# GROUND-WATER HYDROLOGY OF THE AREA BORDERING THE OHIO RIVER BETWEEN CHESTER AND WAVERLY, WEST VIRGINIA

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## CONVERSION FACTORS AND VERTICAL DATUM

| *Multiply* | *By* | *To* |
|---|---|---|
| | *Length* | |
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| | *Area* | |
| square mile ($mi^2$) | 2.590 | square kilometer |
| | *Volume* | |
| gallon (gal) | 3.785 | liter |
| million gallons (Mgal) | 3,785 | cubic meter |
| cubic foot ($ft^3$) | 0.02832 | cubic meter |
| cubic mile ($mi^3$) | 4.166 | cubic kilometer |
| acre-foot (acre-ft) | 1,233 | cubic meter |
| | *Flow* | |
| cubic foot per second ($ft^3/s$) | 28.32 | liter per second |
| gallon per minute (gal/min) | 0.06308 | liter per second |
| million gallons per day (Mgal/d) | 43.81 | cubic decimeter per second |
| | *Aquifer characteristics* | |
| gallon per minute per foot [(gal/min)/ft] | 0.207 | liter per second per meter |
| foot per day (ft/d) | 0.305 | meter per day |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day |

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°F = 1.8 \times °C + 32$$

**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 of 1929."

Chemical concentration in water is expressed in milligrams per liter (mg/L) and micrograms per liter (µg/L).

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## ABSTRACT

Ground-water reserves in West Virginia are contained in the consolidated rock underlying the State and in the alluvium bordering the Ohio and Kanawha Rivers. Ground-water use in the study area, which includes all or parts of Hancock, Brooke, Ohio, Marshall, Wetzel, Tyler, and Pleasants Counties in northern West Virginia, was at least 6.3 billion gallons in 1980. The consolidated rock (bedrock) that crops out in the study area is of Pennsylvanian or Permian age. Alluvial deposits in the study area are limited mostly to the flood plain of the Ohio River. The alluvium is not vertically homogeneous; the lower part of the deposits consists of sand and gravel of glacial outwash origin, and the upper deposits consist of clay and silt interspersed with sand stringers. In some areas, the tributary streams have deposited a gravel delta where they enter the valley of the Ohio River. In places, ground water in the alluvium has been degraded by contaminants from industrial waste. Ground water flows from the adjacent hills toward the river. The alluvium and bedrock are hydraulically connected, and the saturated zone is continuous in both rock units. The alluvium is recharged by the following sources: (1) precipitation on the flood plain, (2) inflow from fractures in the bedrock beneath and adjacent to the alluvium, (3) inflow from tributary streams through gravel deltas and bedding-plane partings, and (4) induced inflow from the river. In some ground-water samples, concentrations of iron, manganese, sulfate, arsenic, barium, mercury, and phenols exceeded recommended limits for drinking water established by the West Virginia State Board of Health. Ground-water hardness exceeded 120 milligrams per liter in 91 percent of the samples.

# 1.0 INTRODUCTION

## 1.1 Acknowledgments

The authors appreciate the cooperation of the many well owners who provided information about their wells and permitted samples of water to be taken for analysis. The cooperation of many well drillers who provided records and information also is acknowledged. Special appreciation is given to Charles Brown, Jr. and Ray Maxwell. Mr. Brown provided access to his property for drilling eight test wells and loaned equipment and materials to the authors throughout the project. Mr. Maxwell also provided access, material, and assistance on numerous occasions during the project.

## 1.2 Purpose and Scope of Report

PROTECTION OF PUBLIC WATER SUPPLY IS PRIMARY CONCERN

*The geologic and hydrologic properties of an aquifer system must be understood so it can be fully used and protected from overdevelopment and contamination.*

Most ground water in West Virginia is derived from two aquifer systems. The most widespread is the system of fractures in the consolidated rock (bedrock) that underlies the State. The other is the narrow band of alluvium that borders the Ohio and Kanawha Rivers. Both aquifer systems can be contaminated by percolation or injection of harmful materials, and both can become uneconomical for water supply by overuse.

This report describes the results of an investigation to improve understanding of the hydrologic properties of the aquifer systems in the study area. Sensible and orderly development of the ground-water resources of an area requires a thorough understanding of the geology and hydrology of the area. The adequacy of a ground-water supply can be affected by many natural and human-induced processes. An understanding of the hydrologic environment can aid in making sound decisions that would protect the ground-water resources of an area from detrimental practices.

The scope of the work included ground-water data collection from numerous sources. Selected wells in the study area were visited. Details of well construction were obtained from the owners and, where possible, depth to water was measured. If available, additional information on well construction was obtained from the driller. Water from many of the wells was analyzed for selected inorganic and organic chemical constituents. Reports from previous studies in the area were obtained, as were reports on other alluvial aquifers in and near the Ohio River drainage. Data also were obtained from the files of the U.S. Geological Survey; the West Virginia Department of Natural Resources, Division of Water Resources, and the West Virginia Department of Health. Those data, together with those collected as part of this project, were analyzed and are reported herein.

Eight test wells were drilled near Sistersville. Water-level data were obtained from all the wells, and physical water-quality data were obtained from most.

## 1.3 Location and General Features of Project Area

### PROJECT AREA IS IN NORTHERN WEST VIRGINIA AND INCLUDES ALL OR PARTS OF SEVEN COUNTIES

*The area extends from the Wood County line near Waverly northward to the Pennsylvania border.*

The project area is the West Virginia side of the Ohio River valley from the Wood County line near Waverly to the Pennsylvania border near Chester. It includes all or parts of Hancock, Brooke, Ohio, Marshall, Wetzel, Tyler, and Pleasants Counties (fig. 1.3-1).

The area is part of the highly industrialized Ohio River valley. It contains major facilities for the manufacture and processing of steel, glass, ceramics, coal products such as coke and graphite, and chemicals, as well as coal mines, coal-fired, electric-power generating plants, an oil refinery, and a natural gas processing plant. The larger population centers are in the northern panhandle of the State and include Moundsville, Wheeling, and Weirton.

The topography of the area adjacent to the flat Ohio River flood plain is the typical hilly terrain found in the dissected Appalachian Plateaus physiographic province (Fenneman and Johnson, 1946). Maximum relief of the hills is about 600 feet. The flood plain is only about 0.6 mile wide at its widest point. The elevation of the flood plain ranges from about 600 feet above sea level at Waverly to about 700 feet above sea level at Chester. The elevation of the Ohio River in the area is controlled by five locks and dams with the following pool elevations (above sea level): New Cumberland, 664 feet; Pike Island, 644 feet; Hannibal, 623 feet; Willow Island, 602 feet; and Belleville, 582 feet.

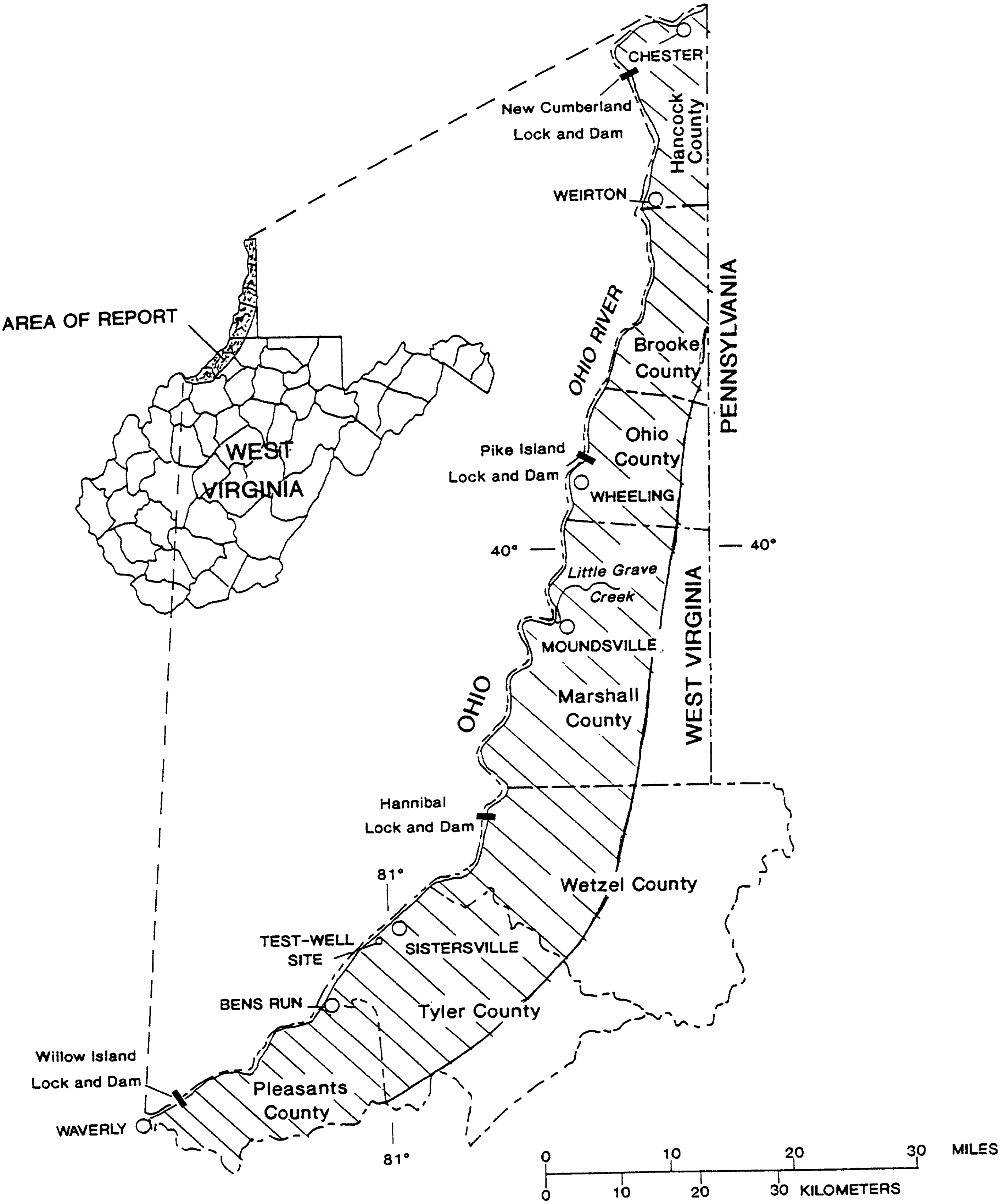


Figure 1.3-1. - - Location of project area.

## 1.4 Previous Investigations

### NUMEROUS STUDIES HAVE BEEN MADE OF THE GEOLOGY AND HYDROLOGY OF THE AREA

*The geology of the area was studied in detail in the early part of the century, and more recently, the hydrology has been studied in basinwide, countywide, and local projects.*

The geology of the study area is described in three county reports by Grimsley (1907 and 1910) and Hennen (1909), and it also is shown on the "1968 Geologic Map of West Virginia" (Cardwell and others, 1968). See figure 1.4-1.

The geologic units beneath the rocks saturated by freshwater are discussed in oil and gas reports of the counties in the project area, including those by Haught (1955a and 1955b) and Cardwell (1978).

A description of the hydrology of the entire Ohio River basin is published in the "Ohio River Basin Comprehensive Survey" (Deutsch and others, 1966; Jordan, 1966). The part of the Ohio River valley that lies in West Virginia is described in the three-part report "Geology and Economic Resources of the Ohio River Valley in West Virginia." The geology is described in Part I by Cross and Schemel (1956), and the ground-water resources are described in Part III by Carlston and Graeff (1955). An atlas by Shultz (1984) describes the geology and ground-water hydrology of the minor tributary basins of the Ohio River. The ground-water hydrology of Ohio County is described in "Occurrence and Availability of Ground Water in Ohio County, West Virginia," by Robison (1964). U.S. Geological Survey Circular 340, "Water Resources of the Wheeling-Steubenville Area, West Virginia and Ohio" by Smith and others (1955) describes both the surface-water and ground-water resources of that area.

Numerous reports that discuss the geology and hydrology of alluvial aquifers outside this project area are available. Some are listed as selected references in this report (section 7.0). Among the most noteworthy are: Gallaher and Price (1966), Crain (1966), Rorabaugh (1946 and 1948), Norris and Fidler (1969), Whitesides and Ryder (1969), Grubb and Zehner (1973), Jeffords (1945), and Norris and Eagon (1971).

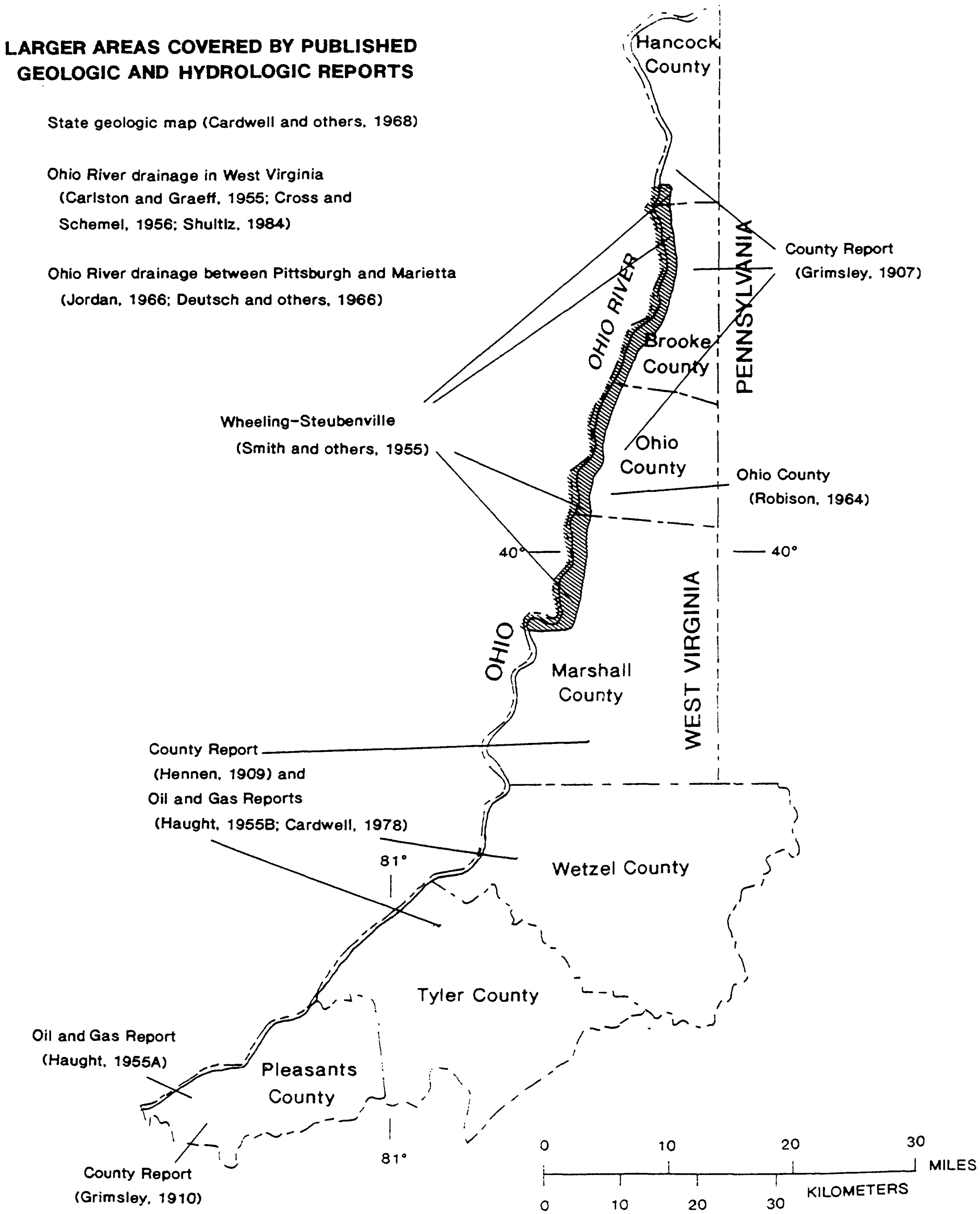


Figure 1.4-1. - - Areas covered by published geologic and hydrologic reports (see selected references for complete citations).

## 1.5 Climate and Recharge

### POTENTIAL FOR RECHARGE VARIES SEASONALLY

*The potential for recharge to the ground-water reservoir is greater during winter and spring.*

Potential for recharge to the ground-water reservoir is greater from November through April than during the rest of the year because precipitation is significantly greater than evapotranspiration during these months. Hydrographs of two wells near Sistersville (fig. 3.1-1) show that the ground-water level is higher during this period. Mean monthly precipitation was at least 1 in. greater than estimated mean monthly evapotranspiration for each of these months (table 1.5-1). Mean monthly precipitation slightly exceeded mean monthly evapotranspiration in May and October and was less than mean monthly evapotranspiration in June, July, August, and September. Mean annual evapotranspiration was estimated to be 27.70 in. Both monthy and annual evapotranspiration were estimated using the Munson P.E. Index method described in Munson (1966).

Recharge from precipitation also varies seasonally because of variations in the form and rate of precipitation, in the condition of the ground surface, and in the density of the forest canopy. During winter and early spring, precipitation is usually less intense and more widespread; thus, it is more conducive to recharge than summer thunderstorms of greater intensity and smaller coverage which are more conducive to runoff. If there is a snow pack, melting often increases soil moisture, except when the ground is frozen. Figure 1.5-1 shows the mean monthly and mean annual precipitation for four locations.

Forest areas reduce the water available for recharge because trees intercept precipitation before it hits the ground, and the ground covering of leaves or litter absorbs a large amount of moisture. Based on two formulas given in Chang and others (1976, p. 78), the forest canopy intercepts 13 to 22 percent of the precipitation. More precipitation is intercepted from May through October when the leaf canopy is full than from November through April. Although the Ohio River flood plain does not have a significant amount of forest area, the adjacent hills are covered mostly by deciduous and mixed forest.

*Table 1.5-1.--Mean monthly precipitation and evapotranspiration*

| Month | Mean monthly precipitation (inches) *a,c* | Mean monthly evapotranspiration (inches) *b,c* | Precipitation minus evapotranspiration (inches) |
|---|---|---|---|
| January | 2.84 | 0.27 | 2.57 |
| February | 2.43 | .50 | 1.93 |
| March | 3.58 | 1.21 | 2.37 |
| April | 3.59 | 2.20 | 1.39 |
| May | 3.81 | 3.48 | -.33 |
| June | 3.85 | 4.18 | -.33 |
| July | 4.22 | 4.95 | -.73 |
| August | 3.83 | 4.42 | -.59 |
| September | 3.02 | 3.09 | -.07 |
| October | 2.60 | 1.92 | .68 |
| November | 2.54 | 1.00 | 1.54 |
| December | 2.70 | .48 | 2.22 |

*a* Modified from National Oceanic and Atmospheric Adminstration (1982) for period 1951-80.

*b* Calculated using Munson P.E. Index (Munson, 1966) for period 1951-80.

*c* Mean of four sites shown in figure 1.5-1.

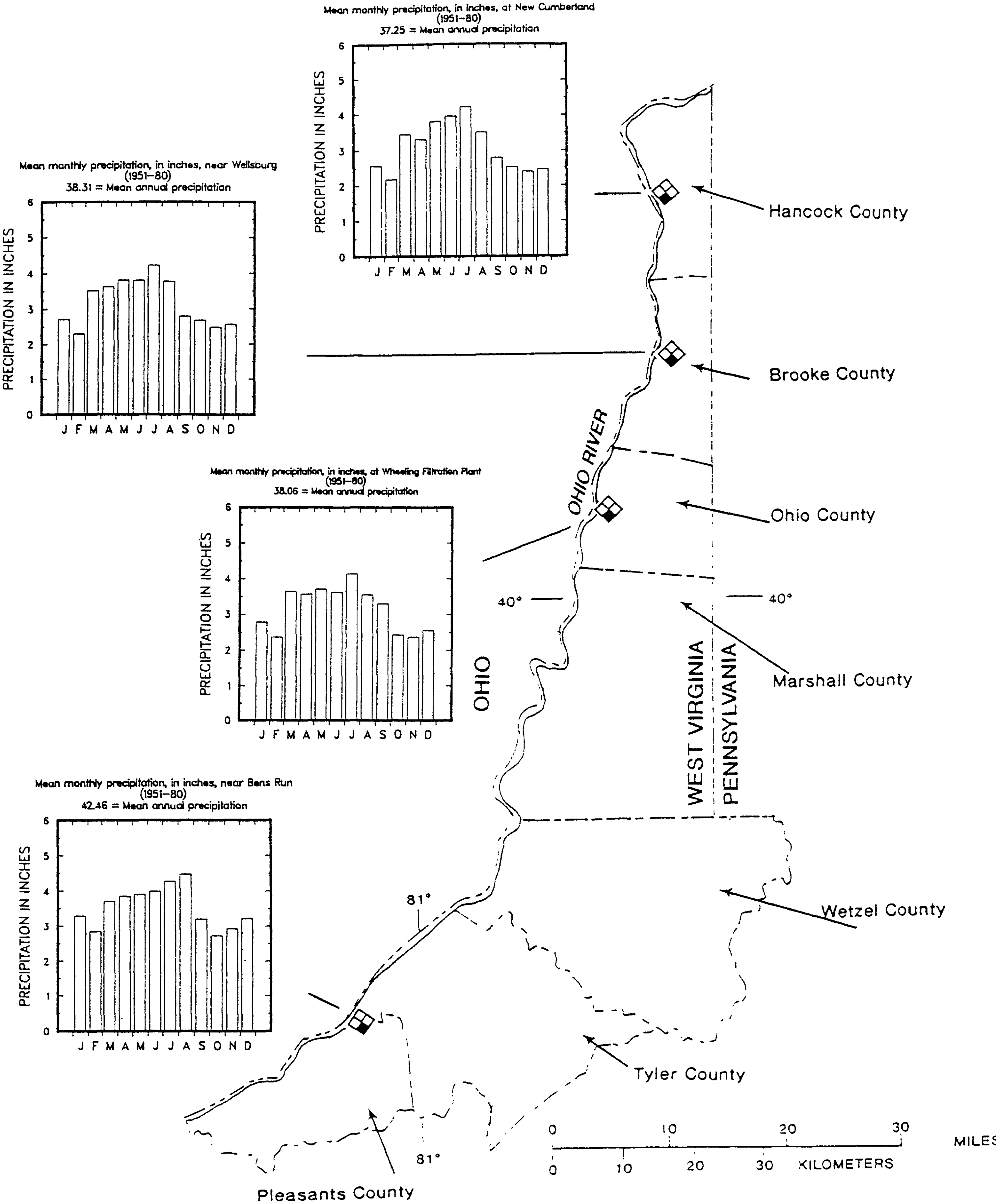


Figure 1.5-1. - - Mean monthly precipitation (1951-80).

## 1.6 Ground-Water Use

### MORE THAN 6.3 BILLION GALLONS OF GROUND WATER PUMPED IN 1980

*Ground water in the seven-county project area is withdrawn for public supply, industry, mining, and domestic use.*

Ground-water use in Hancock, Brooke, Ohio, Marshall, Wetzel, Tyler, and Pleasants Counties was at least 6.3 billion gallons in 1980 for public supply, mining, and domestic purposes according to Stevens and Lessing (1982) (fig. 1.6-1). This includes the entire county areas, but does not include industrial use, for which data are not available.

Nearly 4.0 billion gallons of ground water were withdrawn for public supply in 1983. This does not include pumpage by the smaller facilities supplying mobile-home parks or other small communities. Figure 1.6-2 shows the location of major public-supply wells.

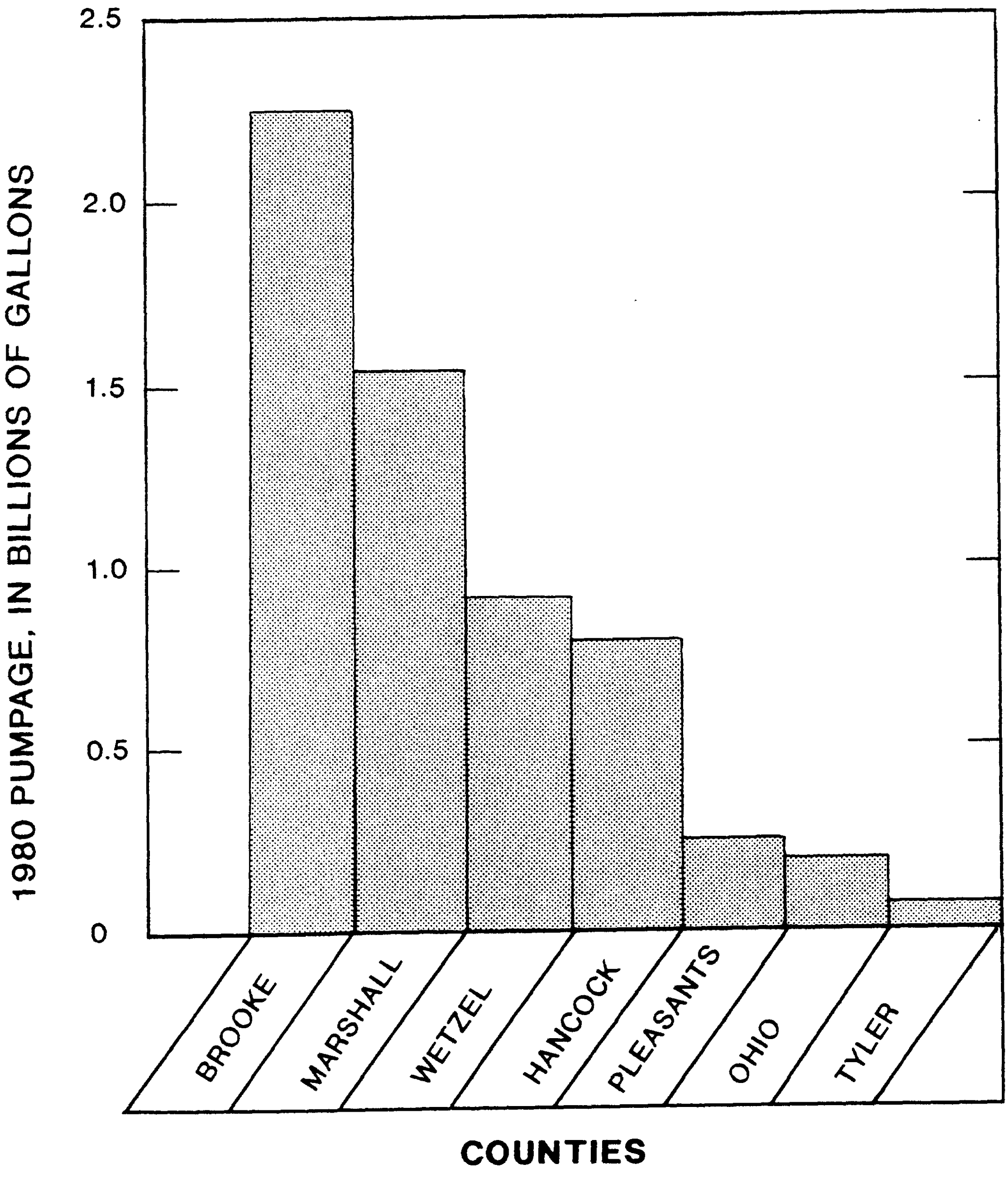


Figure 1.6-1. - - Ground-water withdrawals by county, excluding industrial use.

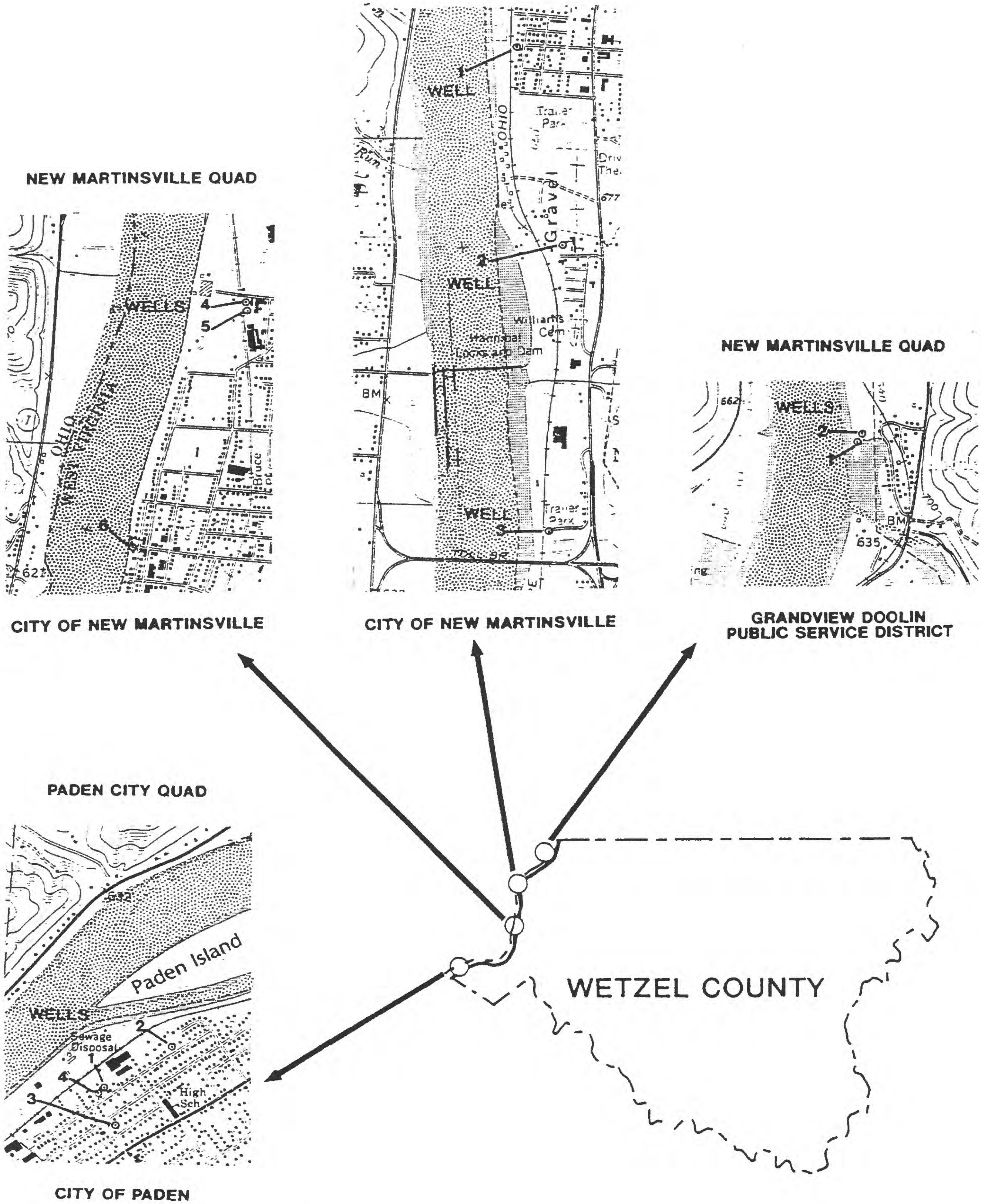


Figure 1.6-2. - - Location of public-supply wells.

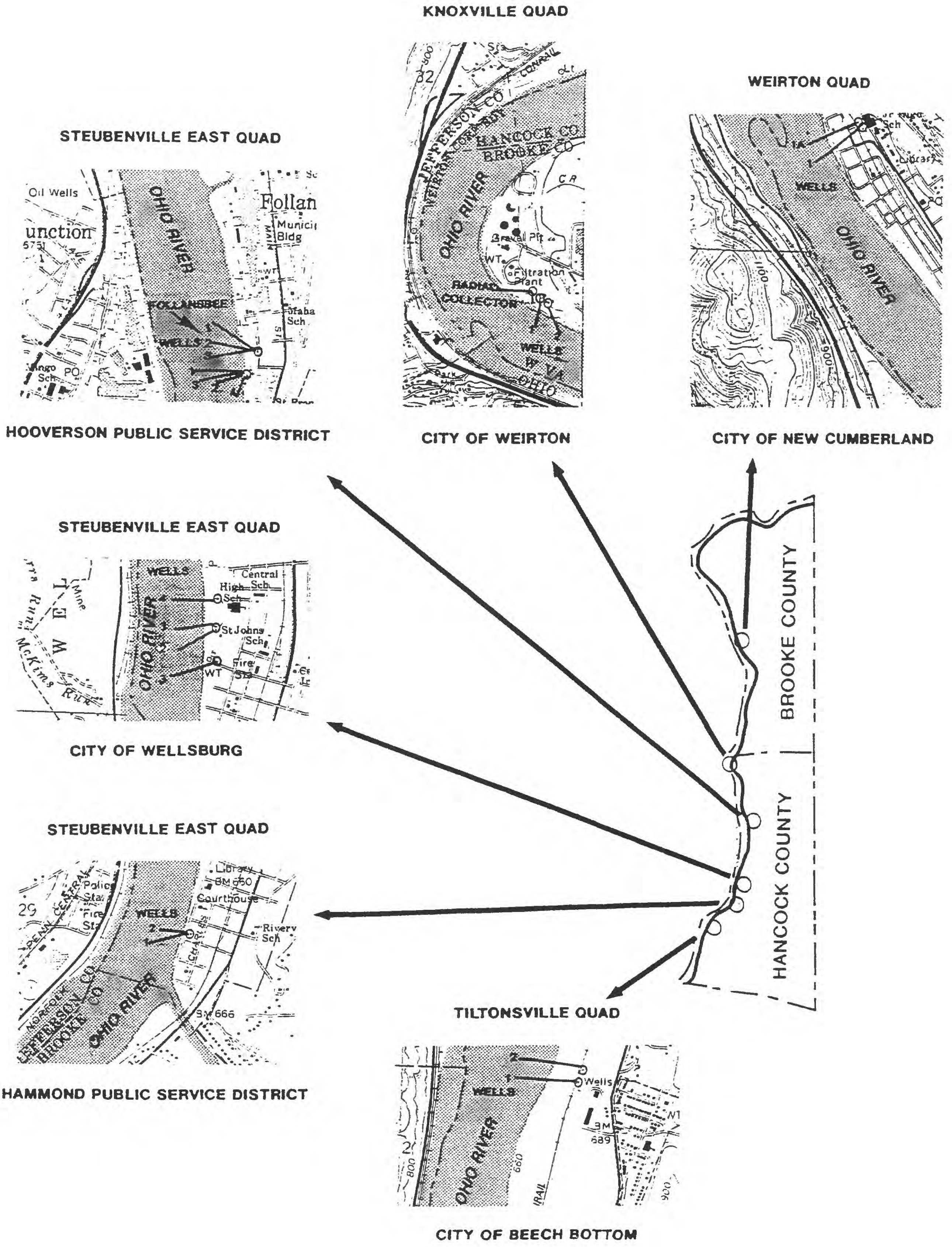


Figure 1.6-2. - - Location of public-supply wells (continued).

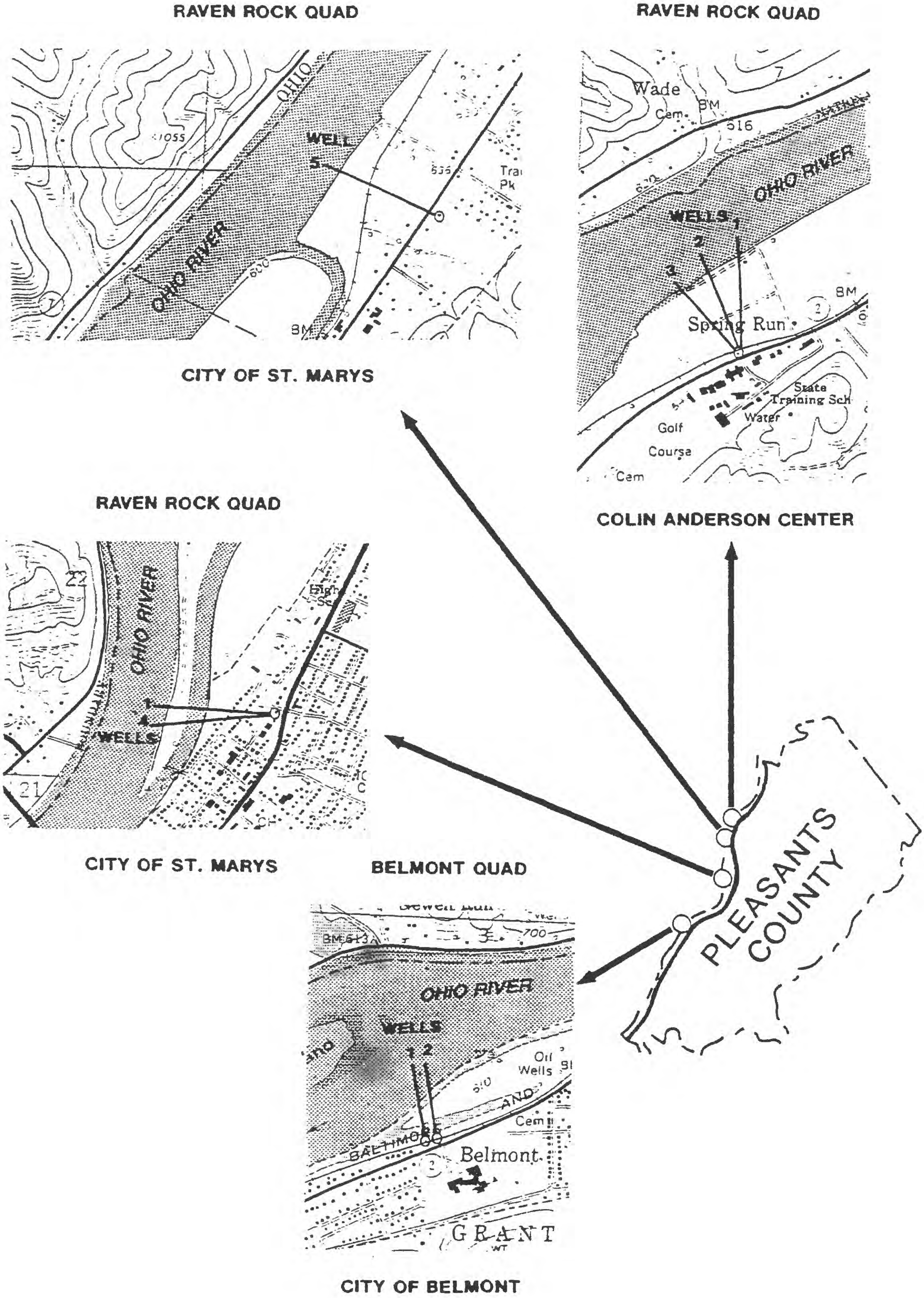


Figure 1.6-2. - - Location of public-supply wells (continued).

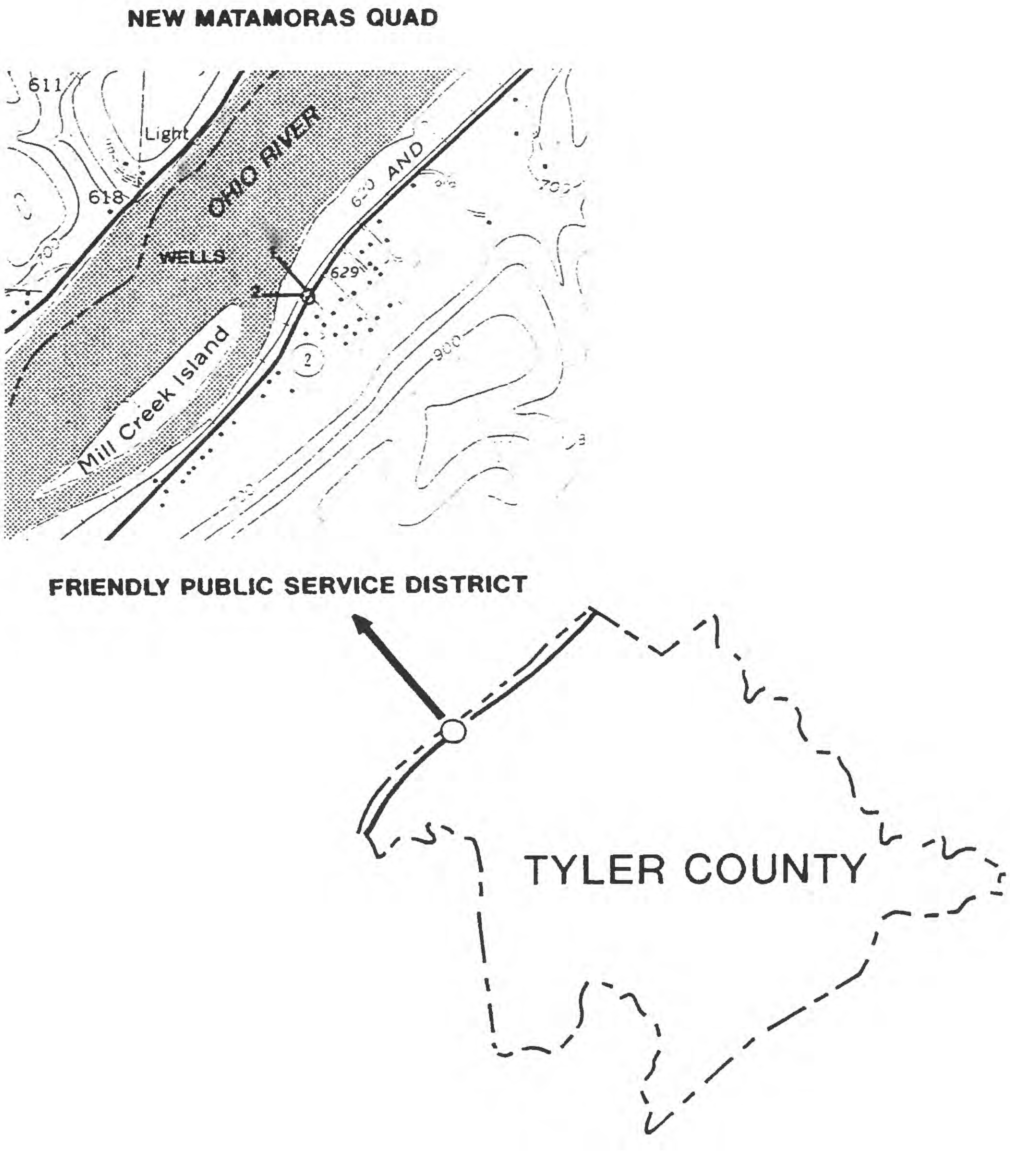


Figure 1.6-2. - - Location of public-supply wells (continued).

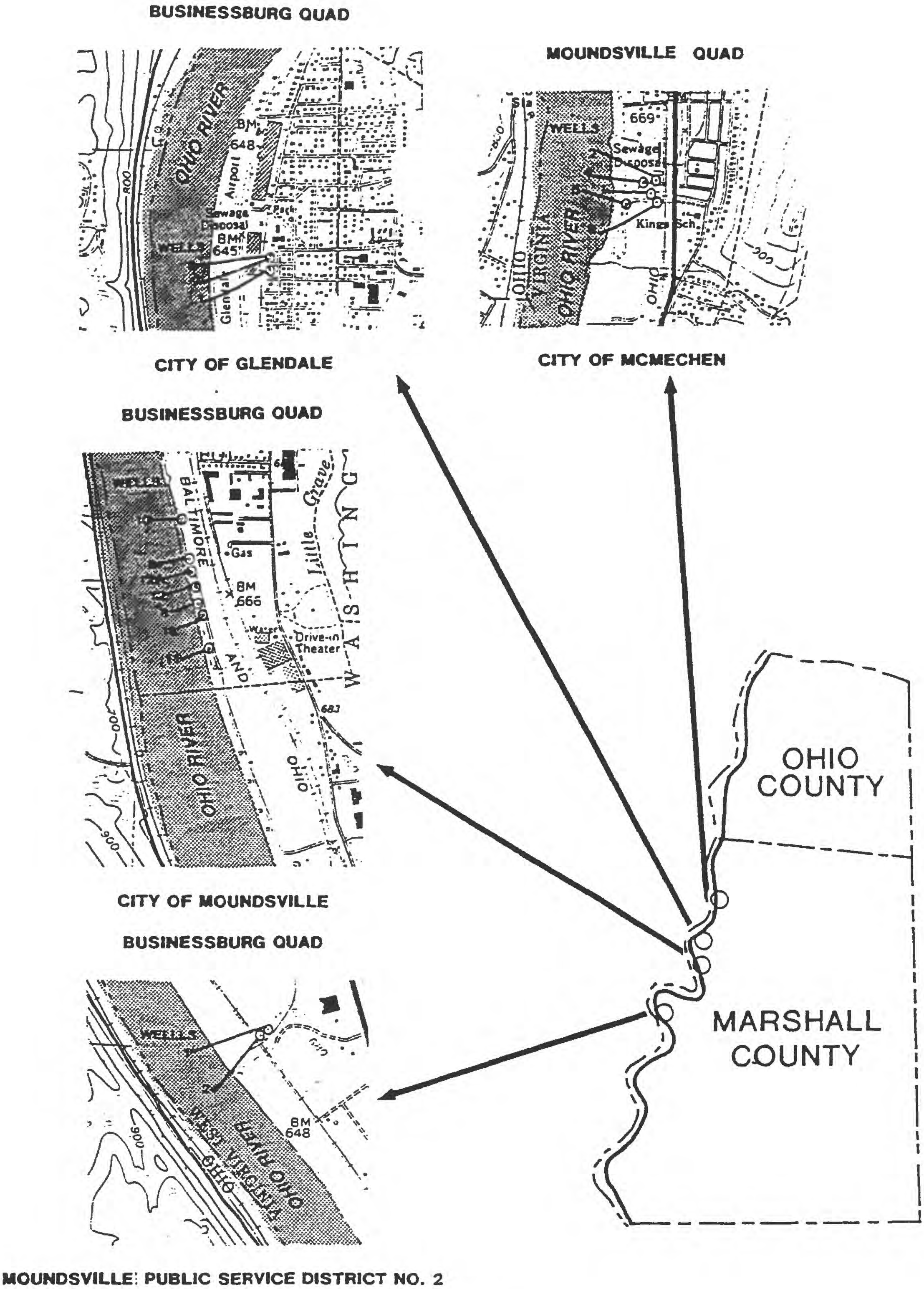


Figure 1.6-2. - - Location of public-supply wells (continued).

# 2.0 GEOLOGY AND WATER-BEARING CHARACTERISTICS

## 2.1 Consolidated Sedimentary Rocks

### AREA IS UNDERLAIN BY SEDIMENTARY ROCKS

*Most of the study area is underlain by sedimentary rocks of Pennsylvanian and Permian age.*

The oldest rock unit exposed in the area is the Allegheny Formation of Pennsylvanian age. It is exposed in the valleys and on the lower hillsides in the extreme northern part of the Hancock County and along the axis of the Burning Springs anticline in Pleasants County.

The Conemaugh Group of Pennsylvanian age, which overlies the Allegheny Formation, is the predominant unit exposed in Hancock County and also is exposed on the lower slopes and in the valleys in Brooke County and western Ohio County and along the Burning Springs anticline in Pleasants County.

The Monongahela Group of Pennsylvanian age, overlies the Conemaugh Group and is exposed on the hills in northern Brooke County and in the valleys in Pleasants, Marshall, and Ohio Counties. In Tyler and Wetzel Counties, it is exposed in a few places along the Ohio River.

The Dunkard Group of Pennsylvanian and Permian age, overlies the Monongahela Group and is exposed over most of the area. The major exceptions are all of Hancock County and the northern half of the Brooke County and a narrow band along the Burning Springs anticline in Pleasants County.

Cardwell and others (1968, geologic map) describe the above lithology. The stratigraphic nomenclature used in this report follows the usage of the West Virginia Geological and Economic Survey and does not necessarily conform to that used by the U.S. Geological Survey.

The only major geologic structure in the project area is the north-trending Burning Springs anticline in the western part of Pleasants County. "The structural relief of this anticline is fully 1,800 feet" (Haught, 1955a), bringing rocks of the Allegheny Formation to the surface along its axis. The other structural features in the project area are gentle anticlines and synclines with minor structural relief.

The yield of water from wells that tap the consolidated rock units is typically low, ranging from less than 1 to as much as 300 gal/min. The median yield is about 6 gal/min. The mean specific capacity of wells drilled in the consolidated rocks is about 0.5 (gal/min)/ft of drawdown. Most of the ground water withdrawn from the consolidated sedimentary rocks is derived from secondary permeability features such as bedding-plane partings and fractures.

## 2.2 Unconsolidated Alluvial Deposits

### THE ALLUVIUM, WHICH IS MORE THAN 100 FEET THICK IN SOME PLACES, PROVIDES CONSIDERABLE GROUND-WATER STORAGE

*The alluvial deposits of Quaternary age are limited mostly to the flood plain of the Ohio River but contain an estimated 50 billion gallons of ground water.*

The alluvium is limited mostly to the flood plain of the Ohio River and ranges in thickness from 0 feet along the hillsides to more than 100 feet in some places near the river. The lower part of the alluvial deposits consists of sand and gravel of glacial outwash origin (Deutsch and others, 1966) and is overlain by a layer of clay and silt of fluvial origin as thick as 30 to 40 feet (fig. 2-2-1). The clay and silt layer contains sand stringers. On the basis of drillers' logs of some test wells near Sistersville, the clay-silt layer thins toward the hills (fig. 2.2-2). In some areas, tributary streams have deposited a gravel delta on the alluvial deposits described above where they enter the valley of the Ohio River. The gravel deltas are in probable hydrologic continuity with the gravel in the Ohio River valley. This situation is believed to be similar to that in southwestern New York described by Crain (1966).

In some localities, the alluvium has been covered with fill such as slag from steel-processing plants, waste from coal mines, or other locally derived waste. This material ranges in thickness from a few inches to 25 feet or more and may contain soluble constituents that could be leached by water percolating to the water table.

The amount of water in storage in the alluvium of the project area can be estimated if certain assumptions are made. The areal extent of the alluvium is estimated to be about 32 square miles. The mean thickness of the saturated sand and gravel aquifer is estimated to be about 36 feet as determined from well logs and water-level measurements. This amounts to about 0.2 cubic mile of saturated aquifer, or about 740,000 acre-feet. **Specific yield**[1] is assumed to be 20.5 percent, based on the **porosity** and **specific retention** of typical sand and gravel aquifers (Heath, 1983). Consequently, the amount of water in storage in the alluvial aquifer within the project area is approximately 152,000 acre-feet or 50 billion gallons.

The ground water in the alluvium is generally in a water-table (**unconfined**) condition. In some localities where the gravel is relatively thin and the overlying clay-silt layer is relatively thick, **semiconfined** conditions may exist. These conditions are more common at higher river stage. **Perched** water has also been reported in fill overlying the alluvium.

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[1] Words that appear in **bold** are found in the "Definition of Terms" section.

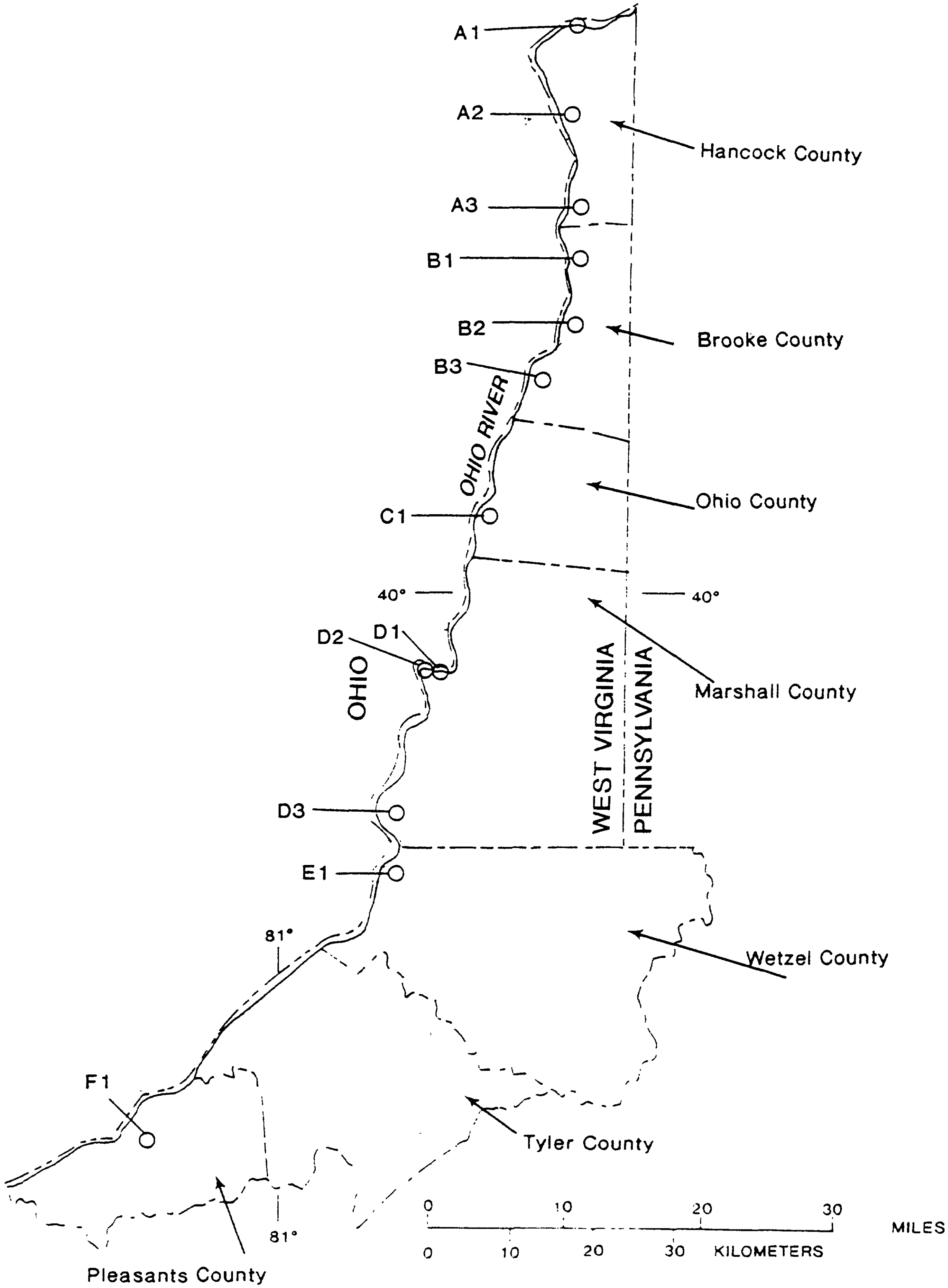


Figure 2.2-1. - - Drillers' logs of selected wells in the alluvium (Carlston and Graeff, 1955).

DEPTH (feet)

| A1 | |
|---|---|
| Fill | 0 - 25 |
| Sand and gravel | 25 - 30 |
| Sand and gravel, some clay | 30 - 83 |
| Bedrock | 83 - |

| A2 | |
|---|---|
| Sand, gravel and boulders | 0 - 33.9 |
| Clay (bedrock) | 33.9 - |

| A3 | |
|---|---|
| Sand, gravel, and boulders | 0 - 37.2 |
| Soft shale (bedrock) | 37.2 - |

| B1 | |
|---|---|
| Ashes | 0 - 15 |
| Yellow clay and sand | 15 - 30 |
| Clay, sand, and stones | 30 - 35 |
| Hard clay and sand | 35 - 38 |
| Clay and stones | 38 - 44 |
| Gravel, 7% clay | 44 - 46 |
| Gravel | 46 - 55 |
| Gravel, 4% clay | 55 - 60 |
| Gravel, 7% clay | 60 - 65 |
| Bedrock | 65 - |

| B2 | |
|---|---|
| Loam | 0 - 3 |
| Dry sand, dirt, and gravel | 3 - 27 |
| Coarse sand, gravel, and boulders | 27 - 82 |

| B3 | |
|---|---|
| Cinders and clay | 0 - 15 |
| Clay | 15 - 20 |
| Sand | 20 - 30 |
| Clay and stones | 30 - 35 |
| Gravel and sand | 35 - 55 |
| Sand | 55 - 60 |
| Sand and gravel | 60 - 74 |
| Rock | 74 - |

| C1 | |
|---|---|
| Silt and fine sand | 0 - 8 |
| Coarse gravel, fine sand | 8 - 16 |
| Coarse gravel, boulders, and fine sand | 16 - 26 |
| Coarse gravel, medium sand, and boulders | 26 - 37 |
| Medium gravel, medium sand | 37 - 46.3 |
| Shale (bedrock) | 46.3 - |

Figure 2.2-1. - - Drillers' logs ... (continued).

DEPTH (feet)

| D1 | |
|---|---|
| Sandy clay | 0 - 22 |
| Clay, sand, and gravel | 22 - 33 |
| Silt, sand, and gravel | 33 - 40 |
| Sand and gravel | 40 - 72 |

| D2 | |
|---|---|
| Clay | 0 - 8 |
| Clay and sand | 8 - 31 |
| Clay, sand, and gravel | 31 - 40 |
| Gravel and sand | 40 - 75 |
| Bedrock | 75 - |

| D3 | |
|---|---|
| Sand, yellow clay | 0 - 7 |
| Clay-bound, mixed gravel | 7 - 16 |
| Coarse gravel and cobbles | 16 - 20 |
| Very coarse gravel and cobbles | 20 - 27 |
| Coarse sand, pea gravel and scattered medium and coarse gravel | 27 - 33 |
| Fine and medium sand, pea gravel scattered medium gravel | 33 - 35 |
| Medium and coarse sand, pea gravel, and scattered medium and coarse gravel | 35 - 45 |
| Coarse sand, pea gravel, and scattered medium gravel | 45 - 50 |
| Coarse sand, pea gravel, medium gravel, and scattered coarse gravel | 50 - 55 |
| Fine to coarse sand, with pea gravel and scattered medium gravel (heaved strongly at 63 feet) | 55 - 65 |
| Medium and coarse sand, pea gravel, and medium gravel | 65 - 70 |
| Coarse sand, pea gravel, medium gravel, and occasional boulders | 70 - 86.8 |
| Blue-green shale (bedrock) | 86.8 - |

| E1 | |
|---|---|
| Topsoil | 0 - 4 |
| Sand and gravel and clay | 4 - 24 |
| Fine gravel and sand | 24 - 44 |
| Coarse gravel and sand | 44 - 59 |
| Bedrock | 59 - |

| F1 | |
|---|---|
| Clay | 0 - 15 |
| Sandy loam | 15 - 55 |
| Sand and gravel | 55 - 75 |
| Rock | 75 - |

Figure 2.2-1. - - Drillers' logs ... (continued).

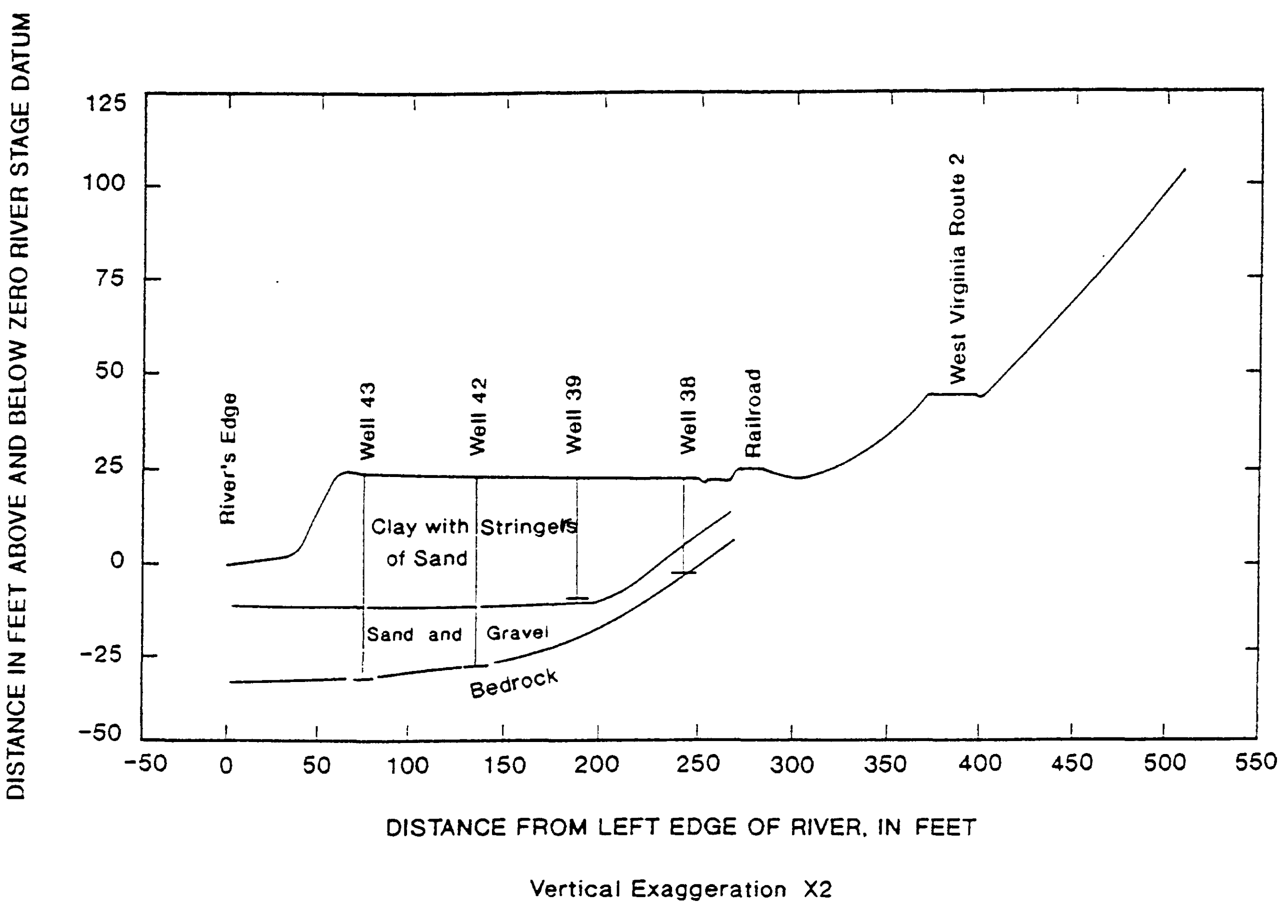


Figure 2.2-2. - - Geologic section of alluvium at the Sistersville section.

## 3.0 GROUND-WATER SYSTEM

### 3.1 Recharge, Movement, and Discharge

### RECHARGE TO THE ALLUVIUM IS DERIVED FROM SEVERAL SOURCES

*Sources of recharge to the aquifer are infiltration of precipitation through the clay-silt layer, inflow through fractures and bedding-plane partings in the bedrock beneath and adjacent to the alluvium, inflow from tributary streams through gravel deltas, and induced inflow from the river.*

Part of the precipitation that falls on the surface of the alluvium, as well as some of the overland flow from the bedrock highlands, percolates through the clay-silt layer to recharge the sand and gravel deposits of the alluvium. Although the clay-silt layer overlying the sand and gravel was originally believed to be nearly impermeable (Carlston and Graeff, 1955), water-quality data indicate that water does percolate through this layer into the more permeable sand and gravel zone. As shown by the drillers' logs in figure 2.2-1 (preceding section), the clay-silt layer is not uniform in thickness and composition; thus, the amount and rate of percolation are variable.

Further evidence of percolation through the clay-silt layer is indicated by the abnormally high concentration of sulfate in ground water beneath or near areas containing fill. This indicates that sulfate has been leached from the fill (see section 4.6).

Under natural conditions, ground water flows from the adjacent hills toward the Ohio River. The water level in wells at the Sistersville site remained slightly above the level of the river during this project. Response of the water table in the aquifer system was almost immediate when the level of the river rose or fell, as indicated by river stage and water-level fluctuations shown in figure 3.1-1. Well 43 is about 75 feet from the river's edge and does not penetrate bedrock. Well 34, open only to the bedrock, is about 120 feet downstream from well 43 and about 250 feet from the river. The hydrographs (fig. 3.1-1) indicate that the water level in both wells responds almost identically. The almost instantaneous response of the bedrock well to river-stage fluctuations indicates that the bedrock and the alluvium are hydraulically interconnected. This condition probably exists throughout the study area.

Some inflow into the alluvium occurs through fractures in the bedrock under the hillsides. The occurrence of open fractures is dependent on stress acting on the rock. Some fractures are located near anticlines (Clark and others, 1976), and a system of bedding-plane partings exists beneath the floor of the valleys (Wyrick and Borchers, 1981). Both of these fractures systems allow recharge to enter the alluvium from the adjacent bedrock.

Tributary streams flowing onto the alluvium from the hills have deposited gravel deltas at the edge of the Ohio River valley. Water flowing from these streams can percolate through the deltas to the gravel under the clay-silt layer. This phenomenon has been described by Crain (1966) in western New York State. Discharge in Little Grave Creek at Moundsville, West Virginia (see fig. 1.3-1), decreased from an estimated 10 $ft^3/s$ in the upstream bedrock area to an estimated 0.5 $ft^3/s$ downstream on the alluvial flood plain (Friel, E.A., U.S. Geological Survey, oral commun., 1984). Thus, Little Grave Creek appears to be providing considerable recharge to the alluvium.

Man's activities can change the natural ground-water flow pattern and thus affect recharge. Recharge to the alluvium from the Ohio River may occur when the aquifer close to the river is pumped heavily and the ground-water level is drawn below the river level. This recharge is limited to the alluvial area between the river and pumped well. However, under natural conditions the water level in the aquifer is above the river in most places. Furthermore, the permeability of the streambed probably is quite low. In describing conditions in the Scioto River valley in Ohio, Norris and Fidler (1969, p. 45) state: "The vertical permeability of the streambed sediments is thus only about one-thirteenth as high as the vertical permeability measured across the full thickness of the aquifer. A layer of silt, mud, and organic debris, possibly having penetrated no more than a few inches into the underlying sediments, is thought to be chiefly responsible for the relatively low permeability of the streambed." The same conditions have been observed on the Ohio River and probably limit recharge to the alluvium from the river.

Discharge from the alluvium occurs at the riverbed and riverbank from both the saturated and unsaturated zones. Ground water from the saturated zone of the alluvium, which is comprised mostly of sand and gravel, enters the river through its bed. Discharge from the unsaturated zone occurs at the riverbank where water emerges from the thin sand layers in the upper clayey part of the alluvium. The water in that part of the unit can flow horizontally along the sand layers more easily than vertically through the clay and silt layers.

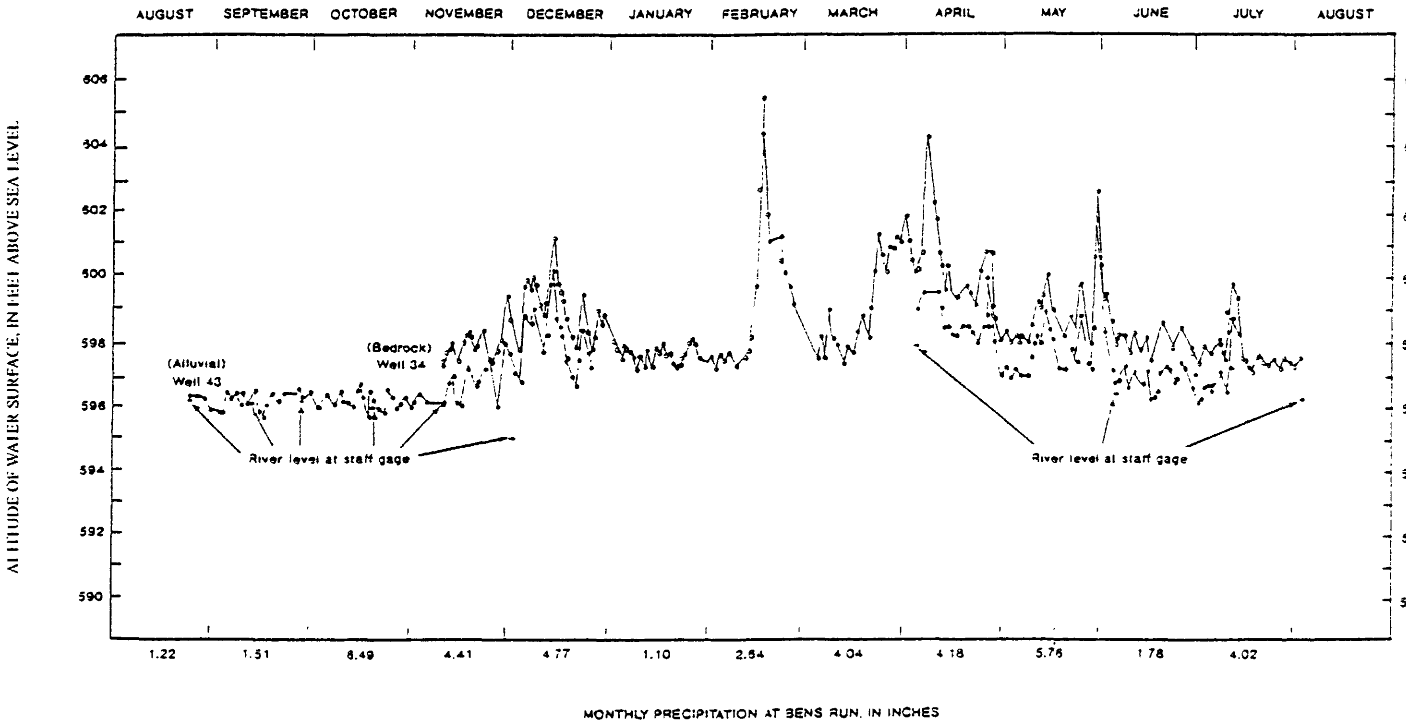


Figure 3.1-1. - - Hydrographs of two wells at Sistersville site.

## 3.2 Hydraulic Characteristics of Alluvial Aquifer

### SPECIFIC CAPACITY, SATURATED THICKNESS, TRANSMISSIVITY, AND HYDRAULIC CONDUCTIVITY WERE DETERMINED FOR THE OHIO RIVER ALLUVIUM

*The alluvium has the following hydraulic characteristics: Mean specific capacity--49 gallons per minute per foot of drawdown, mean saturated thickness of aquifer--36 feet, mean transmissity--6,300 feet squared per day, and mean hydraulic conductivity--170 feet per day.*

**Specific capacity** of 65 wells ranged from 7 to 198 (gal/min)/ft with a mean of 49 (gal/min)/ft and a median of 38 (gal/min)/ft (fig. 3.2-1). Specific capacities were obtained from well-site inventories, drillers' records, earlier studies, and consultants' reports. The specific capacities were determined for varying conditions of river stage, well efficiency, and direction of ground-water movement, as well as water-table and semiconfined aquifer conditions. Drawdown for a given yield increases as well screens become partially clogged, and thus well efficiency decreases with time. Induced infiltration from the Ohio River decreases drawdown and increases specific capacity. Some alluvial wells are capable of yielding several hundred gallons of water per minute. Yields of more than one thousand gallons per minute have been reported.

The saturated thickness of the alluvium ranged from 19 to 56 feet with a mean of 36 feet and a median of 34 feet (fig. 3.2-2). These values were obtained during various river stages, which directly affect the water level and thus the saturated thickness. The construction of locks and dams and the consequent raising of the river pools behind these dams has increased the saturated thickness of the alluvium. Saturated thickness was determined by subtracting the depth to the static water level from the depth to bedrock. The effect of confinement upon static water levels was assumed to be minimal for the purpose of estimating saturated thickness.

Estimated transmissivities ranged from 1,100 to 17,000 $ft^2/d$ with a mean of 6,300 $ft^2/d$ and a median of 5,100 $ft^2/d$ (fig. 3.2-3). **Transmissivity** gives an indication of the rate of movement of ground water. Transmissivities were estimated from the specific capacities of 32 alluvial wells with pumping tests of known duration using the following equation developed by Theis (Bentall, 1963):

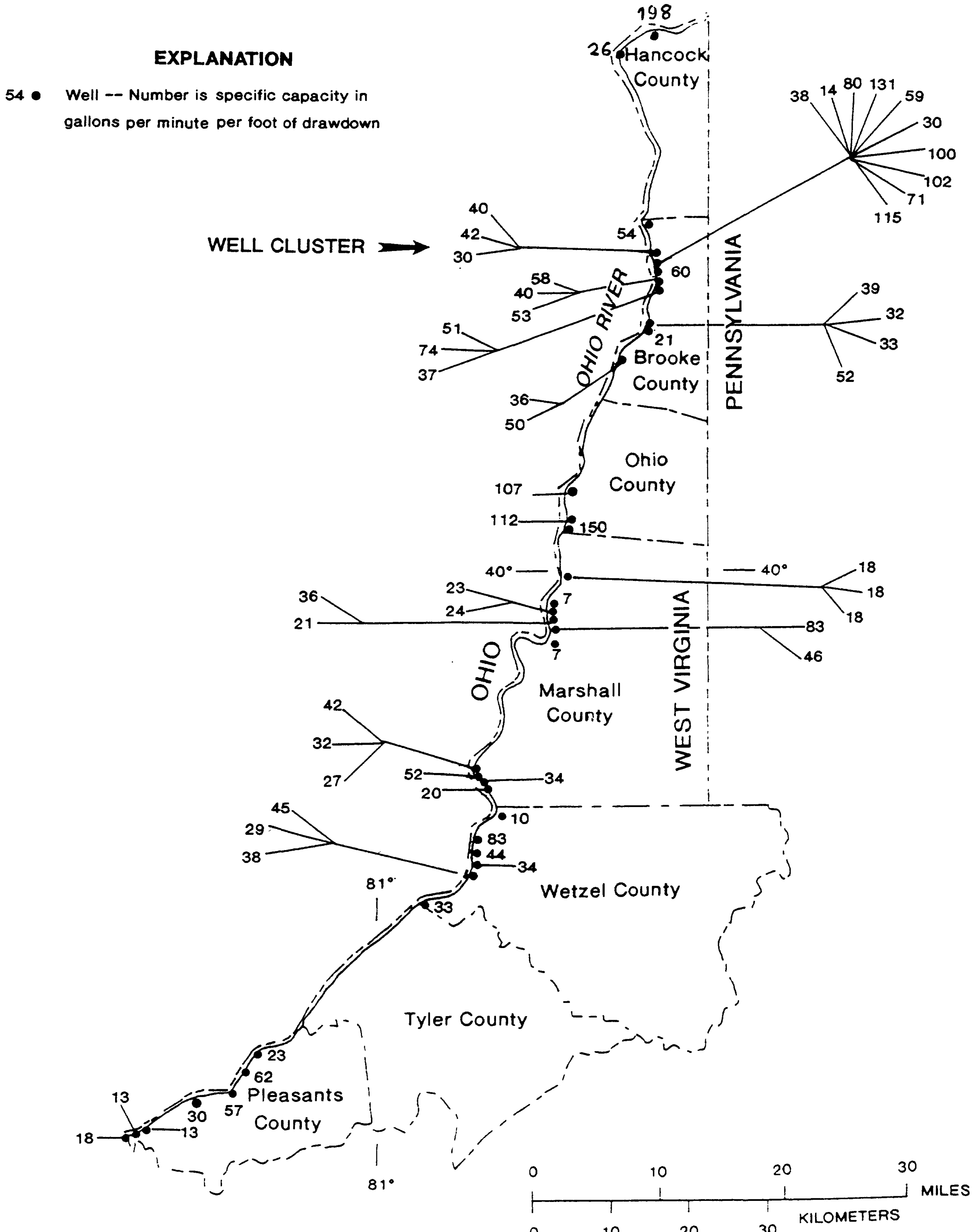


Figure 3.2-1. - - Specific capacity.

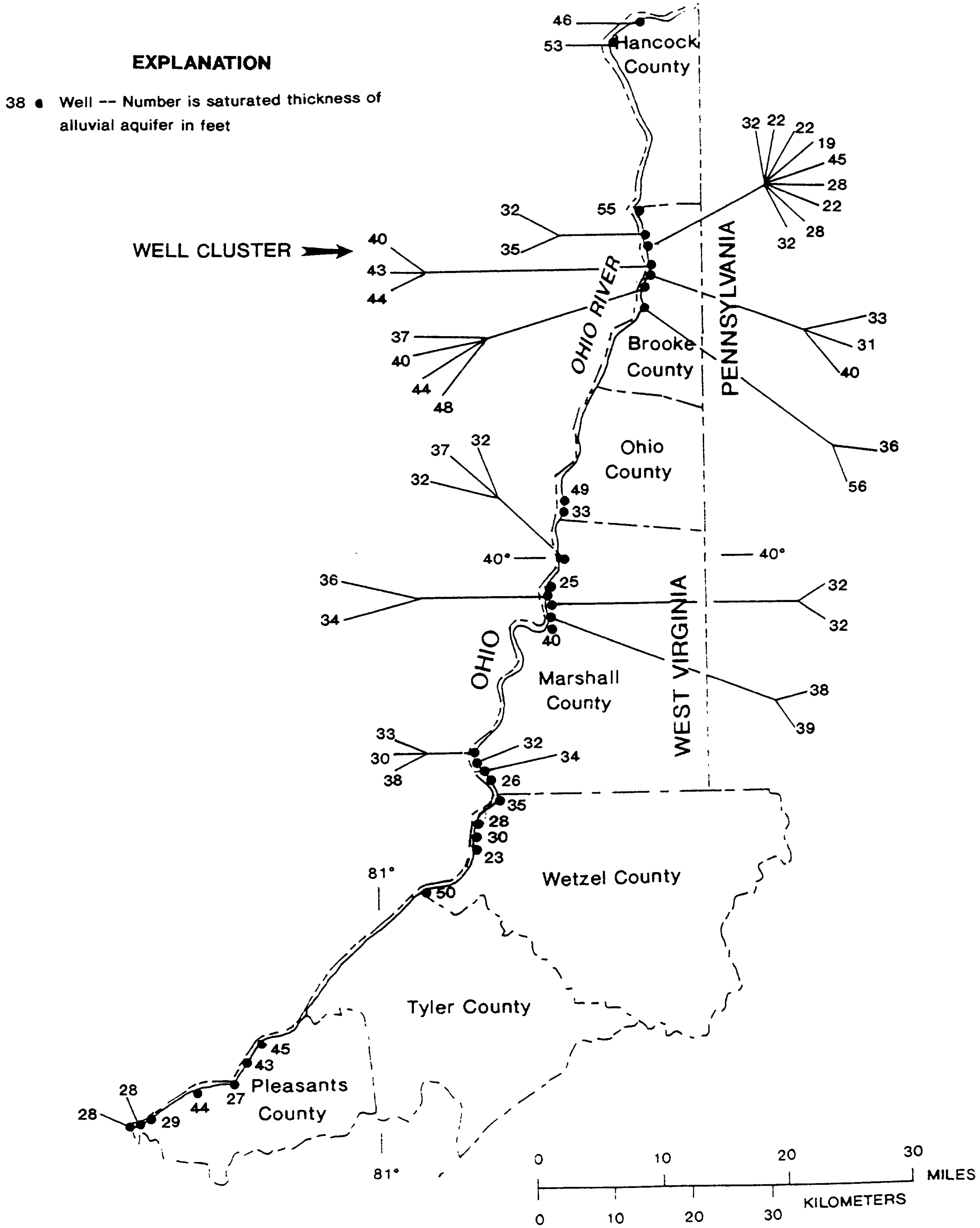


Figure 3.2-2. - - Saturated thickness of aquifer.

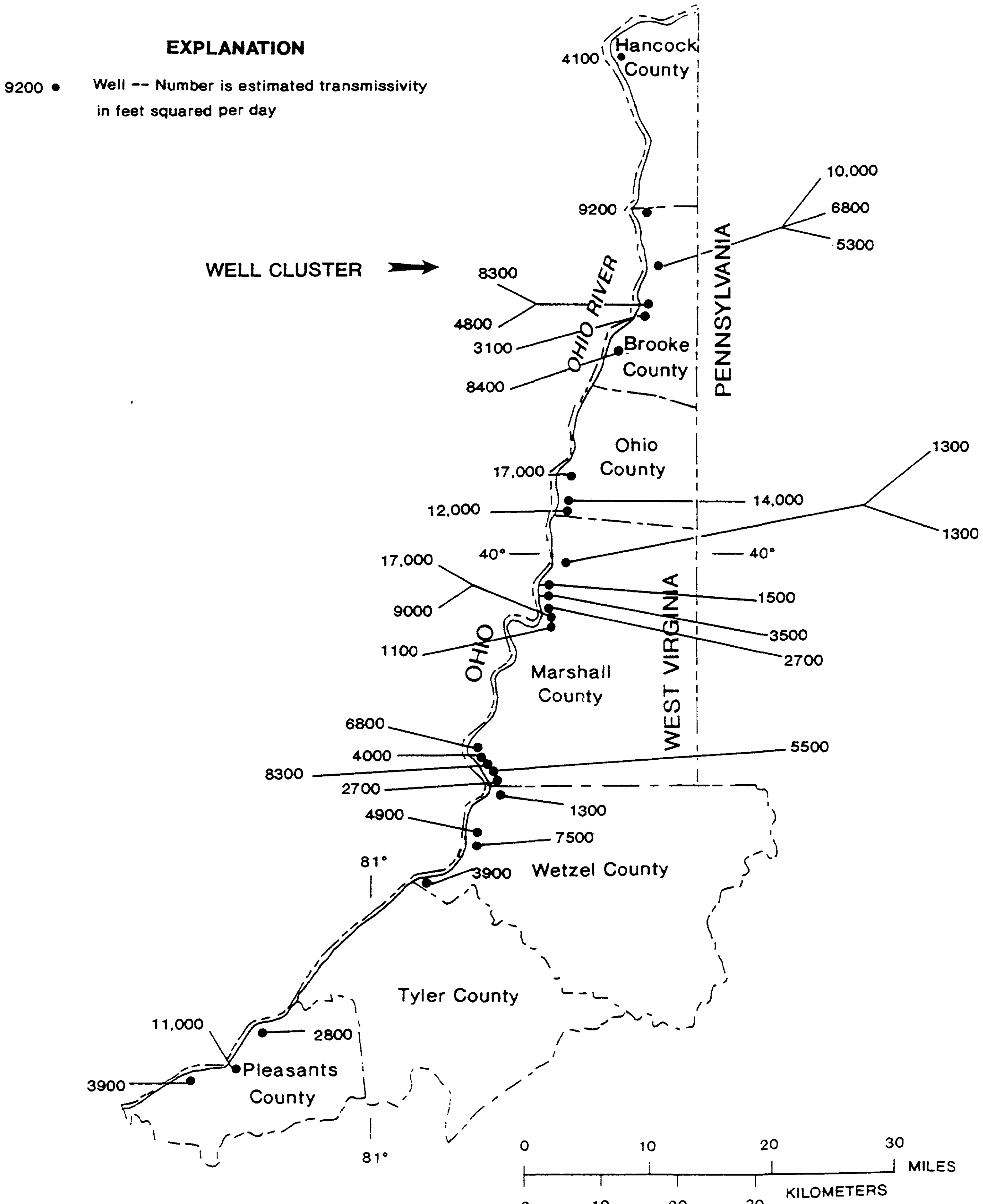


Figure 3.2-3. - - Estimated transmissivity.

$$T' = C(1 \pm 0.3)\ (1{,}300 - 264 \log_{10} 5S + 264 \log_{10} t)$$

where:
T' is an intermediate value of transmissivity,
C is the specific capacity of the pumped well,
S is the aquifer **storage coefficient**, and
t is the time, in days, that the well was pumped.

The estimated transmissivity is determined graphically from "T'" and "C". To simplify calculations, well diameter was assumed to be 1 foot, and storage coefficient was assumed to be 0.2.

Several transmissitivities reported in previous studies were much higher than those estimated in this report. Reasons for the higher reported transmissivities are (1) pumping tests of insufficient duration, (2) storage coefficients less than 0.2 in some areas, and (3) induced infiltration to the alluvium from the Ohio River.

**Hydraulic conductivity** was computed for 30 wells by dividing the estimated transmissivity by the saturated thickness. The hydraulic conductivity ranged from 27 to 460 ft/d with a mean of 170 ft/d and median of 140 (ft/d) (fig. 3.2-4). The hydraulic conductivity can be used to compute the **specific discharge** if the **hydraulic gradient** is known. Ground-water movement is in the direction of the hydraulic gradient. Under natural conditions, the hydraulic gradient dips gently from the hills to the Ohio River. The median slope of the water table at the Sistersville site was 0.001 foot/foot during the period April 1983 to November 1984. Withdrawal of large quantities of water from wells close to the Ohio River can reverse this gradient between the pumped wells and the river. The direction and slope of the hydraulic gradient is affected close to lock and dam sites where river pools of different elevations meet abruptly. Sources of recharge such as ponds, lakes, and streams on the alluvial flood plain also affect the hydraulic gradient.

All aquifer characteristics calculated in this report are variable with time and geographical location and should be used with discretion.

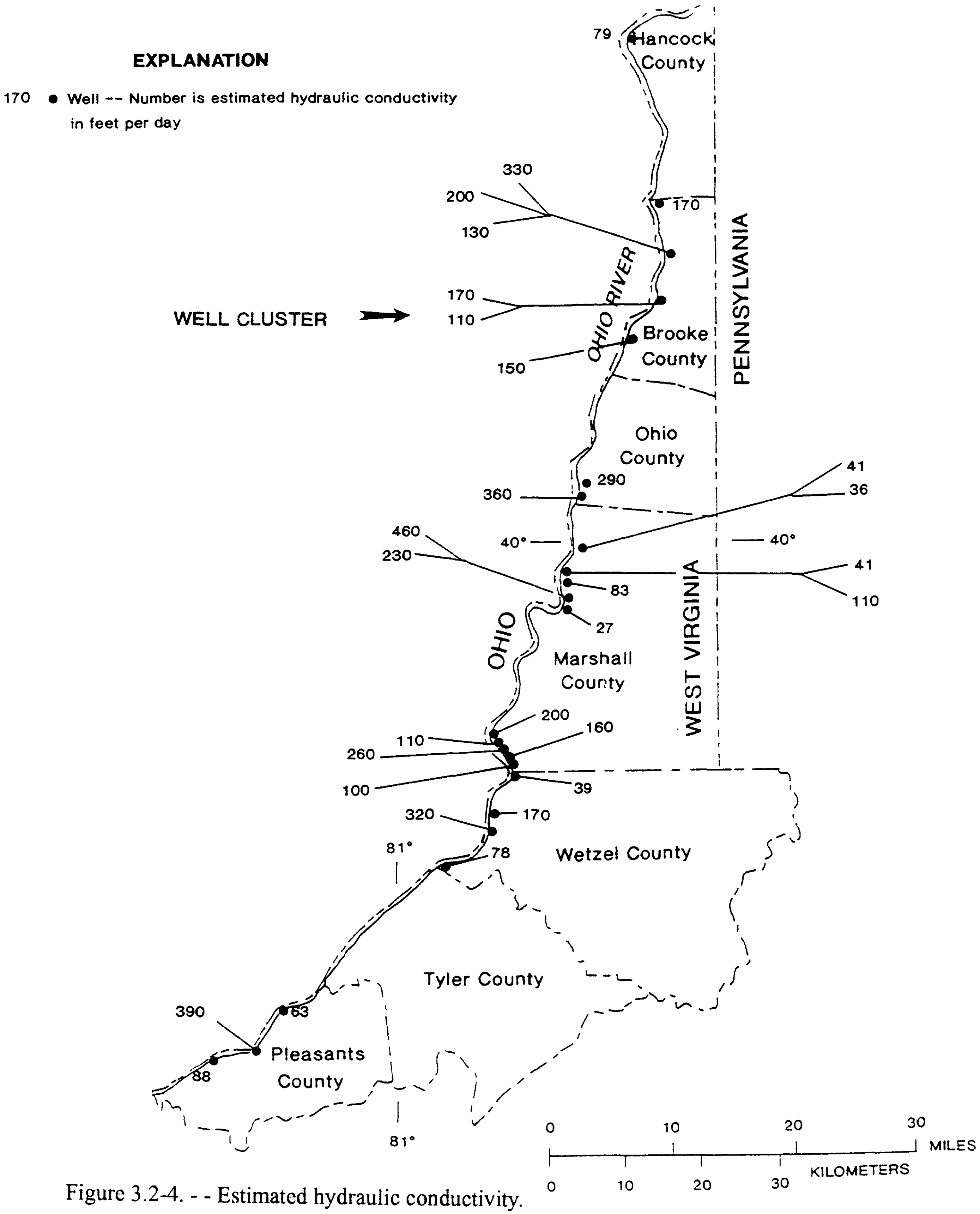


Figure 3.2-4. - - Estimated hydraulic conductivity.

# 4.0 WATER QUALITY

## 4.1 Data Collection

### GROUND-WATER SAMPLES FROM MORE THAN FIFTY WELLS WERE ANALYZED

*Water samples from alluvial wells, bedrock wells on or near the alluvial flood plain, and radial collectors were analyzed.*

More than 50 ground-water samples were analyzed during the study. Samples were collected from wells drilled into alluvium, wells drilled into bedrock, and from radial collectors with laterals extending into the alluvium and, in places, under the Ohio River. Analyses included all major cations and anions, several metals, phenols, and dissolved organic carbon. Several additional samples from bedrock wells near the alluvial flood plain were collected during a previous study (Shultz, 1984) and are incorporated into this report. These wells were sampled for major cations and anions and common metals. The locations of sampled wells are shown on figure 4.1-1. Alluvial wells are designated with an "A," bedrock wells with a "B," and radial collectors with an "R." The data collected as part of this study are in the U.S. Geological Survey files.

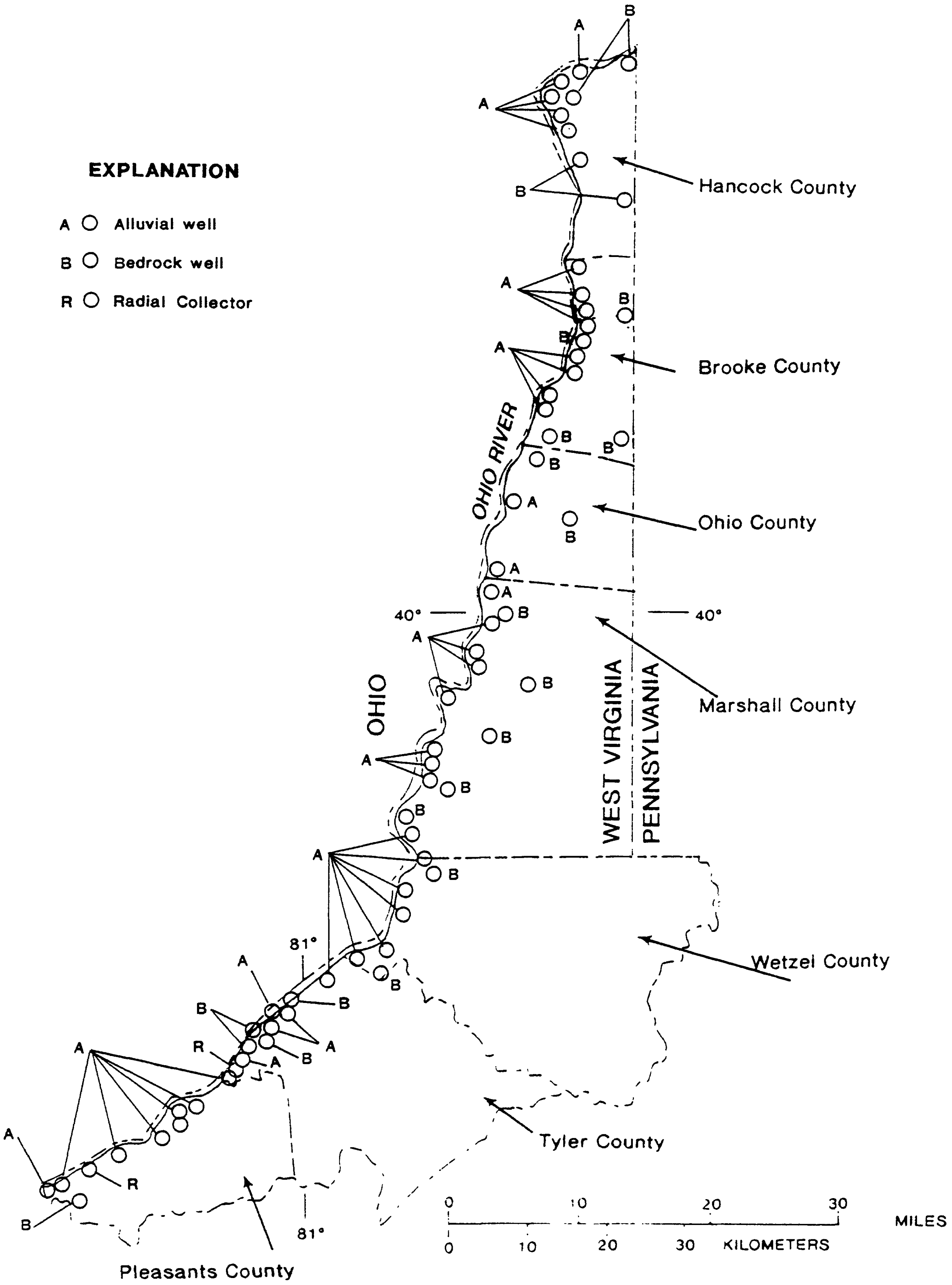


Figure 4.1-1. - - Location of ground-water sampling sites.

## 4.2 Water Type

### CALCIUM BICARBONATE WAS THE MOST COMMON WATER TYPE

*Calcium bicarbonate was the predominant water type in 35 percent of the well samples.*

Water type was determined for well samples collected during the study (fig. 4.2-1). Water type is based on predominant cations and anions. Calcium bicarbonate was the most common water type, accounting for 35 percent of the samples. Calcium, with a mixture of bicarbonate and sulfate, was the second most common type, comprising 18 percent of the samples. Ten other water types were present, each totaling 8 percent or less of the samples. These water types included various combinations of calcium, sodium, and magnesium with bicarbonate, sulfate, and chloride.

Calcium was the most predominant cation in 71 percent of the samples. Sodium was the second most common cation and was predominant in 15 percent of the samples. The remaining samples were various mixtures of calcium, sodium, and magnesium, with no single cation predominating.

Bicarbonate was the predominant anion in 50 percent of the samples. Sulfate and chloride were predominant in 9 and 8 percent of the samples respectively. The remaining samples were various mixtures of bicarbonate, sulfate, and chloride, with no single anion predominating.

Saltwater (sodium chloride type water) is a problem in Tyler and Pleasants Counties and in parts of the northern panhandle (see section 4.3). Sulfate is not normally a predominant anion, but can predominate in areas containing fill (see section 4.6).

Plates 1-3 contain more detailed descriptions of the ground-water chemistry.

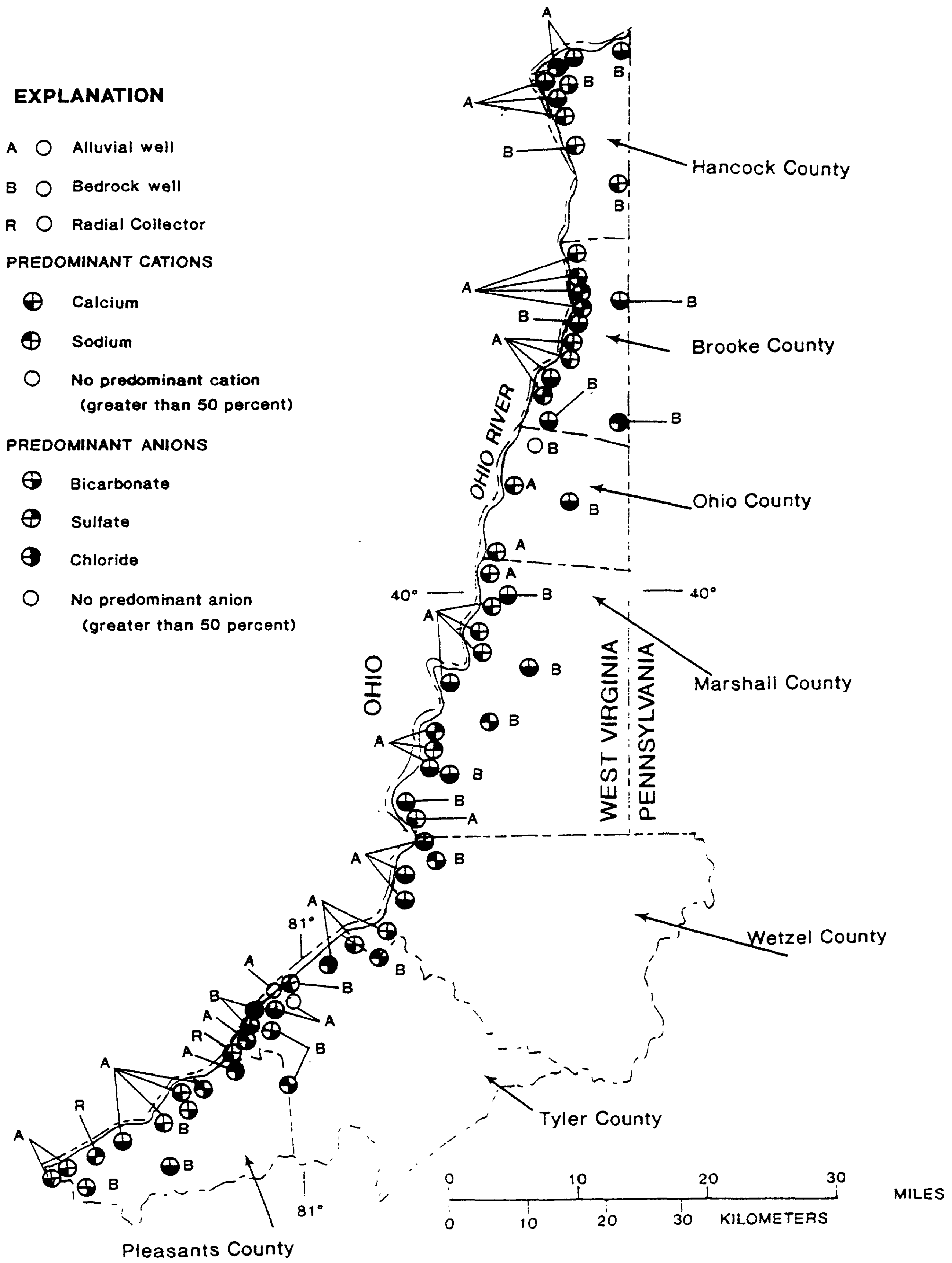


Figure 4.2-1. - - Areal distribution of cations and anions.

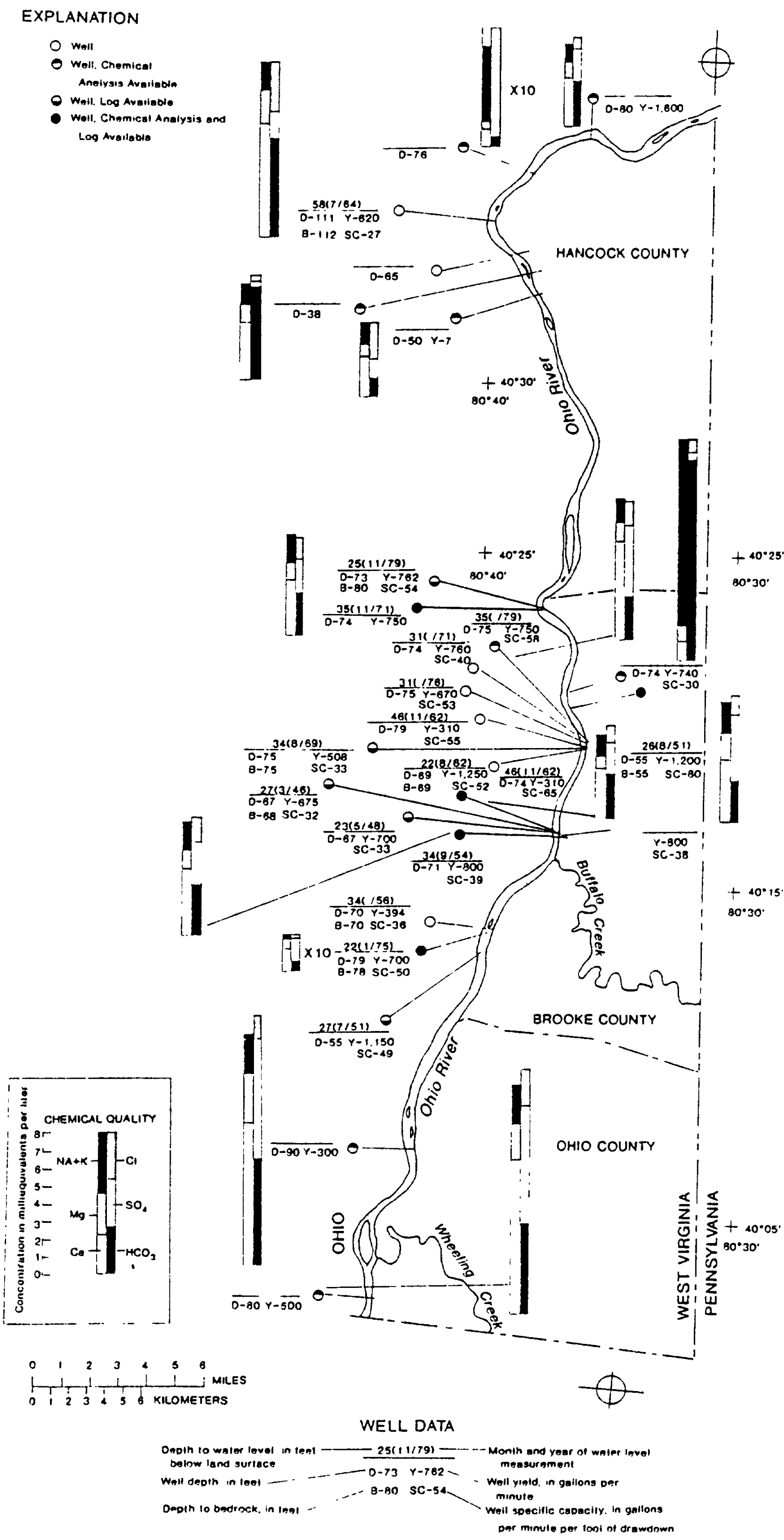


Plate 1.--Map showing hydrologic and physical characteristics of selected alluvial wells in Ohio, Brooke, and Hancock Counties.

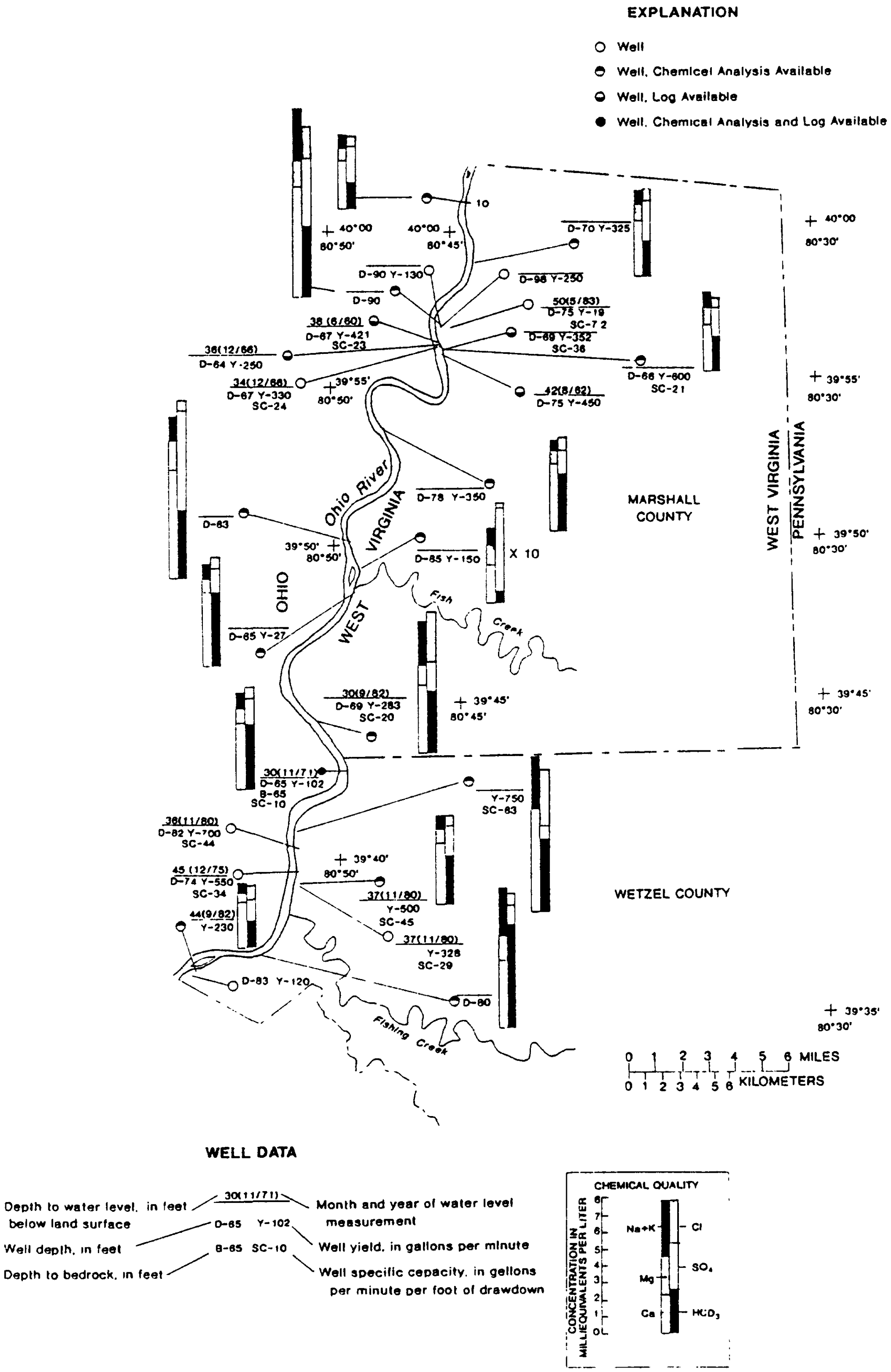


Plate 2.--Map showing hydrologic and physical characteristics of selected alluvial wells in Marshall and Wetzel Counties.

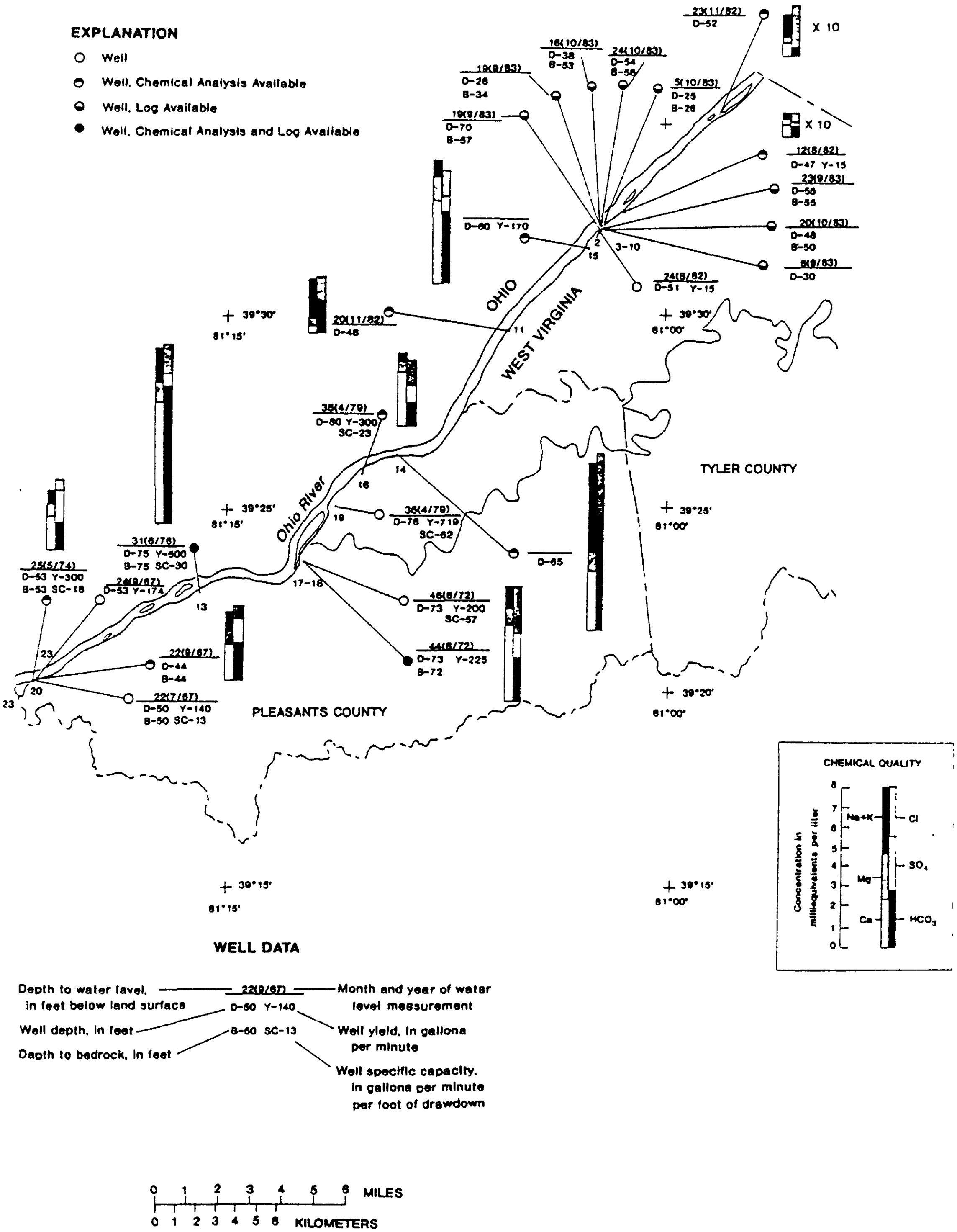


Plate 3.--Map of hydrologic and physical characteristics of selected alluvial wells in Tyler and Pleasants Counties.

## 4.3 Chemical Constituents

### *4.3.1 Saltwater*

### EIGHT PERCENT OF SAMPLED WELLS CONTAINED SALTWATER

*Although saltwater underlies all of the area at varying depth, only eight percent of the sampled wells contained sodium chloride type water.*

Sodium chloride was the predominant constituent in 8 percent of the sampled wells. Increasing chloride concentration may be the first indication of saltwater contamination. The West Virginia State Board of Health (1981) recommends a limit of 250 mg/L of chloride for drinking water. Figure 4.3.1-1 shows the areal distribution of chloride concentration in ground water. One area of high chloride concentration is in Tyler and Pleasants Counties. Carlston and Graeff (1955) report that leakage from old oil wells may be contaminating freshwater zones in the Sistersville, Bens Run, St. Marys, Belmont, and Waverly areas.

Saltwater underlies all of the area at depths ranging from land surface to about 500 feet (Foster, 1980). (Foster, 1980) shows locations where it is within 100 feet of the land surface. Factors affecting the depth to saltwater include geology, topography, ground-water circulation, and human activities.

The depth to saltwater is shallower on the alluvial flood plain and in valleys than on hillside or hilltops. Fewer well owners report saltwater contamination on hillsides and hilltops than in valleys. This can be explained by the relation between the fresh ground water and the underlying saltwater and by the circulation of water from areas of recharge to areas of discharge (fig. 4.3-1.2).

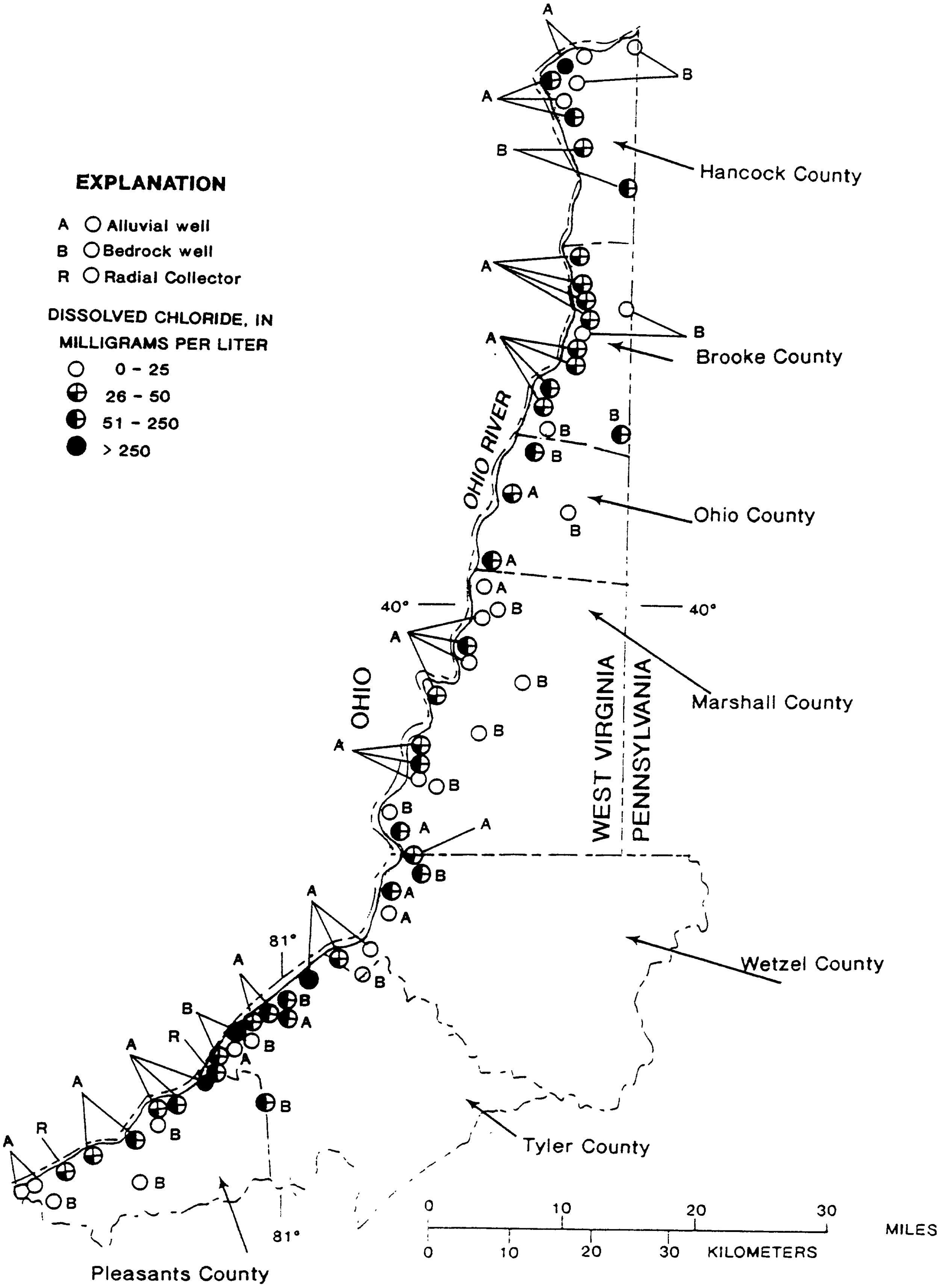


Figure 4.3.1-1. - - Areal distribution of dissolved chloride.

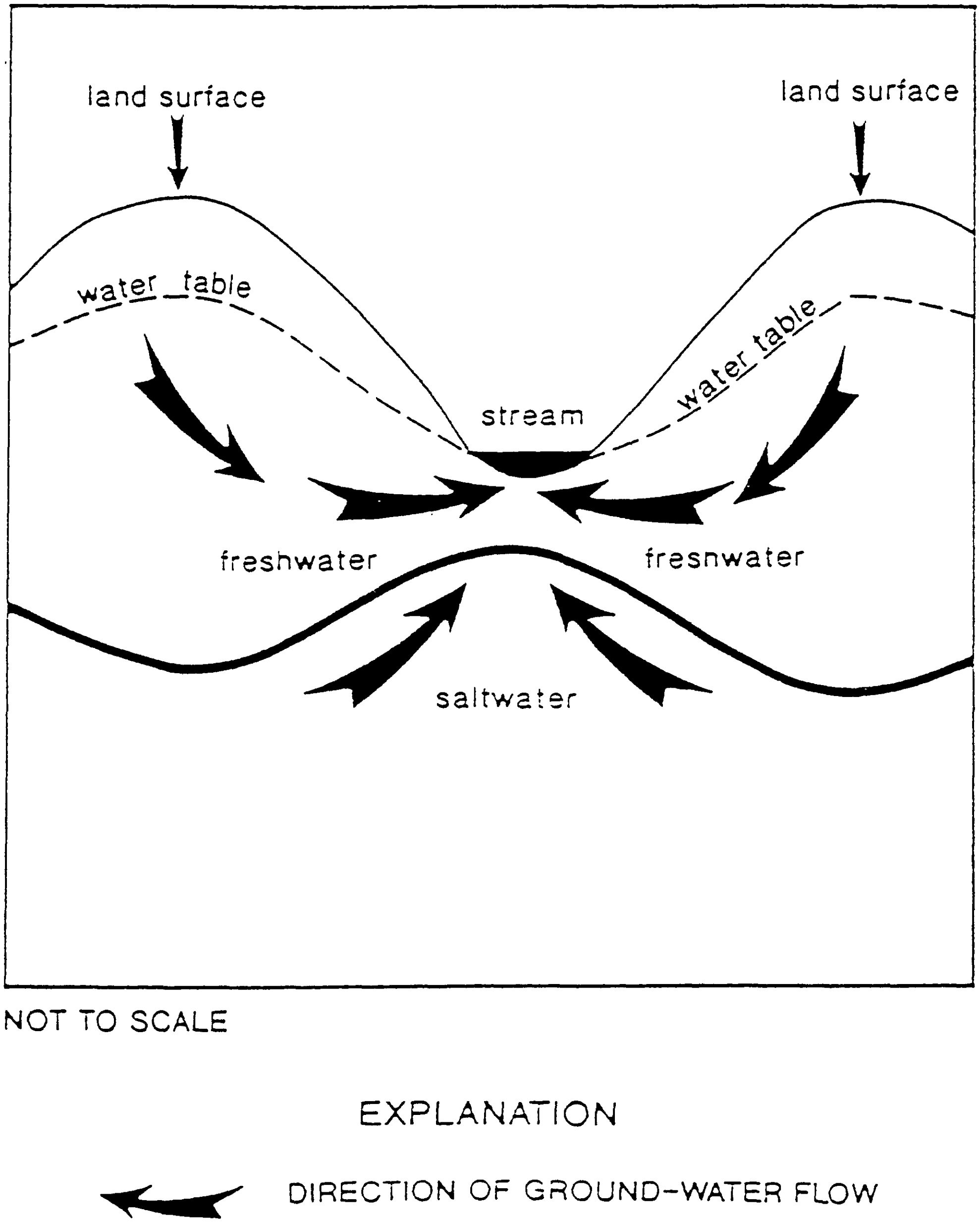


Figure 4.3.1-2. -- Relation between freshwater and saltwater.

The ground-water circulation in a drainage basin is from recharge areas in the hills to discharge areas in the valleys. The mean altitude of the water table is much higher under the hills, and saltwater is found at greater depth there than elsewhere in the basin. Some of the water percolating downward in the recharge area penetrates deeply enough to become part of the flow system involving the underlying saltwater.

In the discharge areas of the basins, deeper water is moving toward the surface. This water has mixed with the saltwater underlying the region and may be under greater hydraulic head than the overlying freshwater. Therefore, the saltwater moves upward to the surface when it reaches a fracture or well.

Man can also influence the depth to saltwater. Heavy pumping from the overlying freshwater zone can cause upward migration of the saltwater in areas where the saltwater is at shallow depth. Saltwater in oil and gas reservoirs is frequently under sufficient head to flow upward through wells. When deep wells are uncased or improperly cased, contamination of upper freshwater zones may occur (Bain and Friel, 1972). Secondary recovery techniques, such as the injection of carbon dixoide or saltwater under high pressure into deep oil-bearing zones, could cause saltwater to move into the freshwater zone by forcing it toward the surface. This is believed to be the problem around some oil fields in Tyler and Pleasants Counties.

### *4.3.2 Iron and Manganese*

## IRON AND MANGANESE POSE A PROBLEM FOR GROUND-WATER USE

*Iron and manganese concentrations exceeded State drinking-water limits in many alluvial wells along the Ohio River.*

Dissolved iron exceeded the 300 μg/L limit for drinking water (West Virginia State Board of Health, 1981) in 14 of 41 alluvial wells, and dissolved manganese exceeded the 50 μg/L limit for drinking water in 27 of 41 alluvial wells (figs. 4.3.2-1 and 4.3.2-2). Elevated iron and manganese concentrations in drinking water are not serious health hazards, but can cause problems in wells, distribution systems, food processing, and industrial processes.

Elevated iron and manganese concentrations in ground water can cause precipitates to form on well screens and in distribution lines. Iron and manganese can be removed from ground water after it has been withdrawn from a well. Thus, distribution lines usually can be protected from such precipitates, whereas well screens are more difficult to protect. Precipitates of iron and manganese and calcium carbonate clog screens and thus decrease well efficiency. As well efficiency decreases, increased drawdown can lower the water level below the top of the screen. Oxygen brought into contact with the screen further accelerates precipitation. Clogged well screens necessitate expensive cleaning or even the need for new wells (Jeffords, 1945).

The concentration of dissolved iron ranged from less than 3 to 52,000 μgL for all ground-water samples. The concentration of dissolved manganese ranged from less than 1 to 1,900 μg/L. Iron and manganese concentrations were significantly higher in ground water from alluvial wells than in ground water from bedrock wells. The median iron concentration was 50 μg/L in alluvial wells and 16 μg/L in bedrock wells. Likewise, median manganese concentration was 510 μg/L in alluvial wells and 56 μg/L in bedrock wells.

Ground water from some alluvial wells contained a higher concentration of manganese than iron. Hem (1970) states that ground water containing a higher concentration of manganese than iron is uncommon, but is present in wells along the Ohio River in West Virginia.

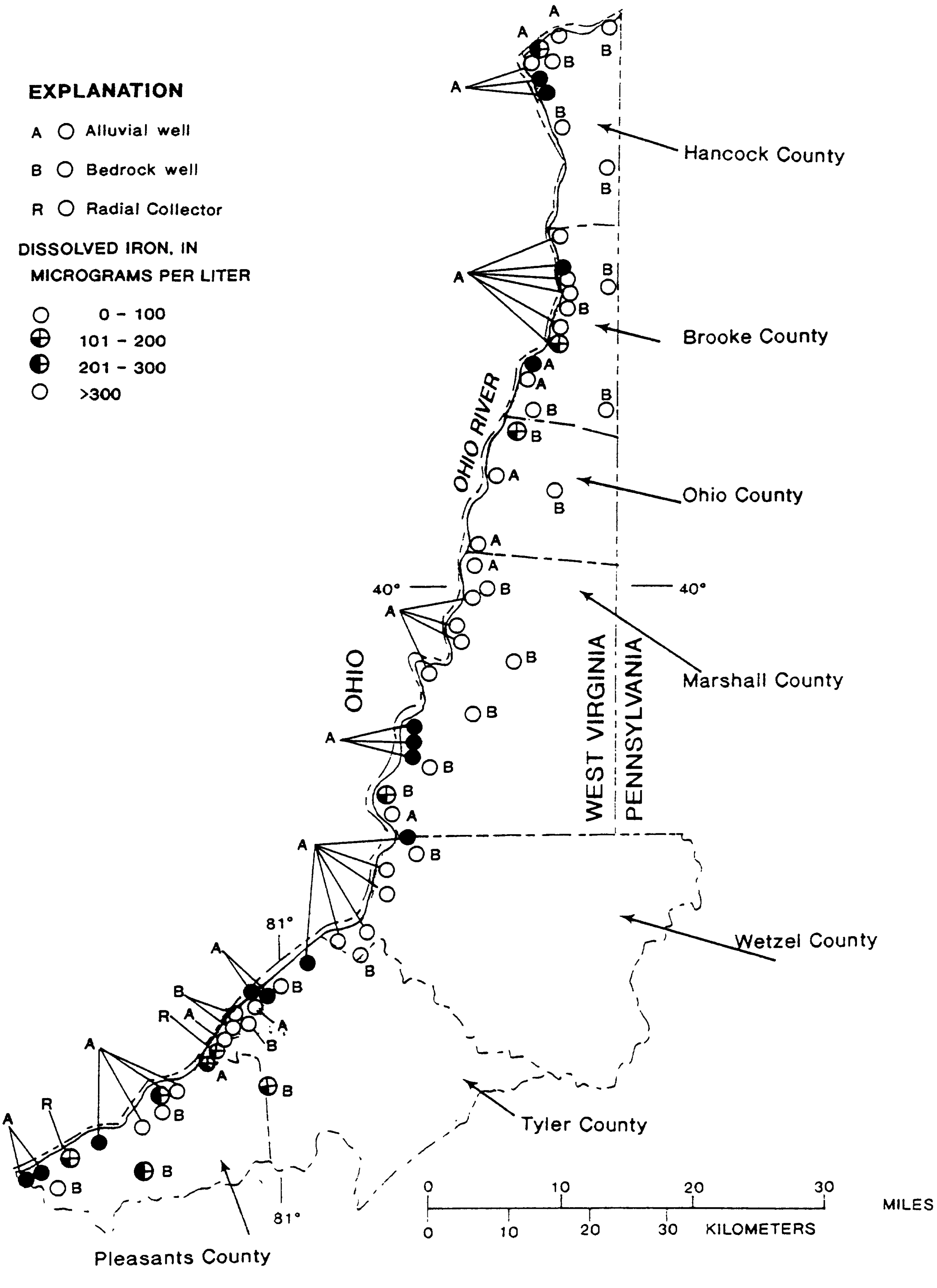


Figure 4.3.2-1. - - Areal distribution of dissolved iron.

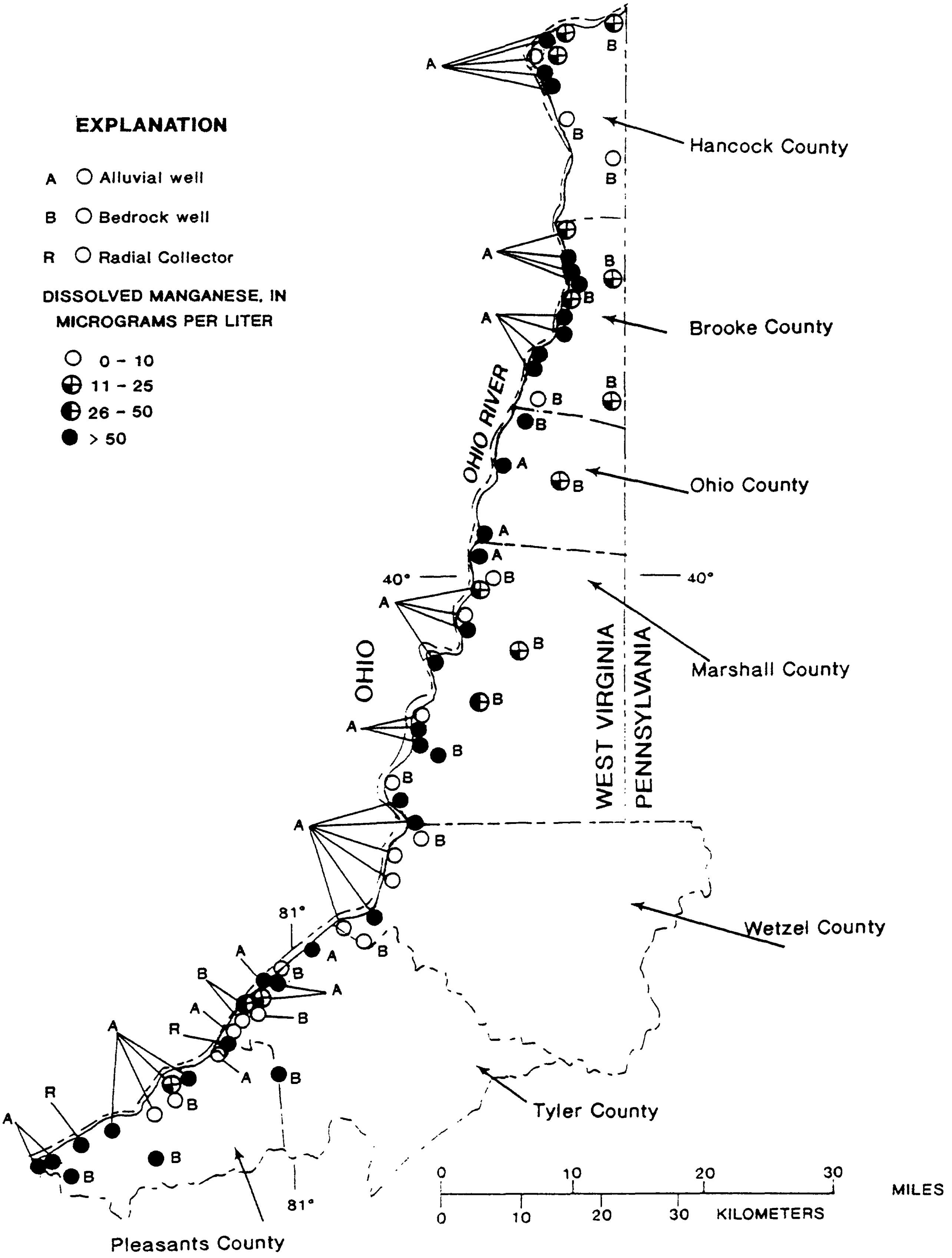


Figure 4.3.2-2. - - Areal distribution of dissolved manganese.

#### *4.3.3 Hardness*

## HARD WATER IS A COMMON PROBLEM

*Hard ground water is found throughout the area and clogs well screens and distribution lines.*

Hard water is a common problem throughout the area and is independent of the topographic location of the well or the geologic unit tapped. Hard water can cause well screens and distribution lines to become clogged with iron, manganese, and calcium carbonate precipitates. Ninety-one percent of the ground-water samples had a hardness concentration greater than 120 mg/L. Concentrations ranged from 30 to 1,700 mg/L, and the mean was 290 mg/L. Figure 4.3.3-1 shows the areal distribution of hardness. Hardness is classified by the U.S. Geological Survey (Durfor and Becker, 1964) based on the following ranges of equivalent calcium carbonate concentration in milligrams per liter: 0 to 60 is soft, 61 to 120 is moderately hard, 121 to 180 is hard, and greater than 180 is very hard. Calculations were based on the summation of calcium, magnesium, strontium, iron, aluminum, zinc, manganese, and barium concentrations (American Public Health Association, Inc., 1960, p. 132).

Calcium ions comprised an average of 74 percent of the hardness of each sample and magnesium ions comprised 24 percent. Together they comprised more than 90 percent of the hardness in every sample with one exception. A sample collected near Sistersville contained 52,000 $\mu$g/L of iron, which contributed 44 percent of the hardness.

The major source of calcium and magnesium ions probably is limestone. Lithologic analyses of the Ohio River alluvium (Carlston and Graeff, 1955) contain limestone pebbles. Chemically, limestone is classified as a carbonate rock, and pure limestone consists of calcium carbonate. Limestone in this area generally is impure and contains variable amounts of magnesium carbonate; iron carbonate; iron oxide; iron sulfide (pyrite and marcasite); calcium phosphate; and sulfates of calcium, titanium, strontium, and barium. McCue and others (1939) list analyses of limestone samples collected in Ohio, Brooke, Marshall, and Tyler Counties.

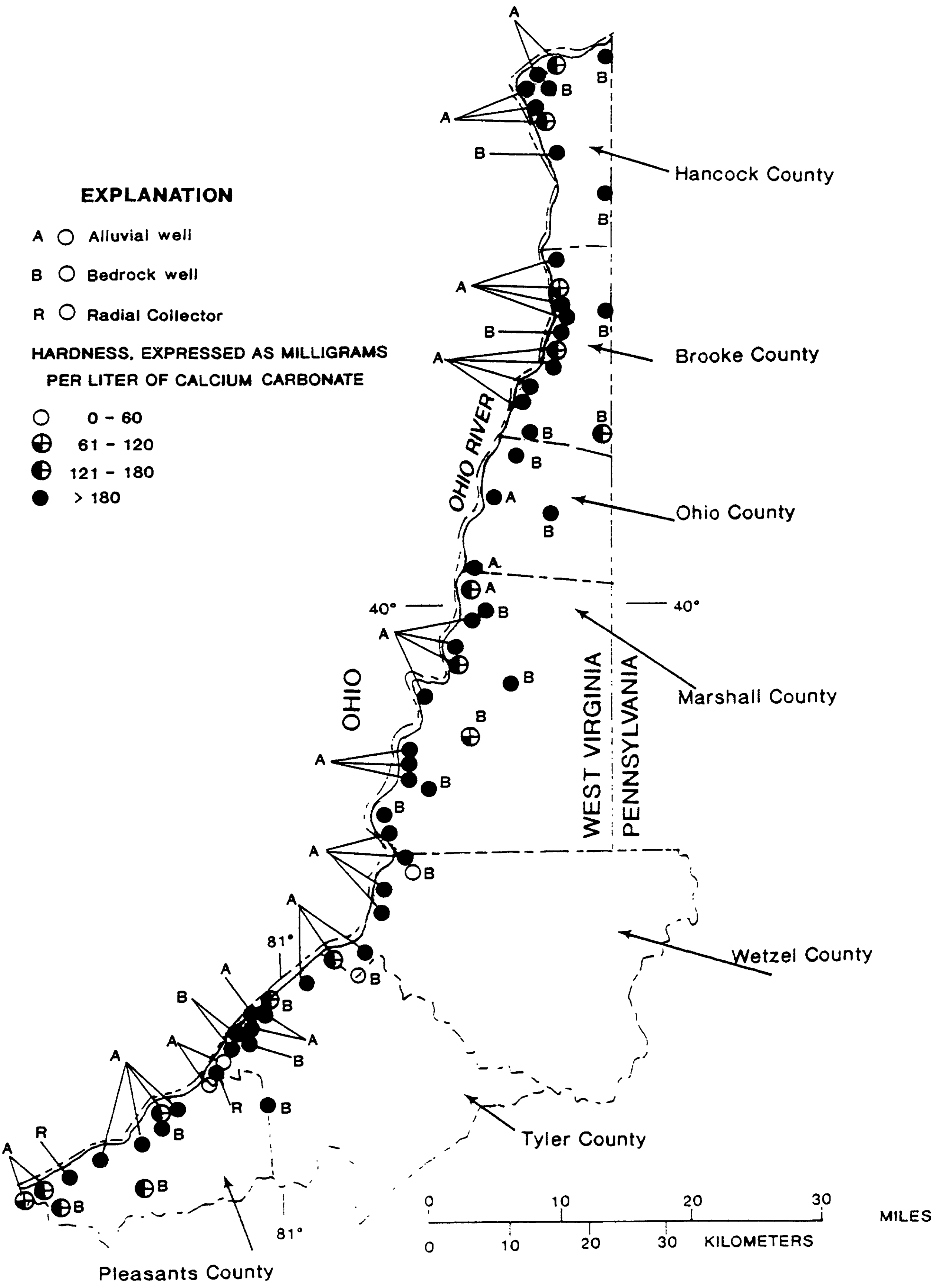


Figure 4.3.3-1. - - Areal distribution of hardness.

### *4.3.4 Sulfate*

## FILL MAY CAUSE AN INCREASE IN DISSOLVED-SULFATE CONCENTRATION

*An increase in dissolved sulfate may occur where fill is used to level or raise the land surface. Fill is commonly rich in pyrite and other sulfide minerals.*

There is a strong correlation between elevated concentration of dissolved sulfate and location of areas containing such fill materials as cinders, fly ash, slag, and other waste associated with coal and steel industries. Five ground-water samples from wells exceeded the 250 mg/L limit of sulfate as recommended by the West Virginia State Board of Health (1981) for public-drinking water. All five wells are located on the alluvial flood plain in or near areas containing fill. The mean sulfate concentration for all samples was 123 mg/L, and values ranged from less than to 1 to 2,400 mg/L. Radial collectors with laterals under the river were not included in the calculations because the samples contained a mixture of river water and ground water. Figure 4.3.4-1 shows the areal distribution of sulfate.

Fill is commonly rich in pyrite ($FeS_2$) and other sulfide minerals. Water percolating through the fill oxidizes the pyrite, which yields sulfate ions that dissolve in the water. Robison (1964) states that elevated sulfate in ground water from wells drilled on the flood plain in Ohio County may be attributed to the common practice of using coal-mine and steel-mill waste as fill.

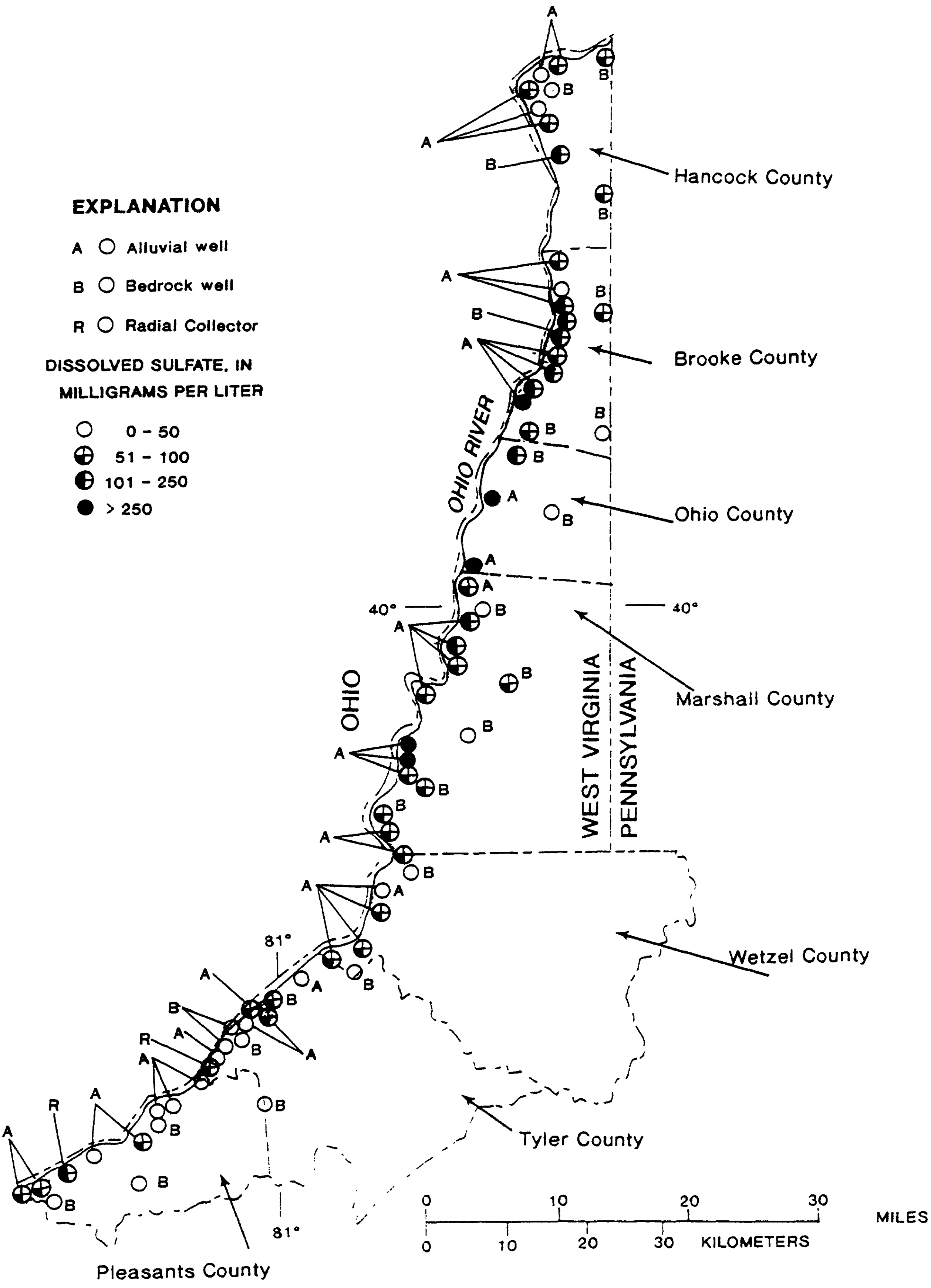


Figure 4.3.4-1. - - Areal distribution of dissolved sulfate.

*4.3.5 Contaminants*

## CONTAMINANTS EXCEEDED STATE DRINKING-WATER LIMITS IN SOME WELLS

*Arsenic, barium, mercury, or phenol concentrations exceeded State drinking-water limits in 7 of 50 ground-water samples.*

Drinking-water limits, as established by the West Virginia State Board of Health (1981) for contaminants, were exceeded in 7 of 50 ground-water samples (fig. 4.3.5-1). Contaminant limits were exceeded as follows: arsenic, one well; barium, three wells; mercury, two wells; and phenols, three wells. Contaminants analyzed that did not exceed drinking-water limits in any well were cadmium, copper, lead, nitrate, selenium, silver, and zinc.

Concentration of arsenic ranged from 1 to 110 $\mu$g/L. Arsenic is reportedly not harmful in concentrations up to 1,000 $\mu$g/L in drinking water for short-term use; but concentrations as low as 210 $\mu$g/L have been reported as poisonous after long-term use (Hem, 1970).

Concentration of barium ranged from 20 to 11,000 $\mu$g/L; mercury ranged from less than 0.1 to 4.2 $\mu$g/L; and phenol ranged from less than 1 to 87 $\mu$g/L. Median concentration for barium in public-water supplies was reported to be 43 $\mu$g/L (Durfor and Becker, 1964). Higher concentration of barium is associated with brines or water that has an elevated chloride concentration (Hem, 1959). The occurrence of detectable mercury in ground water is usually associated with industrial or mining waste. Likewise, phenols in water are the result of industrial pollution. Both mercury and phenols are toxic (Doll and others, 1963).

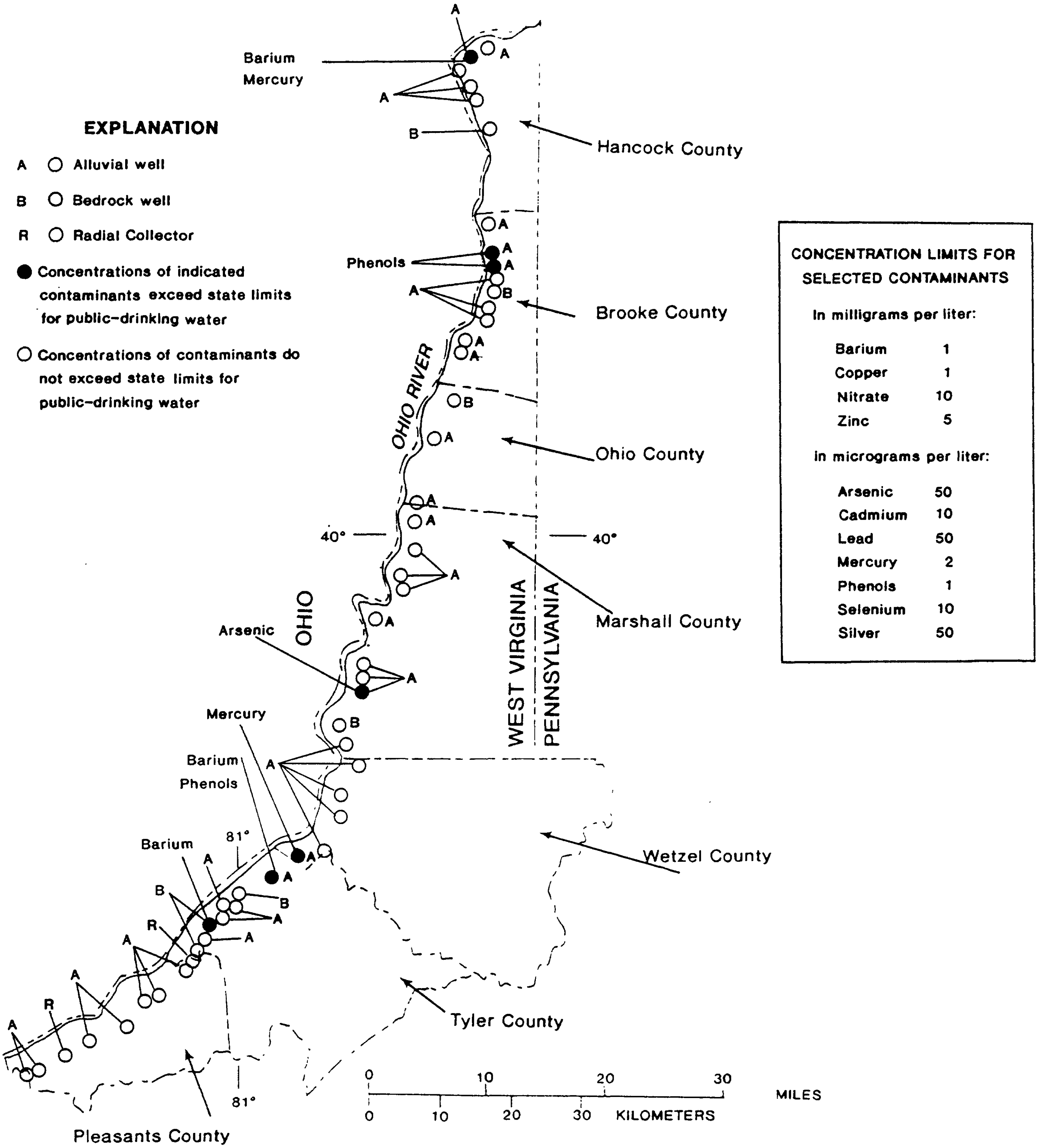


Figure 4.3.5-1. - - Areas where selected contaminant concentration exceeds established State limits (West Virginia State Board of Health, 1981).

## 4.4 Relation to Ground-Water Movement

### CHEMICAL QUALITY OF GROUND WATER PROVIDES INFORMATION ON GROUND-WATER MOVEMENT AND RECHARGE

*Results of water-quality analyses indicate that (1) ground water flows from the adjacent hills toward the Ohio River; (2) a hydraulic connection exists between the alluvium and bedrock; and (3) precipitation is the major source of recharge to the alluvium.*

Ground water flows from the adjacent hills toward the Ohio River. This is supported by changes in the chemical composition of ground water along the flow paths. The mean hardness of ground water from wells drilled into bedrock is as follows: bedrock underlying hilltops--280 mg/L, bedrock underlying hillsides--240 mg/L, bedrock underlying tributary valleys--140 mg/L, and bedrock underlying the Ohio River flood plain--280 mg/L. The decrease in ground-water hardness from hilltop to tributary-valley wells is probably due in part to sodium-calcium exchange. As water moves toward the valleys, it comes into contact with minerals having exchangeable sodium. Sodium has a higher exchange rate than calcium; thus, calcium ions in the ground water are exchanged for sodium ions. The higher ground-water hardness in wells that tap the bedrock underlying the Ohio River valley alluvium is probably due to induced mixing with the harder alluvial water. Ground water from wells open only to the alluvium has a mean hardness of 320 mg/L. When a well that is open to the underlying bedrock is pumped, water in the vicinity of the well may move downward from the alluvium into the bedrock. When this water mixes with water in the bedrock fractures, it causes an increase in hardness of the ground water in the bedrock. The amount of mixing depends on well depth, pumping rate, well efficiency, and local geology.

The trilinear water-analysis diagram in figure 4.4-1 shows the general chemical character of the water from the bedrock, alluvium, and Ohio River. On the central part of the diagram, some of the samples from alluvium and bedrock wells overlap, indicating that mixing of ground water from the two sources has been occurring. In order for the mixing of ground water from alluvium and bedrock to take place, there must be a hydraulic connection. However, only two ground-water samples overlap the group of Ohio River sample.

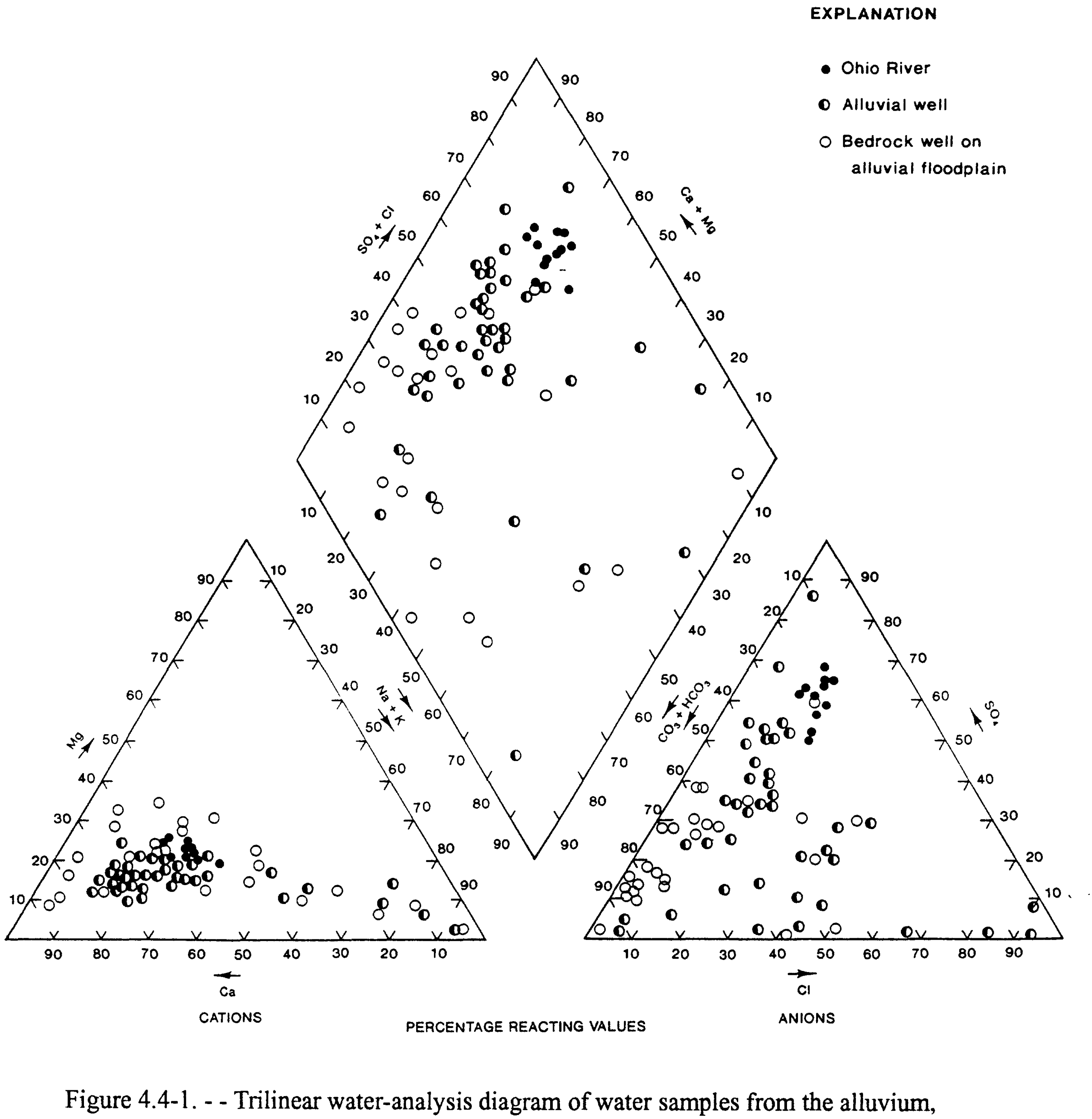


Figure 4.4-1. - - Trilinear water-analysis diagram of water samples from the alluvium, bedrock, and Ohio River.

Sulfate concentration also indicates a hydraulic connection between the alluvium and bedrock. The mean sulfate concentration of ground water from bedrock wells in the hills and tributary valleys was only 48 mg/L, while the mean sulfate concentration for wells open to the bedrock underlying the Ohio River valley alluvium was 100 mg/L. This increase in sulfate concentration may be caused by the mixing of ground water in the bedrock with ground water from the overlying alluvium that has a greater sulfate concentration. One probable source of the higher sulfate concentration in the alluvium is the fill material composed of industrial and mining waste that covers much of the alluvium (see section 4.3.4). Coal piles at coal-fired generating plants and at other industrial sites could be another source of the relatively high sulfate concentration in the alluvium. If sulfate leached from fill and from coal piles is reaching the ground water in the alluvium, precipitation must be an important source of recharge to the alluvium.

## 5.0 SUMMARY

Ground-water reserves in West Virginia are contained in two aquifer systems. The largest is the system of fractures in the consolidated rock that underlies the State, and the other is the narrow band of alluvium that borders the Ohio and Kanawha Rivers. Ground-water use in Hancock, Brooke, Ohio, Marshall, Wetzel, Tyler, and Pleasants Counties was at least 6.3 billion gallons in 1980 for public supply, mining, and domestic purposes.

The consolidated rock that crops out in the study area is of Pennsylvanian or Permian age and includes the Allegheny Formation, Conemaugh Group, Monongahela Group, and Dunkard Group. Ground-water yields from these rock units are typically low for most wells in the study area. The only major geologic structure is the north-trending Burning Springs anticline in western Pleasants County. The alluvial deposits of Quaternary age are limited mostly to the flood plain of the Ohio River, but are the most productive aquifer system in the area. The lower part of the alluvial deposits consists of sand and gravel of glacial outwash origin and is overlain by clay and silt interspersed with sand stringers. In some areas, the tributary streams have deposited gravel deltas where they enter the valley of the Ohio River. In places, the alluvium has been covered or filled with industrial waste.

Ground water flows from the adjacent hills toward the river. As ground water from the hills enters bedrock underlying the flood plain, it mixes with the ground water percolating through the alluvium. Water-level measurements and water quality indicate that the alluvium and underlying bedrock are hydraulically connected and that the saturated zone is continuous in both rock units.

The alluvium is recharged by the following sources: (1) precipitation on the flood plain, (2) inflow from fractures and bedding-plane partings in the bedrock beneath and adjacent to the alluvium, (3) inflow from tributary streams through gravel deltas, and (4) induced inflow from the river. Precipitation is more likely to recharge the alluvial and bedrock aquifers during the months of November through April.

Drinking-water limits recommended by the West Virginia State Board of Health were exceeded in places by concentrations of iron, manganese, sulfate, arsenic, barium, mercury, and phenols. Hardness exceeded 120 mg/L in 91 percent of the samples. Chemical quality can help explain ground-water movement and recharge. Hardness decreases as the ground water moves through the bedrock from hills to valleys and then increases when it reaches the bedrock beneath the alluvial flood plain. Sulfate leached from fill in the alluvium appears in alluvial wells on the flood plain, indicating that precipitation is a significant source of recharge to the alluvium. Sulfate concentration was higher in bedrock underlying the alluvium than in bedrock underlying adjacent hills. This indicates that a good hydraulic connection exists between bedrock and alluvium. A trilinear water-analysis diagram shows that mixing of ground water from the bedrock and alluvium is occurring.

## 6.0 DEFINITION OF TERMS

**Confined ground water.**--Confined ground water is under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined water occurs (Lohman and others, 1972).

**Hydraulic conductivity.**--A medium has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of ground water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through unit lengh of flow (Lohman, 1972).

**Hydraulic gradient.**--The hydraulic gradient is the change in static head per unit of distance in a given direction (Lohman and others, 1972).

**Porosity.**--The porosity of a rock or a soil is its property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume (Lohman and others, 1972).

**Semiconfinement.**--The distinction between confined and unconfined water is entirely gradational. The term semiconfined is used for the intermediate conditions. The material overlying an aquifer may be semipermeable so that water is only semiconfined (Davis and DeWiest, 1966).

**Specific capacity.**--The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level within the well (Lohman and others, 1972).

**Specific discharge.**--The specific discharge, or specific flux, for ground water is the rate of discharge of ground water per unit area measured at right angles to the direction of flow (Lohman and others, 1972).

**Specific retention.**--The specific retention of a rock or soil is the ratio of the volume of water, which the rock or soil, after being saturated, will retain against the pull of gravity to the volume of the rock or soil (Lohman and others, 1972).

**Specific yield.**--The specific yield of a rock or soil is the ratio of the volume of water which the rock or soil, after being saturated, will yield by gravity to the volume of the rock or soil (Lohman and others, 1972).

**Storage coefficient.**--The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman and others, 1972).

**Transmissivity.**--Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972).

**Unconfined ground water.**--Unconfined ground water is water in an aquifer that has a water table (Lohman and others, 1972).

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