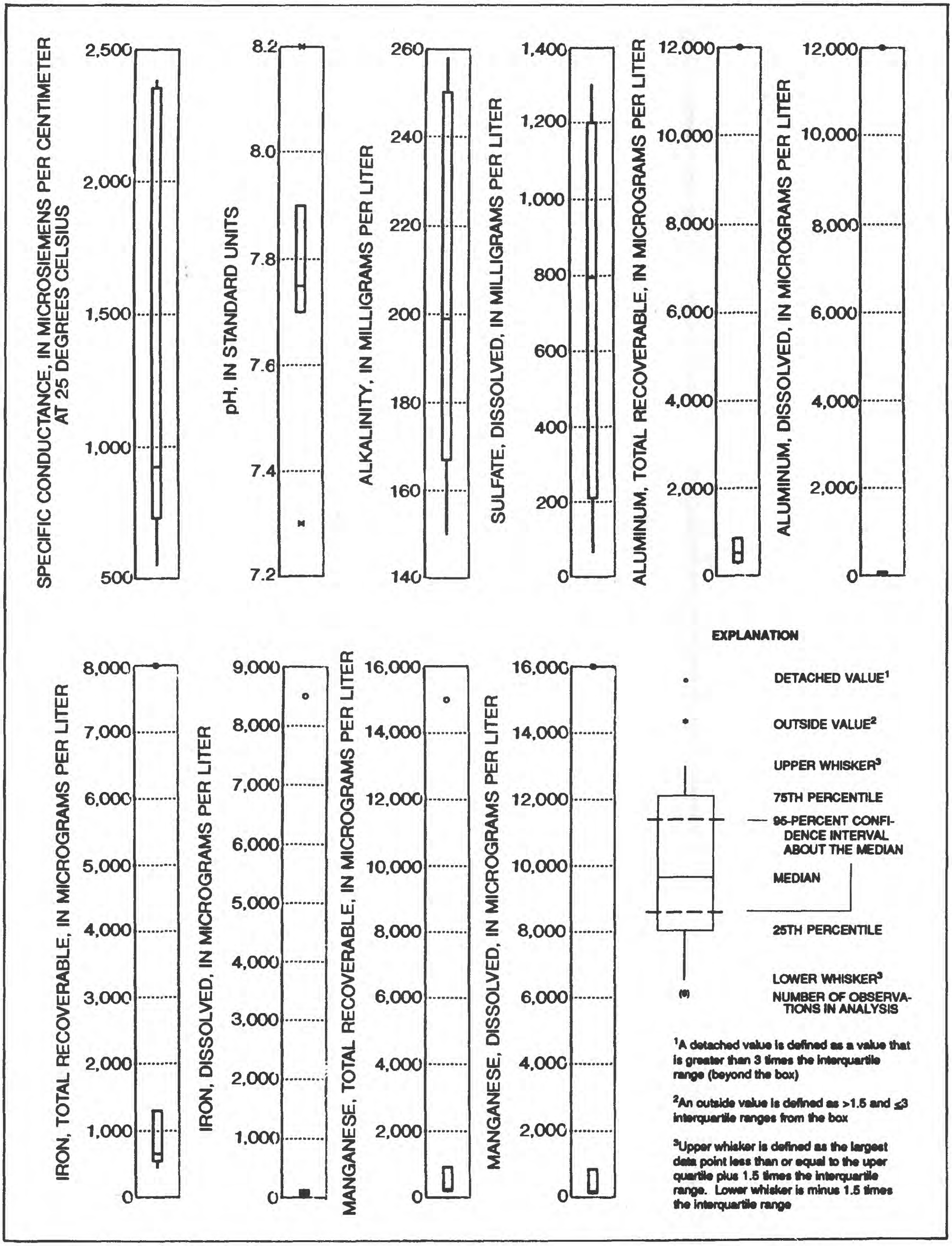

Figure 18.--Box plots showing the range, percentiles, and median values of constituents at surface-water sites in Upper Wills Creek basin.

Table 16.--Water-quality data for surface-water sites in Upper Wills Creek basin, October 1988

[°C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
395404081191100 K-5 BEAVER C AB SENECAVILLE LK NR BATESVILLE OH (LAT 39 54 04N LONG 081 19 11W)							
OCT 1988 04...	0.14	730	8.2	13.5	--	229	210
03140700 K-4 BUFFALO F AT PLEASANT CITY OH (LAT 39 54 15N LONG 081 33 14W)							
OCT 1988 04...	4.1	2,350	7.8	15.0	--	258	1,300
395417081323000 K-1 WILLS C AT PLEASANT CITY OH (LAT 39 54 17N LONG 081 32 30W)							
OCT 1988 04...	4.0	2,380	7.9	15.5	--	250	1,200
395444081273400 K-6 OPOSSUM RN NR SENECAVILLE OH (LAT 39 54 44N LONG 081 27 34W)							
OCT 1988 05...	0.05	550	7.7	11.5	--	169	65
395923081294400 K-2 LEATHERWOOD C NR KIPLING OH (LAT 39 59 23N LONG 081 29 44W)							
OCT 1988 05...	0.63	1,000	7.7	10.5	--	150	390
395858081341500 K-3 CHAPMAN RN AT SR 209 NR BYESVILLE OH (LAT 39 58 58N LONG 081 34 15W)							
OCT 1988 05...	0.01	850	7.3	10.5	--	167	1,200

Table 16.--Water-quality data for surface-water sites in Upper Wills Creek basin, October 1988--Continued

Date	Alu-minum, total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)
395404081191100 K-5 BEAVER C AB SENECAVILLE LK NR BATESVILLE OH (LAT 39 54 04N LONG 081 19 11W)						
OCT 1988						
04...	850	30	1,300	<10	190	110
03140700 K-4 BUFFALO F AT PLEASANT CITY OH (LAT 39 54 15N LONG 081 33 14W)						
OCT 1988						
04...	570	80	610	100	240	190
395417081323000 K-1 WILLS C AT PLEASANT CITY OH (LAT 39 54 17N LONG 081 32 30W)						
OCT 1988						
04...	460	40	550	50	240	190
395444081273400 K-6 OPOSSUM RN NR SENECAVILLE OH (LAT 39 54 44N LONG 081 27 34W)						
OCT 1988						
05...	270	20	710	120	920	830
395923081294400 K-2 LEATHERWOOD C NR KIPLING OH (LAT 39 59 23N LONG 081 29 44W)						
OCT 1988						
05...	300	30	450	60	200	130
395858081341500 K-3 CHAPMAN RN AT SR 209 NR BYESVILLE OH (LAT 39 58 58N LONG 081 34 15W)						
OCT 1988						
05...	12,000	12,000	8,000	8,500	15,000	16,000

Table 17.--Ranges and medians for selected water-quality characteristics for surface-water sites in Upper Wills Creek basin

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent	Range and locations (fig. 17)	Median
Specific conductance, in µS/cm	550(K-6) to 2,380(K-1)	925
pH	7.30(K-3) to 8.2(K-5)	7.75
Alkalinity, in mg/L as $CaCO_3$	150(K-2) to 258(K-4)	199
Sulfate, in mg/L as SO_4	65(K-6) to 1,300(K-4)	795
Aluminum, total, in µg/L as Al	270(K-6) to 12,000(K-3)	515
Aluminum, dissolved, in µg/L as Al	20(K-6) to 12,000(K-3)	35
Iron, total, in µg/L as Fe	450(K-2) to 8,000(K-3)	660
Iron, dissolved, in µg/L as Fe	10(K-5) to 8,500(K-3)	80
Manganese, total, in µg/L as Mn	190(K-5) to 15,000(K-3)	240
Manganese, dissolved, in µg/L as Mn	109(K-5) to 16,000(K-3)	190

Water samples from site K-3, which is located downstream from surface-mined areas, had the highest concentrations of the three metals analyzed and high concentrations of sulfate. None of the sampled stream sites was acidic, which indicates that some stream waters downstream from areas of coal mining were being neutralized by a buffering action.

Buffalo Fork and Buffalo Creek join to form Wills Creek about 0.5 mi upstream from long-term surface-water site K-1 at Pleasant City, Ohio (fig. 17). Synoptic site K-4 on Buffalo Fork just upstream from the confluence of Buffalo Fork and Buffalo Creek is downstream from several active mining areas near Cumberland, Ohio, and less than a mile downstream from a recently opened (as of August 1988) 99-acre tract to mine the Freeport (No. 7) coal. Results of the synoptic water-sample collections made in October 1988 show little difference in the substance loads carried in the streams at K-4 and K-1, indicating little or no dilution by Buffalo Creek is taking place. Runoff from old mining areas near Mt. Ephraim, Ohio, at the upper reaches of the

Buffalo Creek watershed, could be contributing constituent loads to Wills Creek similar to those of Buffalo Fork. State of Ohio files do not indicate any currently active mining areas in the area drained by Buffalo Creek.

There is little if any mining activity south of Senecaville Reservoir (fig. 17) and only a small amount to the northeast. As might be expected, sites K-5 and K-6, in comparison with sites K-1, 3, and 4, have been little affected by surface-mining runoff. Site K-2 is some distance downstream from mining operations. Water quality there could have been modified by the distance the runoff has traveled.

Ground water

Analyses of ground-water samples for this basin are given in table 18. Two of the four sites sampled were municipal wells. Both GU-83, at Byesville's well field along Chapman Run, and GU-84, at Pleasant City's field along Wills Creek, are less than a mile downstream from active surface-mining operations. GU-86, a domestic well, is only a few hundred feet from an active mining area (ODNR permit D-0578). Another domestic well, GU-85, near Byesville, is several miles downstream from the nearest area of active mining (as of August 30, 1988, when sampled). Only iron and manganese levels exceed the OEPA standards. Stiff diagrams of the wells (fig. 17) indicate that the waters were a mixture of cation types. Bicarbonate was the principal anion constituent.

Upper Raccoon Creek Basin

The Upper Raccoon Creek basin has a drainage area of 384 mi^2. Most of the basin lies in the eastern half of Vinton County and small sections of Hocking County on the north, Athens and Meigs Counties on the east, and Gallia County on the southeast (fig. 19).

The basin includes all of the drainage to Raccoon Creek upstream from, but not including, Little Raccoon Creek, which enters Raccoon Creek below the town of Vinton in Gallia County. Raccoon Creek begins just south of New Plymouth where two branching tributaries meet. Raccoon Creek flows generally toward the south. The largest tributary is Elk Fork, which enters the Raccoon Creek near the center of the basin.

All of the Upper Raccoon Creek basin lies in the Unglaciated Allegheny Plateau section of the Appalachian Plateaus Province (Fenneman, 1938). Because of differences in rock types, such as those that exist between massive sandstone and clays, shales or friable sandstones, several erosional cycles have produced a land surface that ranges from one of long ridges and narrow valleys in

Table 18.--Water-quality data for ground-water sites in Upper Wills Creek basin, August 1988

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Date	Depth to water below land-surface datum (feet)	Specific conductance (µS/cm)	pH	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
395417081330100 GU-84 VILLAGE OF PLEASANT CITY OH (LAT 39 54 17N LONG 081 33 01W)									
AUG 1988									
30...	27.42	915	8.0	12.0	1.8	290	0	64	31
395418081335800 GU-86 B MIKES NR PLEASANT CITY OH (LAT 39 54 18N LONG 081 33 58W)									
AUG 1988									
30...	24.96	520	7.3	14.0	0.2	140	0	37	11
395758081345700 GU-83 WATER PLANT NO 1 BYESVILLE OH (LAT 39 57 58N LONG 081 34 57W)									
AUG 1988									
30...	59.52	625	7.9	12.0	5.2	260	52	72	19
395906081331600 GU-85 FLOYD MAY BYESVILLE OH (LAT 39 59 06N LONG 081 33 16W)									
AUG 1988									
30...	16.88	640	7.1	14.0	1.6	300	130	68	32

Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity total, field (mg/L as $CaCO_3$	Alkalinity, carbonate, field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)
395417081330100 GU-84 VILLAGE OF PLEASANT CITY OH (LAT 39 54 17N LONG 081 33 01W)								
AUG 1988								
30...	84	1.0	416	416	7.0	39	7.5	499
395418081335800 GU-86 B MIKES NR PLEASANT CITY OH (LAT 39 54 18N LONG 081 33 58W)								
AUG 1988								
30...	53	2.2	241	246	3.3	14	14	281
395758081345700 GU-83 WATER PLANT NO 1 BYESVILLE OH (LAT 39 57 58N LONG 081 34 57W)								
AUG 1988								
30...	21	0.60	206	206	80	18	12	363
395906081331600 GU-85 FLOYD MAY BYESVILLE OH (LAT 39 59 06N LONG 081 33 16W)								
AUG 1988								
30...	17	0.60	174	174	120	22	16	401

Table 18.--Water-quality data for ground-water sites in Upper Wills Creek basin, August 1988--Continued

Date	Solids, sum of constit- uents, dis- solved (mg/L)	Alu- minum total recov- erable (µg/L as Al)	Alu- minum, dis- solved (µg/L as Al)	Iron, total recov- erable (µg/L as Fe)	Iron, dis- solved (µg/L as Fe)	Manga- nese, total recov- erable (µg/L as Mn)	Manga- nese, dis- solved (µg/L as Mn)	Carbon, organic dis- solved (mg/L as C)
395417081330100 GU-84 VILLAGE OF PLEASANT CITY OH (LAT 39 54 17N LONG 081 33 01W)								
AUG 1988								
30...	484	20	<10	3,800	1,400	70	56	3.0
395418081335800 GU-86 B MIKES NR PLEASANT CITY OH (LAT 39 54 18N LONG 081 33 58W)								
AUG 1988								
30...	280	30	50	1,300	990	140	140	0.9
395758081345700 GU-83 WATER PLANT NO 1 BYESVILLE OH (LAT 39 57 58N LONG 081 34 57W)								
AUG 1988								
30...	352	<10	<10	6,100	5,700	220	230	1.6
395906081331600 GU-85 FLOYD MAY BYESVILLE OH (LAT 39 59 06N LONG 081 33 16W)								
AUG 1988								
30...	381	170	<10	350	160	500	510	1.0

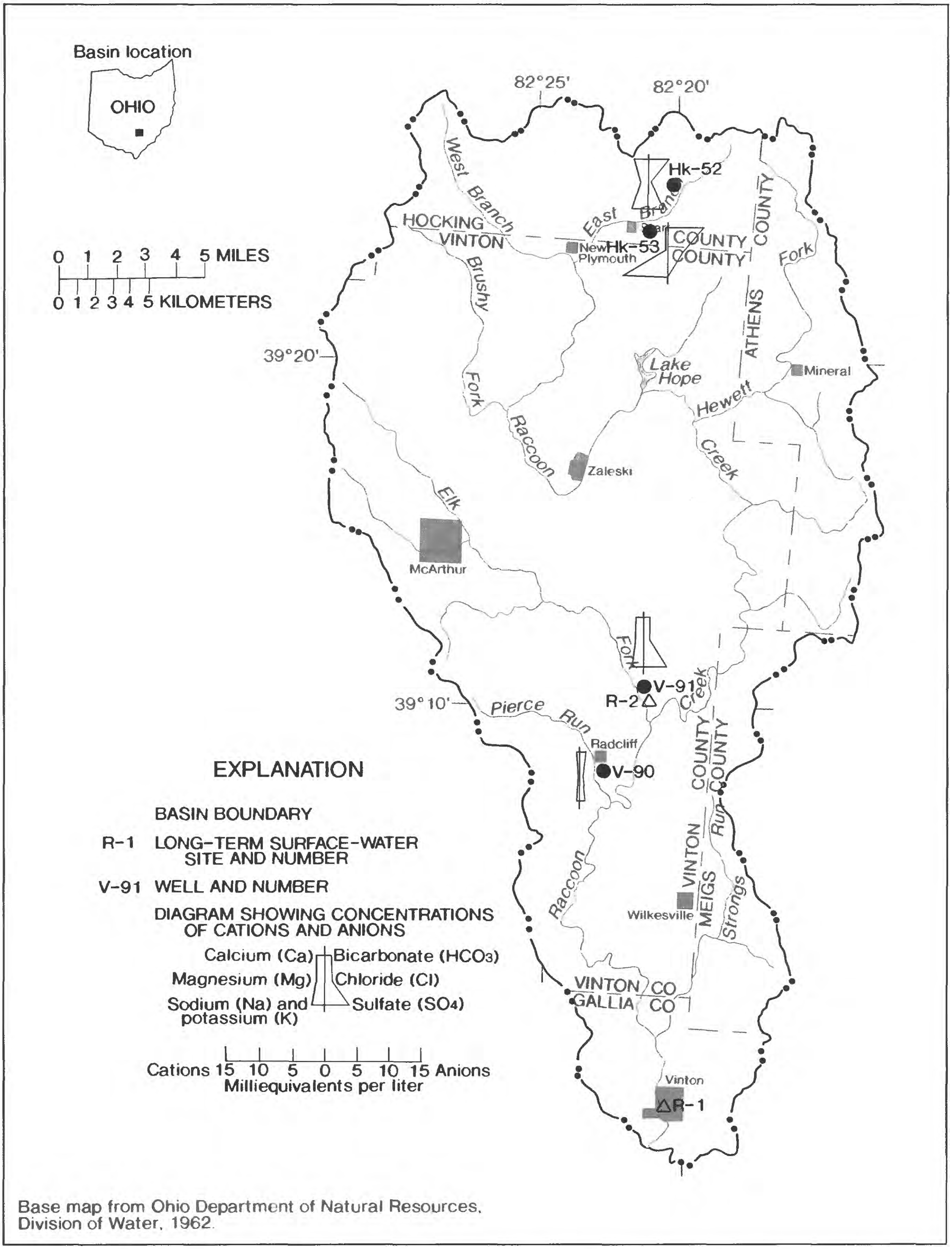

Figure 19.--Upper Raccoon Creek basin (R), showing surface-water sites, ground-water sites and stiff diagrams for ground-water sites.

the eastern part of the basin to a less rugged terrain toward the center of the basin (Stout, 1927). Local relief is about 300 ft in the more hilly parts of the area.

Geologic Setting

The stratigraphic units that are present in the area include, from west to east in ascending order, (1) the Logan Formation of Mississippian Age, which crops out in bottomlands along Brushy Fork Creek, (2) basal Pennsylvanian units of the Pottsville and Allegheny Formations, and (3) the Conemaugh Formation, which is present mostly as remnants along ridges in the eastern part of the basin. These units dip to the east and south, averaging about 33 ft/mi to the southeast, according to Stout (1927).

The principal coal-bearing units are the Lower Mercer (No. 3) coal in the Pottsville Formation and the Brookville (No. 4), Clarion (No. 4A), Lower Kittanning (No. 5), Middle Kittanning (No. 6), Lower Freeport (No. 6A), and Upper Freeport (No. 7) coals in the Allegheny Formation (fig. 6). Three areas of active surface mining include the north corner of the basin, an area east and northeast of McArthur, Ohio, and along the drainage boundary that lies between Upper Raccoon Creek and Lower Raccoon Creek basin on the west. Over much of the rest of the basin the coals are thin or discontinuous.

Principal aquifers are in the surficial bedrock. Of regional importance is the Black Hand Sandstone Member[5] of the Cuyahoga Formation, which is tapped by many wells in Vinton County. The southeastern limit of potable water in the Black Hand Sandstone Member is generally along a line about three miles east of McArthur, Zaleski, and Lake Hope (fig. 19) on the basis of a study by Norris and Mayer (1982). Locally, productive sources of water are available in sandstone units of the Pottsville and Allegheny Formations.

Differences between modern and preglacial drainage systems have been explained in detail by Stout (1927). Alluvial deposits are present along various streams, but these are mostly of fine-grained sand or clay. Except for domestic supplies, shallow ground-water sources in these deposits are unlikely to be productive. In general, most shallow wells are completed in bedrock, except where the alluvial deposits are sufficiently developed for the construction of large-diameter dug wells (Pree, 1962b). One well, V-91, sampled in this investigation was a dug well. The other three sampled wells were completed in bedrock.

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[5] Unit follows usage of Ohio Geological Survey.

Water Quality

The Raccoon Creek basin (R and S combined, fig. 1) was studied previously by the U.S. Geological Survey (Wilson, 1985 and 1988), in cooperation with the Ohio Department of Natural Resources, Division of Reclamation. In the earlier study (1985), a data base was developed for use in individual subbasin reclamation projects, and, in November 1983, a synoptic sampling of 41 surface-water sites during base-flow conditions was carried out. Twenty-six of those sites were in the Upper Raccoon Creek basin (R, fig. 1). In a second study (1988), chemical and biological data were collected from July 1984 through September 1986 at some of these sites in support of reclamation projects in selected subbasins. Because ample surface-water data are available in the Raccoon Creek basin, no short-term surface-water sites were selected in the current study. Ground water was not included in the earlier studies, therefore, an evaluation of ground-water quality in the area was made for this study, and four wells were selected for sampling.

Surface water

Compilation of baseline surface-water-quality data for the Upper Raccoon Creek basin similar to objectives for other selected basins in this study was accomplished with the synoptic sampling in November 1983 (Wilson, 1985). Results of a recent study (Wilson, 1988, p. 27) indicated that major sources of mine drainage to Raccoon Creek include East Branch of Raccoon Creek, Brushy Creek, and Hewett Fork (fig. 19). Long-term sites R-1 and R-2 were used in the earlier studies. R-1 was established to document water quality downstream from the acidic sources (Wilson, 1988). Water-quality samples for Elk Fork, the longest tributary in the Upper Raccoon Creek basin, were collected near its mouth at site R-2. According to Wilson (1988), Elk Fork has not been significantly affected by mine drainage.

Table 19, summarizing data over two periods of investigation, is based on data collected by Wilson, 1988; Jones, 1988; and the current study. The 1984-86 data is based on eight samples at site R-1 and seven at R-2. The 1986-88 median values were derived from five measurements at site R-1 and four at R-2. The data are based on Jones (1988) measurements in October 1986 and those of this study. Site R-2 was dry in the fall of 1987 and not sampled.

Table 19.--Medians for selected water-quality characteristics for long-term sites R-1 and R-2 in Upper Raccoon Creek basin, 1984-86 and 1986-88

[mg/L, milligrams per liter; ug/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Constituent and unit of measure	Site R-1		Site R-2	
	1984-86[1]	1986-88[2]	1984-86[1]	1986-88[2]
Specific conductance, uS/cm	560	510	370	450
pH	7.0	6.9	7.1	7.2
Alkalinity, mg/L as $CaCO_3$	19	33	38	46
Sulfate, mg/L as SO_4	135	180	100	125
Aluminum, total, ug/L as Al	200	90	100	180
Aluminum, dissolved, ug/L as Al	100	20	100	25
Iron, total, ug/L as Fe	670	780	1,000	840
Iron, dissolved, ug/L as Fe	110	120	220	255
Manganese, total, ug/L as Mn	1,100	810	730	715
Manganese, dissolved, ug/L as Mn	1,050	820	760	710

[1] July 1984 through September 1986 data from Wilson, 1988.
[2] October 1986 through October 1988 data from Jones, 1988, and current study.

Ground water

Locations of the four wells sampled and Stiff diagrams depicting the ionic character of the water samples are shown in figure 19. Analyses of ground-water samples for this basin are given in table 20.

The waters from wells HK-52 and 53, located in the northern part of the basin, were a sodium bicarbonate type. The waters at wells V-90 and V-91, near Radcliff, at pH 5.8, were slightly acidic. Cation proportions between calcium, magnesium, and sodium were fairly even, but sulfate was the dominant anion.

Table 20.--Water-quality data for ground-water sites in Upper Raccoon Creek basin, August 1988

[°C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Depth to water below land-surface datum (feet)	Specific conductance (µS/cm)	pH	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Acidity (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
390810082221900 V-90 S CORRELL AT RADCLIFF OH (LAT 39 08 10N LONG 082 22 19W)									
AUG 1988									
29...	28.40	120	5.8	16.0	5.1	30	22	20	6.4
391002082211100 V-91 R BARNES NR RADCLIFF OH (LAT 39 10 02N LONG 082 21 11W)									
AUG 1988									
29...	21.04	560	5.8	15.0	0	150	130	24	28
392347082205300 HK-53 JW HENDERSON NR STARR OH (LAT 39 23 47N LONG 082 20 53W)									
AUG 1988									
23...	23.95	835	8.8	14.5	0	13	0	--	3.4
392500082195100 HK-52 TRI CO COON HUNTERS ASSOC NR STARR OH (LAT 39 25 00N LONG 082 19 51W)									
AUG 1988									
23...	10.84	610	7.3	15.5	0	180	0	--	50

Date	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity total, field (mg/L as $CaCO_3$)	Alkalinity, carbonate, field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C dissolved (mg/L)
390810082221900 V-90 S CORRELL AT RADCLIFF OH (LAT 39 08 10N LONG 082 22 19W)									
AUG 1988									
29...	3.5	7.4	0.80	8	8.0	36	3.0	38	107
391002082211100 V-91 R BARNES NR RADCLIFF OH (LAT 39 10 02N LONG 082 21 11W)									
AUG 1988									
29...	19	43	5.9	23	27	180	22	17	351
392347082205300 HK-53 JW HENDERSON NR STARR OH (LAT 39 23 47N LONG 082 20 53W)									
AUG 1988									
23...	1.1	180	2.1	287	288	1.1	71	7.1	472
392500082195100 HK-52 TRI CO COON HUNTERS ASSOC NR STARR OH (LAT 39 25 00N LONG 082 19 51W)									
AUG 1988									
23...	13	60	3.0	188	189	110	9.8	14	379

Table 20.--Water-quality data for ground-water sites in Upper Raccoon Creek basin, August 1988--Continued

Date	Solids, sum of constit-uents, dis-solved (mg/L)	Alu-minum total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)	Carbon, organic dis-solved (mg/L as C)
390810082221900 V-90 S CORRELL AT RADCLIFF OH (LAT 39 08 10N LONG 082 22 19W)								
AUG 1988								
29...	100	310	20	330	86	50	73	1.3
391002082211100 V-91 R BARNES NR RADCLIFF OH (LAT 39 10 02N LONG 082 21 11W)								
AUG 1988								
29...	329	130	10	630	76	90	74	1.2
392347082205300 HK-53 JW HENDERSON NR STARR OH (LAT 39 23 47N LONG 082 20 53W)								
AUG 1988								
23...	438	200	<10	210	<3	10	3	1.0
392500082195100 HK-52 TRI CO COON HUNTERS ASSOC NR STARR OH (LAT 39 25 00N LONG 082 19 51W)								
AUG 1988								
23...	374	30	<10	1,500	1,400	120	120	0.7

As a group, the waters from the four wells were low in dissolved-solids content, with well V-90 having the lowest level of dissolved solids for all ground-water samples analyzed during this study.

With respect to OEPA standards for public supply, only water from well HK-52 was excessive in dissolved iron, and wells HK-52, V-90, and V-91 in manganese.

SUMMARY

Twenty-one drainage basins have been selected for study in the area of eastern Ohio where surface mining of coal is active. Most of the area lies in the unglaciated part of Ohio. The region is underlain by Mississippian-, Pennsylvanian-, and Permian-age strata that dip gently eastward toward the Appalachian Basin. The strata consist of sandstone and shale interbedded with coal, clay, and limestone.

Along the western and northern margins of the study area, a covering of glacial drift has left a smoother land surface, which, in its original state, probably resembled the rugged upland that characterizes most of the region. In places, the steep-sided narrow valleys broaden into wide valleys cut by the larger streams.

In the northern part of the study area, local accumulations of permeable sands and gravels, as well as alluvial deposits of these materials, were laid down as outwash deposits in major drainage channels when the ice melted. Shallow, productive sources of ground water where these materials exist are important to the region but are largely limited to northern areas and major drainage systems. Bedrock sources of ground water are widely available, but, in many areas, yields are sufficient for domestic use only.

This report presents and discusses data from the second phase of a study begun in 1985. The data were collected from July 1987 through October 1988. Discharge measurements and water-sample collections were made at 41 long-term surface-water sites from which 162 water-quality samples were collected for analysis. Of these, the following ranges in field measurements or concentrations were noted: specific conductance, 290 to 2,700 µS/cm; pH, 2.8 to 8.6; dissolved sulfate, 23 to 1,500 mg/L; dissolved iron, 10 to 51,000 µg/L; dissolved manganese, 10 to 47,000 ug/L; and dissolved aluminum, 10 to 17,000 ug/L. The highest concentrations of iron, manganese, and aluminum were at sites where the water also was acidic. The highest specific conductance and sulfate concentration were each at sites where waters were alkaline.

In six drainage basins chosen for intensive study, several surface-water sites were selected for once-only measurements and collection of water-quality samples. A total of 40 short-term surface-water sites and 24 ground-water sites were sampled from basins selected to be intensively studied.

In 1987, the Sandy Creek, Sugar Creek and Middle Tuscarawas River, and Lower Tuscarawas River basins were chosen for intensive study. Discharge was measured and water was sampled at a total of 30 short-term surface-water sites. Waters from four wells were sampled in each basin. The three basins are generally in the northern part of the study area and collectively are drained by the Tuscarawas and Muskingum River system. The analyses of water samples did not indicate large areas of severely degraded surface water or ground water. Most of the streams had a pH of 7.0 or greater; none were below a pH of 6.6. Iron, manganese, and aluminum concentrations were higher at sites close to active mining areas. Ground water was mostly calcium bicarbonate in type. Water at a few wells was a calcium sulfate or calcium bicarbonate sulfate type. Concentrations of most constituents were within OEPA standards for public-water supply.

In 1988, Short and Wheeling Creeks, Upper Wills Creek, and Upper Raccoon Creek basins were chosen for intensive study. A total of 10 short-term surface-water sites were chosen in Short Creek, Wheeling Creek, and Upper Wills Creek basins. Because the entire Raccoon Creek basin was part of a recent study, no short-term surface-water sites were measured or sampled. In both the Short and Wheeling Creeks and Upper Wills Creek basins several analyses that showed elevated concentrations of sulfate, iron, manganese, and aluminum were not far from active areas of mining. Only one water sample was strongly acidic. The pH values in most places suggest that various stream systems are benefiting from a buffering action probably caused by the presence of carbonate rocks in both basins. In the Upper Raccoon Creek basin, elevated concentrations of constituents, indicative of acid drainage near coal-mining areas, as revealed in earlier studies, were greatly reduced downstream.

Unlike the three basins investigated in 1987, shallow productive aquifers generally are not present in the basins investigated in 1988 (Short and Wheeling Creeks, Upper Wills Creek, and Upper Raccoon Creek), with the possible exception of certain areas along Wills Creek in Upper Wills Creek basin. In some places, small supplies of ground water are available in bedrock units near the land surface. Along some streams, small supplies of ground water are available in shallow bedrock units that are recharged through a thin covering of alluvium. Such ground water is susceptible to degradation by contaminated surface waters.

Results of the 1988 ground-water analyses show that waters from wells in Short and Wheeling Creeks basin were the most mineralized of all the basins studied. Within the three basins sampled, the waters at about half of the wells were a sodium bicarbonate type, and the other types were various combinations of sodium and calcium with bicarbonate and sulfate. OEPA standards were exceeded for iron and manganese concentrations at some wells in Upper Raccoon Creek and Upper Wills Creek basins. In Short and Wheeling Creeks basin, OEPA standards were exceeded for sulfate at two wells and for dissolved solids at three wells.

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Table 21.--Water-quality data for long-term surface-water sites, 1987-88

[°C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03109100 A-2 M F L BEAVER C NR ROGERS OH (LAT 40 43 22N LONG 080 38 03W)							
JUL 1987							
21...	29	730	8.3	25.5	--	139	160
OCT							
27...	27	840	8.2	8.0	--	159	160
JUNE 1988							
07...	22	765	8.2	25.0	--	153	160
OCT							
05...	15	896	8.3	10.0	--	166	160
03109500 A-1 L BEAVER C NR EAST LIVERPOOL OH (LAT 40 40 33N LONG 080 32 27W)							
JUL 1987							
21...	78	770	8.3	27.0	--	121	190
OCT							
28...	114	760	8.2	5.5	--	137	180
JUN 1988							
07...	97	770	8.2	23.5	--	133	200
OCT							
05...	38	896	8.4	12.0	--	147	200
03110000 B-1 YELLOW C NR HAMMONDSVILLE OH (LAT 40 32 16N LONG 080 43 31W)							
JUL 1987							
21...	17	570	8.4	29.5	--	83	130
OCT							
28...	20	590	8.1	6.0	--	96	170
JUN 1988							
07...	12	585	7.9	21.5	--	88	170
OCT							
05...	30	520	8.2	12.0	--	109	140
03111500 C-2 SHORT C NR DILLONVALE OH (LAT 40 11 36N LONG 080 44 04W)							
JUL 1987							
22...	27	2,350	8.0	22.5	--	167	1,100
OCT							
28...	34	2,300	8.3	7.5	--	207	1,100
JUN 1988							
08...	27	2,200	8.2	19.0	--	186	1,100
OCT							
05...	23	2,700	8.6	10.5	--	212	1,500
03111548 C-1 WHEELING C BL BLAINE OH (LAT 40 04 01N LONG 080 48 31W)							
JUL 1987							
20...	28	2,400	8.2	28.0	--	173	1,100
OCT							
27...	23	2,650	8.1	7.0	--	243	1,300
JUN 1988							
06...	28	2,270	8.1	25.5	--	211	1,200
OCT							
06...	12	2,700	8.3	8.5	--	263	1,400
03113550 D-2 MCMAHON C AT BELLAIRE OH (LAT 40 00 39N LONG 080 45 45W)							
JUL 1987							
20...	7.2	1,350	8.2	27.0	--	146	480
OCT							
26...	6.5	1,450	8.2	9.5	--	176	470
JUN 1988							
06...	10	1,100	8.1	23.0	--	157	380
OCT							
04...	3.5	1,300	8.1	16.0	--	154	570
03114000 D-1 CAPTINA C AT ARMSTRONGS MILLS OH (LAT 39 54 31N LONG 080 55 27W)							
JUL 1987							
20...	5.7	510	8.4	27.5	--	151	77
OCT							
26...	9.2	715	8.3	10.5	--	176	150
JUN 1988							
06...	12	530	8.4	25.0	--	149	100
OCT							
04...	4.0	880	8.5	20.0	--	142	270

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Aluminum, total recoverable (µg/L as Al)	Aluminum, dissolved (µg/L as Al)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
03109100 A-2 M F L BEAVER C NR ROGERS OH (LAT 40 43 22N LONG 080 38 03W)						
JUL 1987 21...	280	40	210	<10	80	40
OCT 27...	60	<10	270	70	40	50
JUN 1988 07...	150	20	450	40	300	200
OCT 05...	220	20	500	40	100	40
03109500 A-1 L BEAVER C NR EAST LIVERPOOL OH (LAT 40 40 33N LONG 080 32 27W)						
JUL 1987 21...	190	40	260	30	60	30
OCT 28...	40	<10	130	30	30	20
JUN 1988 07...	110	20	230	80	100	40
OCT 05...	100	<10	170	30	50	20
03110000 B-1 YELLOW C NR HAMMONDSVILLE OH (LAT 40 32 16N LONG 080 43 31W)						
JUL 1987 21...	220	60	210	20	30	20
OCT 28...	130	40	490	60	30	20
JUN 1988 07...	140	50	220	10	60	30
OCT 05...	100	10	160	20	40	10
03111500 C-2 SHORT C NR DILLONVALE OH (LAT 40 11 36N LONG 080 44 04W)						
JUL 1987 22...	420	190	470	30	50	40
OCT 28...	300	120	550	70	90	80
JUN 1988 08...	1,100	130	2,900	10	150	70
OCT 05...	200	100	340	20	30	30
03111548 C-1 WHEELING C BL BLAINE OH (LAT 40 04 01N LONG 080 48 31W)						
JUL 1987 20...	870	480	1,300	20	70	70
OCT 27...	330	50	770	30	130	140
JUN 1988 06...	880	410	1,600	50	110	60
OCT 06...	390	80	870	30	120	120
03113550 D-2 MCMAHON C AT BELLAIRE OH (LAT 40 00 39N LONG 080 45 45W)						
JUL 1987 20...	440	140	460	<10	40	40
OCT 26...	120	50	360	30	30	20
JUN 1988 06...	220	110	320	<10	50	40
OCT 04...	140	90	330	40	20	20
03114000 D-1 CAPTINA C AT ARMSTRONGS MILLS OH (LAT 39 54 31N LONG 080 55 27W)						
JUL 1987 20...	370	40	470	<10	50	20
OCT 26...	90	<10	120	20	10	<10
JUN 1988 06...	150	<10	250	<10	40	10
OCT 04...	110	20	160	30	10	<10

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Instantaneous discharge (ft^3/s)	Specific conductance (μS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03114250 D-3 SUNFISH C AT CAMERON OH (LAT 39 46 00N LONG 080 56 09W)							
JUL 1987							
20...	3.7	405	8.4	29.0	--	132	40
OCT							
26...	3.1	455	8.2	11.0	--	146	55
JUN 1988							
06...	4.8	400	8.3	21.0	--	131	58
OCT							
04...	2.7	465	8.2	15.5	--	141	54
03116950 G-2 NEWMAN C NR MASSILLON OH (LAT 40 49 22N LONG 081 33 06W)							
JUL 1987							
22...	3.8	740	8.3	28.5	--	202	240
OCT							
27...	3.0	850	7.4	10.0	--	251	120
JUN 1988							
07...	3.3	920	7.8	22.0	--	227	110
OCT							
05...	2.9	840	8.2	12.0	--	240	120
03117500 E-1 SANDY C AT WAYNESBURG OH (LAT 40 40 21N LONG 081 15 36W)							
JUL 1987							
21...	71	640	8.3	24.0	--	129	240
OCT							
26...	80	530	8.1	10.0	--	102	110
JUN 1988							
07...	54	645	7.7	19.0	--	139	120
OCT							
05...	69	460	7.6	13.0	--	88	77
03123000 G-1 SUGAR C AB BEACH CITY DAM AT BEACH CITY OH (LAT 40 39 24N LONG 081 34 37W)							
JUL 1987							
22...	29	600	8.0	25.0	--	173	140
OCT							
27...	24	680	6.9	9.0	--	200	72
JUN 1988							
07...	17	780	7.7	23.5	--	202	61
OCT							
05...	16	692	8.1	12.5	--	214	62
03127500 H-1 STILLWATER C AT UHRICHSVILLE OH (LAT 40 23 10N LONG 081 20 50W)							
JUL 1987							
21...	69	865	8.0	25.5	--	123	300
OCT							
27...	41	920	7.7	8.5	--	192	320
JUN 1988							
06...	44	1,030	7.9	21.5	--	120	340
OCT							
04...	23	1,020	--	17.5	--	136	370
03129100 I-2 WHITE EYES C NR FRESNO OH (LAT 40 18 17N LONG 081 45 01W)							
JUL 1987							
20...	7.4	400	7.8	26.0	--	98	120
OCT							
26...	5.0	460	7.4	9.0	--	92	79
JUN 1988							
06...	5.0	440	7.5	21.0	--	91	73
OCT							
04...	1.6	446	7.5	13.5	--	98	76
03140000 J-1 MILL C NR COSHOCTON OH (LAT 40 21 46N LONG 081 51 45W)							
JUL 1987							
20...	6.3	350	7.9	26.0	--	91	87
OCT							
26...	2.6	405	7.7	6.5	--	103	58
JUN 1988							
08...	1.4	390	7.5	18.5	--	106	50
OCT							
04...	0.83	419	7.6	11.5	--	120	52

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Alu-minum, total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)
03114250 D-3 SUNFISH C AT CAMERON OH (LAT 39 46 00N LONG 080 56 09W)						
JUL 1987						
20...	240	30	310	<10	50	20
OCT						
26...	50	<10	70	20	20	<10
JUN 1988						
06...	90	<10	190	10	40	10
OCT						
04...	110	20	200	10	20	<10
03116950 G-2 NEWMAN C NR MASSILLON OH (LAT 40 49 22N LONG 081 33 06W)						
JUL 1987						
22...	140	<10	490	60	210	140
OCT						
27...	110	<10	660	180	160	130
JUN 1988						
07...	150	<10	520	60	310	270
OCT						
05...	130	90	480	100	90	70
03117500 E-1 SANDY C AT WAYNESBURG OH (LAT 40 40 21N LONG 081 15 36W)						
JUL 1987						
21...	110	20	410	60	270	230
OCT						
26...	80	20	430	90	280	240
JUN 1988						
07...	90	<10	470	50	410	380
OCT						
05...	50	20	200	30	130	120
03123000 G-1 SUGAR C AB BEACH CITY DAM AT BEACH CITY OH (LAT 40 39 24N LONG 081 34 37W)						
JUL 1987						
22...	1,500	20	2,400	30	270	150
OCT						
27...	210	<10	700	170	110	90
JUN 1988						
07...	560	<10	1,300	40	760	750
OCT						
05...	520	20	930	40	130	110
03127500 H-1 STILLWATER C AT UHRICHSVILLE OH (LAT 40 23 10N LONG 081 20 50W)						
JUL 1987						
21...	440	50	700	30	570	450
OCT						
27...	150	20	640	190	400	390
JUN 1988						
06...	260	20	450	20	800	700
OCT						
04...	210	30	380	30	510	540
03129100 I-2 WHITE EYES C NR FRESNO OH (LAT 40 18 17N LONG 081 45 01W)						
JUL 1987						
20...	200	50	1,300	40	280	250
OCT						
26...	180	20	2,400	720	430	420
JUN 1988						
06...	200	10	2,300	100	580	560
OCT						
04...	190	<10	2,000	340	500	530
03140000 J-1 MILL C NR COSHOCTON OH (LAT 40 21 46N LONG 081 51 45W)						
JUL 1987						
20...	120	<10	940	60	160	130
OCT						
26...	40	10	1,200	320	150	150
JUN 1988						
08...	210	10	1,300	140	390	360
OCT						
04...	100	10	1,000	550	150	150

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03148400 O-2 MOXAHALA C AT ROBERTS OH (LAT 39 51 17N LONG 082 03 23W)							
JUL 1987 20...	15	1,950	3.2	25.5	206	0	450
OCT 28...	11	2,450	3.3	7.5	216	0	1,200
JUN 1988 07...	18	1,900	3.3	20.5	133	0	880
OCT 04...	9.9	2,000	3.1	14.0	203	--	160
03149500 N-1 SALT C NR CHANDLERSVILLE OH (LAT 39 54 31N LONG 081 51 38W)							
JUL 1987 21...	5.1	505	8.0	24.5	--	115	590
OCT 27...	3.8	625	7.8	9.5	--	139	100
JUN 1988 07...	4.9	515	8.0	25.0	--	115	83
OCT 04...	0.82	660	7.6	17.0	--	119	110
03150250 N-2 MEIGS C NR BEVERLY OH (LAT 39 36 00N LONG 081 42 42W)							
JUL 1987 22...	9.1	1,250	8.1	25.5	--	131	550
OCT 27...	1.9	2,100	7.8	9.5	--	144	990
JUN 1988 06...	18	1,300	8.1	21.5	--	172	570
OCT 05...	0.99	2,250	7.9	12.0	--	128	1,100
03156700 P-1 RUSH C NR SUGAR GROVE OH (LAT 39 38 18N LONG 082 30 42W)							
JUL 1987 23...	22	745	7.8	28.5	--	93	210
OCT 26...	12	970	7.5	4.5	--	91	310
JUN 1988 06...	28	680	7.7	19.5	--	88	180
OCT 04...	8.7	918	7.9	14.0	--	69	330
03157000 P-2 CLEAR C NR ROCKBRIDGE OH (LAT 39 35 18N LONG 082 34 43W)							
JUL 1987 22...	17	370	8.3	26.0	--	157	640
OCT 26...	13	390	8.3	7.0	--	158	27
JUN 1988 06...	18	425	8.1	17.0	--	165	41
OCT 04...	13	379	8.6	14.5	--	164	29
03158200 Q-1 MONDAY C AT DOANVILLE OH (LAT 39 26 07N LONG 082 11 30W)							
JUL 1987 22...	7.1	1,050	3.6	27.0	73	0	970
OCT 26...	2.9	1,500	3.6	8.0	111	0	730
JUN 1988 06...	18	1,100	3.6	17.0	64	0	450
OCT 04...	3.5	1,250	3.4	15.0	29	--	600
03160050 QQ-1 LEADING C NR MIDDLEPORT OH (LAT 39 00 31N LONG 082 05 07W)							
JUL 1987 21...	0.61	1,200	7.8	23.5	--	118	280
OCT 27...	0.18	1,400	6.9	10.5	--	104	310
JUN 1988 08...	1.7	700	7.8	18.5	--	101	150
OCT 05...	0.07	890	7.7	14.0	--	113	110

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Aluminum, total recoverable (µg/L as Al)	Aluminum, dissolved (µg/L as Al)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
03148400 O-2 MOXAHALA C AT ROBERTS OH (LAT 39 51 17N LONG 082 03 23W)						
JUL 1987 20...	7,900	8,200	1,100	820	3,300	3,100
OCT 28...	14,000	12,000	13,000	12,000	19,000	18,000
JUN 1988 07...	9,900	1,000	5,100	4,700	50,000	47,000
OCT 04...	460	10	1,300	60	730	580
03149500 N-1 SALT C NR CHANDLERSVILLE OH (LAT 39 54 31N LONG 081 51 38W)						
JUL 1987 21...	4,700	60	310	40	7,100	6,800
OCT 27...	130	<10	810	50	290	280
JUN 1988 07...	190	20	650	50	240	230
OCT 04...	510	130	1,400	120	460	470
03150250 N-2 MEIGS C NR BEVERLY OH (LAT 39 36 00N LONG 081 42 42W)						
JUL 1987 22...	590	10	790	30	100	30
OCT 27...	90	<10	170	20	70	70
JUN 1988 06...	250	10	350	20	100	40
OCT 05...	80	30	110	40	60	50
03156700 P-1 RUSH C NR SUGAR GROVE OH (LAT 39 38 18N LONG 082 30 42W)						
JUL 1987 23...	610	50	1,400	60	670	570
OCT 26...	110	<10	500	60	4,600	4,600
JUN 1988 06...	280	20	620	20	400	340
OCT 04...	340	20	990	<10	1,700	1,600
03157000 P-2 CLEAR C NR ROCKBRIDGE OH (LAT 39 35 18N LONG 082 34 43W)						
JUL 1987 22...	490	470	41,000	36,000	3,300	3,100
OCT 26...	<10	<10	220	10	30	50
JUN 1988 06...	100	<10	290	30	40	20
OCT 04...	320	150	850	50	90	30
03158200 Q-1 MONDAY C AT DOANVILLE OH (LAT 39 26 07N LONG 082 11 30W)						
JUL 1987 22...	17,000	17,000	8,700	8,600	10,000	12,000
OCT 26...	13,000	13,000	4,200	3,400	4,700	4,800
JUN 1988 06...	7,600	7,800	1,400	1,300	3,200	3,200
OCT 04...	11,000	12,000	2,000	2,200	4,200	4,200
03160050 QQ-1 LEADING C NR MIDDLEPORT OH (LAT 39 00 31N LONG 082 05 07W)						
JUL 1987 21...	360	30	370	30	810	670
OCT 27...	20	<10	70	30	1,300	1,200
JUN 1988 08...	90	20	170	50	270	270
OCT 05...	190	20	340	110	1,800	1,600

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Instantaneous discharge (ft^3/s)	Specific conductance ($\mu S/cm$)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
03160105 S-2 CAMPAIGN C NR GALLIPOLIS OH (LAT 38 53 51N LONG 082 11 31W)							
JUL 1987							
20...	0.04	700	7.7	29.0	--	78	160
OCT							
27...	0.01	1,000	7.0	11.0	--	93	91
JUN 1988							
07...	0.18	570	7.7	29.5	--	75	150
OCT							
05...	0.0	--	--	--	--	--	--
03201988 S-1 L RACCOON C NR VINTON OH (LAT 38 57 11N LONG 082 21 56W)							
JUL 1987							
22...	8.8	730	4.4	24.5	28	0	320
OCT							
27...	1.5	835	6.4	9.0	0	31	310
JUN 1988							
06...	6.9	580	6.4	20.5	5.0	5	250
OCT							
06...	0.70	701	7.1	10.5	--	98	270
382715082242400 T-2 INDIAN GUYAN C NR BRADRICK OH (LAT 38 27 15N LONG 082 24 24W)							
JUL 1987							
20...	2.6	550	7.8	24.0	--	86	170
OCT							
28...	0.22	710	7.2	7.0	--	104	220
JUN 1988							
07...	2.1	450	7.6	20.5	--	88	120
OCT							
06...	0.41	540	7.6	13.0	--	132	130
383005082280600 T-1 SYMMES C NR GETAWAY OH (LAT 38 30 05N LONG 082 28 06W)							
JUL 1987							
20...	14	400	7.6	23.0	--	132	65
OCT							
28...	0.55	450	7.2	7.5	--	71	26
JUN 1988							
07...	7.7	348	7.2	21.0	--	59	62
OCT							
06...	0.46	290	7.4	12.5	--	123	30
385826082201800 R-1 RACCOON C AT VINTON OH (LAT 38 58 26N LONG 082 20 18W)							
JUL 1987							
22...	11	510	6.9	25.0	--	17	190
OCT							
27...	0.79	570	6.8	10.0	--	51	180
JUN 1988							
07...	21	485	6.6	22.5	--	9	180
OCT							
06...	0.58	1,300	7.3	11.5	--	85	560
390941082212200 R-2 ELK F (11-5) NR RADCLIFF OH (LAT 39 09 41N LONG 082 21 22W)							
JUL 1987							
22...	0.93	400	7.2	24.0	--	43	120
OCT							
27...	0.0	--	--	--	--	--	--
JUN 1988							
06...	1.3	330	7.0	17.5	--	34	96
OCT							
05...	0.02	625	7.1	12.0	--	51	190
392342082072000 Q-2 SUNDAY C (21-8) AT CHAUNCEY OH (LAT 39 23 42N LONG 082 07 20W)							
JUL 1987							
22...	11	1,650	3.3	25.0	137	0	75
OCT							
26...	6.5	2,250	3.0	9.5	244	0	1,100
JUN 1988							
06...	19	1,150	6.1	17.5	91	14	540
OCT							
05...	7.6	1,870	2.8	13.5	78	--	790

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Aluminum, total recoverable (µg/L as Al)	Aluminum, dissolved (µg/L as Al)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
03160105 S-2 CAMPAIGN C NR GALLIPOLIS OH (LAT 38 53 51N LONG 082 11 31W)						
JUL 1987 20...	460	50	640	90	2,400	2,400
OCT 27...	50	30	190	100	9,500	9,000
JUN 1988 07...	140	10	890	30	2,500	2,400
OCT 05...	--	--	--	--	--	--
03201988 S-1 L RACCOON C NR VINTON OH (LAT 38 57 11N LONG 082 21 56W)						
JUL 1987 22...	4,000	4,200	400	90	2,800	2,600
OCT 27...	160	20	730	350	940	940
JUN 1988 06...	100	<10	320	140	4,300	4,300
OCT 06...	70	10	710	210	280	310
382715082242400 T-2 INDIAN GUYAN C NR BRADRICK OH (LAT 38 27 15N LONG 082 24 24W)						
JUL 1987 20...	610	30	820	30	400	410
OCT 28...	50	<10	400	270	3,700	3,400
JUN 1988 07...	160	<10	570	90	490	460
OCT 06...	340	30	760	100	540	540
383005082280600 T-1 SYMMES C NR GETAWAY OH (LAT 38 30 05N LONG 082 28 06W)						
JUL 1987 20...	340	30	1,300	50	740	760
OCT 28...	20	<10	680	190	2,400	2,200
JUN 1988 07...	230	<10	1,100	120	1,000	1,000
OCT 06...	30	10	640	360	710	730
385826082201800 R-1 RACCOON C AT VINTON OH (LAT 38 58 26N LONG 082 20 18W)						
JUL 1987 22...	270	<10	520	40	700	680
OCT 27...	60	<10	810	360	1,700	1,600
JUN 1988 07...	90	<10	340	30	3,100	2,900
OCT 06...	110	20	780	120	810	820
390941082212200 R-2 ELK F (11-5) NR RADCLIFF OH (LAT 39 09 41N LONG 082 21 22W)						
JUL 1987 22...	250	20	920	130	700	720
OCT 27...	--	--	--	--	--	--
JUN 1988 06...	80	<10	770	160	2,000	1,900
OCT 05...	270	30	880	350	730	700
392342082072000 Q-2 SUNDAY C (21-8) AT CHAUNCEY OH (LAT 39 23 42N LONG 082 07 20W)						
JUL 1987 22...	240	30	570	70	40	40
OCT 26...	3,700	3,900	62,000	51,000	4,800	5,000
JUN 1988 06...	60	30	42,000	38,000	2,100	2,200
OCT 05...	1,300	1,300	13,000	12,000	3,400	3,400

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--
Continued

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
395214082054700 O-3 JONATHAN C (35-8) AT WHITE COTTAGE OH (LAT 39 52 14N LONG 082 05 47W)							
JUL 1987							
20...	5.8	1,020	8.5	28.5	--	107	350
OCT							
28...	6.8	1,970	8.4	8.5	--	72	760
JUN 1988							
07...	0.85	1,300	7.8	19.0	--	125	82
OCT							
04...	4.0	1,650	7.8	15.5	--	52	560
395337082011100 O-1 MOXAHALA C (35-9) NR DARLINGTON OH (LAT 39 53 37N LONG 082 01 11W)							
JUL 1987							
20...	26	1,300	5.4	26.5	14	6	170
OCT							
28...	20	2,350	3.9	6.5	70	0	1,000
JUN 1988							
07...	42	1,250	6.6	22.0	--	11	540
OCT							
04...	19	1,750	4.9	14.5	66	52	180
395417081323000 K-1 WILLS C AT PLEASANT CITY OH (LAT 39 54 17N LONG 081 32 30W)							
JUL 1987							
21...	2.9	1,900	8.3	29.0	--	189	900
OCT							
28...	5.9	2,600	8.2	5.0	--	242	1,200
JUN 1988							
08...	8.2	1,400	7.7	23.5	--	214	560
OCT							
04...	4.0	2,380	7.9	15.5	--	250	1,200
400117081362600 L-1 CROOKED C NR CAMBRIDGE OH (LAT 40 01 17N LONG 081 36 26W)							
JUL 1987							
21...	2.7	555	8.2	25.5	--	157	200
OCT							
27...	4.2	715	7.7	8.0	--	173	140
JUN 1988							
08...	1.0	595	7.8	20.5	--	156	110
OCT							
05...	0.39	810	7.4	12.0	--	164	860
400912082014700 M-2 LITTLE WAKATOMIKA C NR TRINWAY OH (LAT 40 09 12N LONG 082 01 47W)							
JUL 1987							
20...	8.4	1,000	7.8	24.0	--	92	470
OCT							
28...	8.2	1,700	7.6	7.5	--	88	830
JUN 1988							
06...	8.8	1,190	7.6	18.0	--	83	580
OCT							
05...	2.0	1,600	7.5	11.0	--	83	920
400920081432900 L-2 WHITE EYES C NR PLAINFIELD OH (LAT 40 09 20N LONG 081 43 29W)							
JUL 1987							
21...	4.4	720	7.6	25.0	--	84	270
OCT							
27...	5.2	820	7.4	8.0	--	84	340
JUN 1988							
08...	4.9	720	7.4	20.0	--	90	260
OCT							
05...	1.8	1,050	7.5	11.5	--	97	480
401624081363400 I-2 BUCKHORN C AT NEWCOMERSTOWN OH (LAT 40 16 24N LONG 081 36 34W)							
JUL 1987							
21...	3.8	430	7.8	24.0	--	73	170
OCT							
27..	3.4	490	7.5	8.5	--	79	100
JUN 1988							
06...	2.4	530	7.7	21.5	--	71	110
OCT							
04...	0.56	710	7.6	14.0	--	115	110

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--

Continued

Date	Alu-minum, total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)
395214082054700 O-3 JONATHAN C (35-8) AT WHITE COTTAGE OH (LAT 39 52 14N LONG 082 05 47W)						
JUL 1987 20...	170	60	2,400	<10	590	590
OCT 28...	150	90	70	20	3,900	3,800
JUN 1988 07...	50	10	170	30	190	160
OCT 04...	130	70	160	20	2,900	2,900
395337082011100 O-1 MOXAHALA C (35-9) NR DARLINGTON OH (LAT 39 53 37N LONG 082 01 11W)						
JUL 1987 20...	190	20	610	30	210	210
OCT 28...	8,600	8,900	2,100	1,500	14,000	14,000
JUN 1988 07...	520	40	340	120	16,000	14,000
OCT 04...	440	10	1,700	30	740	620
395417081323000 K-1 WILLS C AT PLEASANT CITY OH (LAT 39 54 17N LONG 081 32 30W)						
JUL 1987 21...	1,000	20	1,400	30	370	310
OCT 28...	330	<10	430	20	140	90
JUN 1988 08...	960	10	1,600	30	490	270
OCT 04...	460	40	550	50	240	190
400117081362600 L-1 CROOKED C NR CAMBRIDGE OH (LAT 40 01 17N LONG 081 36 26W)						
JUL 1987 21...	540	<10	1,000	20	360	220
OCT 27...	420	10	860	80	360	330
JUN 1988 08...	470	10	940	<10	660	570
OCT 05...	8,400	7,500	2,000	290	8,900	8,900
400912082014700 M-2 LITTLE WAKATOMIKA C NR TRINWAY OH (LAT 40 09 12N LONG 082 01 47W)						
JUL 1987 20...	160	<10	630	40	420	380
OCT 28...	80	<10	360	90	860	850
JUN 1988 06...	120	10	340	20	670	670
OCT 05...	100	<10	680	30	630	570
400920081432900 L-2 WHITE EYES C NR PLAINFIELD OH (LAT 40 09 20N LONG 081 43 29W)						
JUL 1987 21...	310	20	1,400	40	520	510
OCT 27...	160	<10	990	220	890	930
JUN 1988 08...	390	<10	1,400	30	980	960
OCT 05...	730	30	3,000	140	890	810
401624081363400 I-2 BUCKHORN C AT NEWCOMERSTOWN OH (LAT 40 16 24N LONG 081 36 34W)						
JUL 1987 21...	180	20	700	30	320	290
OCT 27...	100	320	730	410	610	570
JUN 1988 06...	120	20	550	90	520	490
OCT 04...	80	30	280	100	140	130

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--
Continued

Date	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Acidity (mg/L as $CaCO_3$)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
401716080451300	D-2 MCINTYRE C (61-3) NR SMITHFIELD OH (LAT 40 17 16N LONG 080 45 13W)						
JUL 1987							
22...	4.6	2,300	8.2	24.0	--	191	1,100
OCT							
28...	6.3	2,120	8.2	8.0	--	216	1,100
JUN 1988							
08...	6.0	2,150	7.8	20.5	--	194	1,200
OCT							
05...	1.6	2,050	8.6	11.0	--	201	1,200
401857080391700	B-2 CROSS C (61-4) NR MINGO JUNCTION OH (LAT 40 18 57N LONG 080 39 17W)						
JUL 1987							
21...	23	1,550	8.5	28.5	--	114	660
OCT							
28...	40	1,320	8.4	7.0	--	144	590
JUN 1988							
07...	21	1,500	8.1	19.5	--	138	710
OCT							
05...	6.6	1,550	8.6	10.5	--	159	850
401936082001400	J-2 SIMMONS RN NR WARSAW OH (LAT 40 19 36N LONG 082 00 14W)						
JUL 1987							
20...	2.5	700	7.9	23.5	--	112	230
OCT							
26...	0.91	1,150	7.8	6.0	--	106	530
JUN 1988							
08...	0.63	915	7.5	19.5	--	113	330
OCT							
04...	0.48	1,030	7.6	12.5	--	107	500
403426081211900	F-1 CONOTTON C NR SOMERDALE OH (LAT 40 34 26N LONG 081 21 19W)						
JUL 1987							
21...	45	445	7.6	24.0	--	81	190
OCT							
26..	22	480	7.7	8.0	--	91	120
JUN 1988							
07...	43	470	7.2	19.5	--	74	110
OCT							
05...	22	582	7.2	11.0	--	81	140
403823081213700	E-2 NIMISHILLEN CR AT SANDYVILLE OH (LAT 40 38 23N LONG 081 21 37W)						
JUL 1987							
21...	114	1,300	8.2	27.0	--	198	330
OCT							
26...	68	1,480	8.1	10.0	--	192	190
JUN 1988							
07...	80	1,250	7.7	20.0	--	200	200
OCT							
05...	54	1,530	7.9	12.5	--	213	190
410616082075500	M-1 WAKATOMIKA C NR FRAZEYSBURG OH (LAT 41 06 16N LONG 082 07 55W)						
JUL 1987							
20...	33	350	7.6	23.5	--	82	27
OCT							
28..	18	465	7.9	7.5	--	111	23
JUN 1988							
06...	18	390	7.5	18.0	--	87	38
OCT							
05...	10	490	7.6	12.0	--	105	23

Table 21.--Water-quality data for long-term surface-water sites, 1987-88--Continued

Date	Alu-minum, total recov-erable (µg/L as Al)	Alu-minum, dis-solved (µg/L as Al)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Manga-nese, total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)
401716080451300 D-2 MCINTYRE C (61-3) NR SMITHFIELD OH (LAT 40 17 16N LONG 080 45 13W)						
JUL 1987						
22...	260	50	210	30	50	60
OCT						
28...	80	40	110	20	80	90
JUN 1988						
08...	100	40	120	10	90	60
OCT						
05...	60	30	110	30	70	60
401857080391700 B-2 CROSS C (61-4) NR MINGO JUNCTION OH (LAT 40 18 57N LONG 080 39 17W)						
JUL 1987						
21...	620	150	450	20	130	100
OCT						
28...	230	30	90	20	150	130
JUN 1988						
07...	300	70	180	10	120	90
OCT						
05...	550	30	420	20	220	70
401936082001400 J-2 SIMMONS RN NR WARSAW OH (LAT 40 19 36N LONG 082 00 14W)						
JUL 1987						
20...	130	<10	460	40	170	140
OCT						
26...	30	<10	180	40	70	80
JUN 1988						
08...	220	10	480	30	770	560
OCT						
04...	240	30	550	20	290	290
403426081211900 F-1 CONOTTON C NR SOMERDALE OH (LAT 40 34 26N LONG 081 21 19W)						
JUL 1987						
21...	350	20	2,000	50	870	1,100
OCT						
26...	200	20	1,800	600	690	680
JUN 1988						
07...	300	30	1,800	80	2,600	2,700
OCT						
05...	180	20	1,400	120	1,400	1,400
403823081213700 E-2 NIMISHILLEN CR AT SANDYVILLE OH (LAT 40 38 23N LONG 081 21 37W)						
JUL 1987						
21...	150	20	670	30	130	90
OCT						
26...	70	30	450	60	100	80
JUN 1988						
07...	50	10	230	80	60	40
OCT						
05...	70	20	240	70	40	20
410616082075500 M-1 WAKATOMIKA C NR FRAZEYSBURG OH (LAT 41 06 16N LONG 082 07 55W)						
JUL 1987						
20...	110	10	450	80	590	50
OCT						
28..	60	<10	570	320	70	60
JUN 1988						
06...	280	70	1,100	230	230	170
OCT						
05...	120	40	770	260	90	100

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