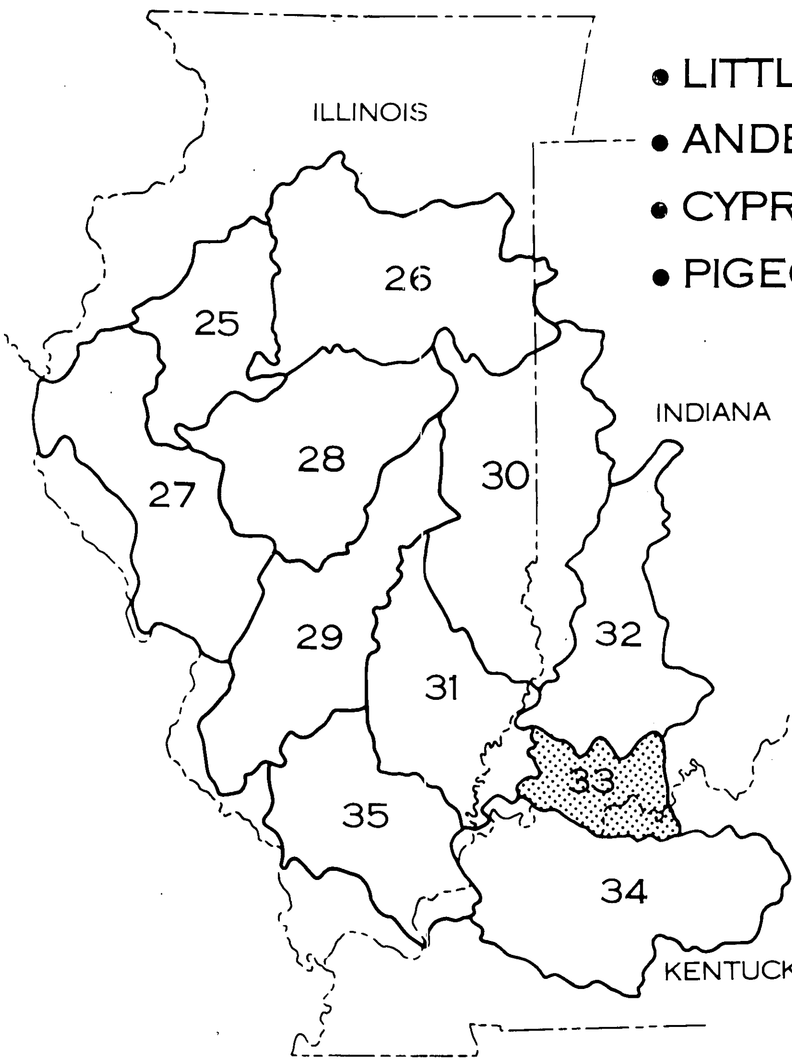
HYDROLOGY OF AREA 33, EASTERN REGION, INTERIOR COAL PROVINCE, INDIANA AND KENTUCKY



- LITTLE PIGEON CREEK
- ANDERSON RIVER
- CYPRESS CREEK
- PIGEON CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 81-423

HYDROLOGY OF AREA 33, EASTERN REGION, INTERIOR COAL PROVINCE, INDIANA AND KENTUCKY

BY
DAVID J. WANGSNESS AND OTHERS

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 81-423

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UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

GEOLOGICAL SURVEY

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CONTENTS

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inch (in)	25.4	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	square hectometer (hm^2)
gallons per minute (gal/min)	0.0631	liters per second (L/s)
gallons per day per foot [(gal/d)/ft]	0.0124	square meters per day (m^2/d)
gallons per day per square foot [(gal/d)/ft^2]	0.0407	meters per day (m/d)
cubic feet per second (ft^3/s)	0.0283	cubic meters per second (m^3/s)
ton (short, 2,000 pounds)	1.102	metric ton (t)

$$^{o}F = 1.8\ ^{o}C + 32$$

ABSTRACT

The Eastern Coal Region is divided into 35 separate hydrologic reporting areas. The division is based on hydrologic factors, location, size, and mining activity. Hydrologic units (drainage basins), or parts of units, are combined to form each area. Area 33 is at the southeastern end of the Interior Coal Province of the Eastern Coal Region and covers an area of about 1,630 square miles.

This report on hydrologic conditions and identification of sources of hydrologic information is designed particularly for use by mine owners, mine operators, and consulting engineers. General hydrologic information is presented in brief text, and illustrations are related to a single water-resources topic.

The Crawford Upland physiographic unit (in Indiana) and the Mississippian Plateau physiographic unit (in Kentucky), along the eastern edge of the study area, have characteristically rugged topography. The central and western parts of the area include the Wabash Lowland physiographic unit (in Indiana) and Western Coal Field physiographic unit (in Kentucky), which are broad, rolling plains.

The bedrock geology of Area 33 is of Pennsylvanian and Mississippian age and is covered by a veneer of unconsolidated sediment of Quaternary age. Most of the coal in the study area has been mined from rocks of Pennsylvanian age along outcrops in the west half of the study area. The Springfield coal (Coal V) is the major coal seam in Indiana, and the Carbondale coal (Number 9 coal) is a major coal seam in Kentucky. The average thickness of the seams is 4.4 feet and just under 5 feet, respectively. The coals in Indiana and Kentucky are highly volatile bituminous type B or C and are generally high in sulfur. As of 1978, more than 400 million short tons of coal had been mined from counties within the study area. Estimated reserves for this area are 6.5 billion short tons. During 1978, 17.3 million short tons of coal were mined from the Indiana and Kentucky counties within Area 33.

There are three major aquifers in the study area. The bedrock aquifer of the Pennsylvanian System is the most extensive of the aquifers. Water yield ranges from 1 to 30 gallons per minute. The alluvial aquifer associated with the Ohio River is less extensive than the bedrock aquifer but yields as much as 3,000 gallons per minute. The fine-grained sand-and-gravel aquifers in bedrock valleys tributary to the Ohio River bedrock valley have the potential of yielding as much as 300 gallons per minute. Flow in the bedrock and alluvial aquifers is toward the Ohio River. The bedrock aquifer is recharged mainly at outcrop areas. The alluvial aquifer is recharged vertically through confining layers. Amounts of recharge and discharge are not known. However, discharge along streams tributary to the Ohio River is minimal.

Water in the Ohio River alluvial aquifer is a hard to very hard (200-400 milligrams per liter) calcium bicarbonate type. Iron concentrations are commonly as much as 10 milligrams per liter, and median chloride concentration is low (11 milligrams per liter). Most of the water near the surface of the Pennsylvanian bedrock is calcium bicarbonate type and is also low in chloride. However, the water downdip is characteristically sodium bicarbonate type, and its chloride concentration is higher than that of water near the surface of the bedrock. Water quality in the bedrock is controlled by the amount and kind of soluble materials in the rock and may be influenced by man's activities. The alluvial aquifer has been affected by agricultural, municipal, and industrial development.

The major streams draining the study area are the Anderson River, Little Pigeon Creek, Pigeon Creek, and Cypress Creek, all tributary to the Ohio River. Because the surficial aquifers in the area have minimal discharge, there is little sustained streamflow. Average annual flows are low, and mean monthly flows are commonly zero. The 7-day, 10-year low flow is also often zero. Streamflow is primarily the result of precipitation. The net precipitation is greater in this area than in most other parts of Indiana and, therefore, flood magnitudes are often greater than those in other parts of the State.

Considerably more coal has been mined in the west half of the study area than in the east half. The exposure and the oxidation of pyrite and marcasite caused specific conductance and concentrations of sulfate and manganese to be higher in surface water in the west half of the study area than in the east half. However, because the bedrock geology of the west half has a high concentration of carbonate minerals, the surface water in the west half has a high buffering capacity. The bedrock geology of the east half of the study area is primarily sandstone and shale, which are characteristically low in carbonate minerals. Therefore, the surface water in the east half has little buffering capacity. Consequently, alkalinity and pH are lower in surface water in the east half of the study area than in the west half.

1.0 INTRODUCTION

1.1 Purpose of Report

REPORT SUMMARIZES AVAILABLE HYDROLOGIC DATA

The need for hydrologic data and other information from coal-mining regions has become critical since enactment of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Section 507(b)(11) of the Act requires that extensive information about the probable hydrologic consequences of mining and reclamation be included in mining-permit applications so that the regulatory authority can determine the probable cumulative impact of mining on the hydrology of the area. The purpose of this report is to summarize available hydrologic information for a subbasin in southwestern Indiana and northern Kentucky and to document the source of this information.

Coal is the most abundant fossil fuel in the United States, and the amount mined will probably be increased to meet our energy demands. Surface mining and reclamation have affected surface waters in much of the continental United States. Water quality has been degraded by acid mine drainage, and hydrologic conditions have been altered by mining.

The U.S. Geological Survey is helping to provide hydrologic data, particularly the water-quality data required by Public Law 95-87. This report is a summary of several reports, maps, oral communications, written communications, and computer data files from Federal and State agencies in Indiana and Kentucky. Much of the data has been summarized, but only some has been interpreted.

The area of study represents the hydrologic unit or drainage-basin area shown on the adjoining map (fig. 1.1). The area includes parts of two States, and, therefore, creates problems in nomenclature and data presentation. Adjoining counties or States may have a slightly different name for virtually the same geologic formation, soil type, and physiographic unit. The authors have not standardized the nomenclature used by the various reporting agencies but instead have presented the information as it was reported. Much of the data are presented by State and county rather than by drainage areas; for example, coal production and land use. Where a part of any county is within the area, data for the whole county are usually presented. Where a total figure is presented, such as total coal production for the area, that figure represents the total for all counties contacted by the area boundary and not just the total for the area. Therefore, some figures may be inflated because they represent a larger area than is shown, and the same county figures may be presented in other area reports in the series of coal hydrology reports if a county lies in parts of two or more study areas.

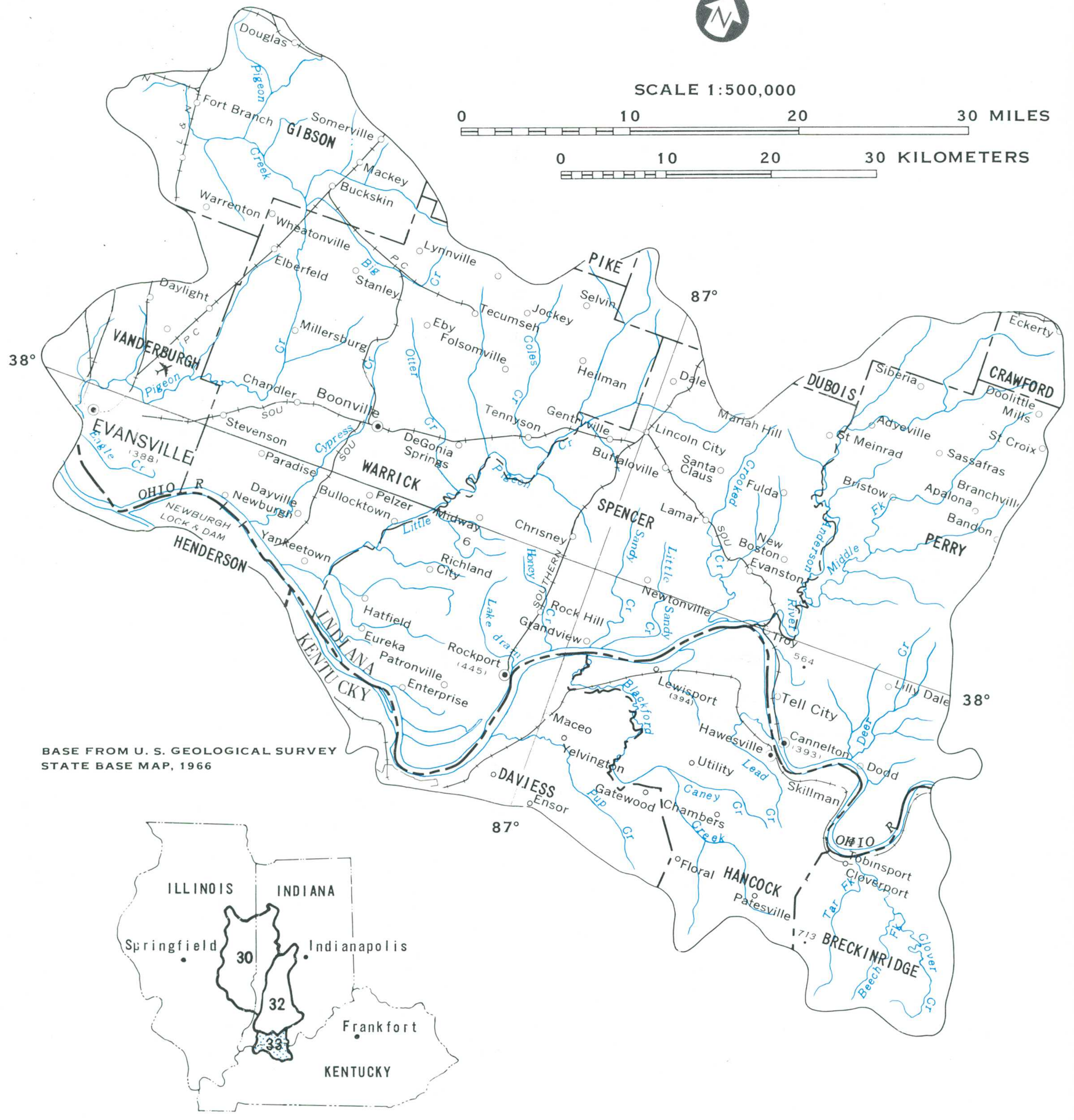


Figure 1.1.-- Study area 33 in southwestern Indiana and northern Kentucky.

1.0 INTRODUCTION

1.1 PURPOSE OF REPORT

TOPOGRAPHY OF AREA 33 IS RUGGED

The Crawford Upland and Mississippian Plateau along the eastern edge of Area 33 have characteristically rugged topography. The central and western part of the area include the Wabash Lowland and Western Coal Field physiographic units which, are broad, rolling plains. More coal is mined in the lowland areas than in the uplands.

In general, the land slopes westward and toward the Ohio River. The highest elevation is in the Crawford Upland and is about 600 feet (NGVD of 1929). The lowest elevation, 338 feet, is the normal pool elevation of the Ohio River at Evansville.

The area is unglaciated, except for the northwest corner. Landforms are a result of normal degradation processes such as weathering, stream erosion, and mass movement. The Indiana part of the area is represented by two bedrock physiographic units, the Crawford Upland and the Wabash Lowland; the Kentucky part is represented by two corresponding units, the Western Coal Field and the Mississippian Plateau. According to Schneider (1966), the topography of the Crawford Upland, and similarly the Mississippian Plateau, is rugged, and local relief is in the range from 300 to 350 feet. The upland is a mature dissected plateau characterized by abundant stream valleys and well-integrated drainage systems. Drainage divides are generally flat but narrow ridges that slope steeply to the valley floors. The bottoms of the largest valleys are moderately wide flood plains and are usually the only level land in the area.

Upland areas slope westward into the Wabash Lowland and the Western Coal Field. The lowland area is a broad plain averaging 400 to 500 feet in elevation. The plains are more rolling and undulating in southern Indiana than in the glaciated northern part of the State. Local relief of 100 to 150 feet is common in the lowland area (Schneider, 1966, and Wayne Kimbell, Lincoln Trail Area Development District, Kentucky, written commun., February 1980).

The adjacent map (fig. 1.2) shows the topography of Area 33.

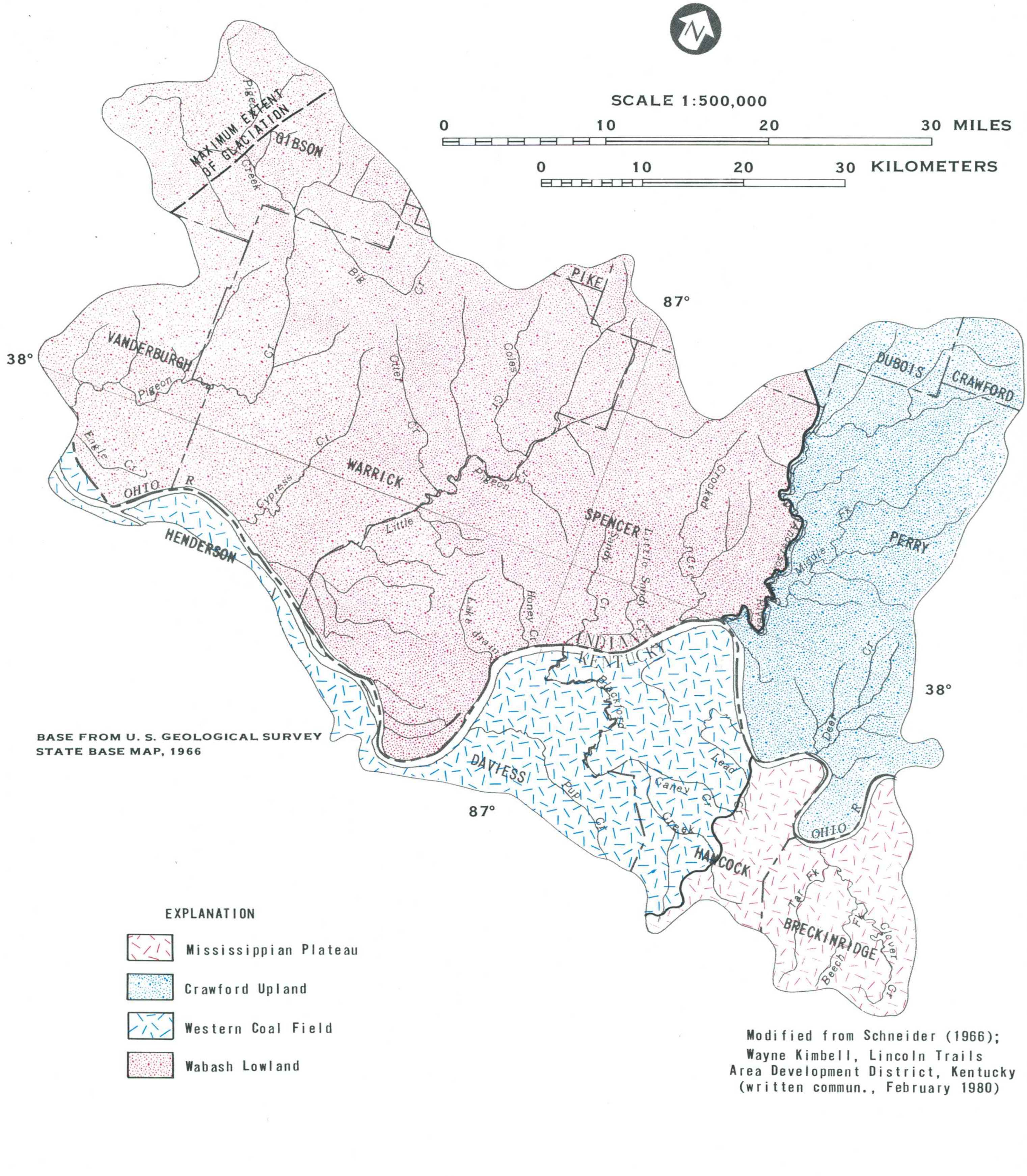


Figure 1.2. -- Glacial extent and physiographic regions.

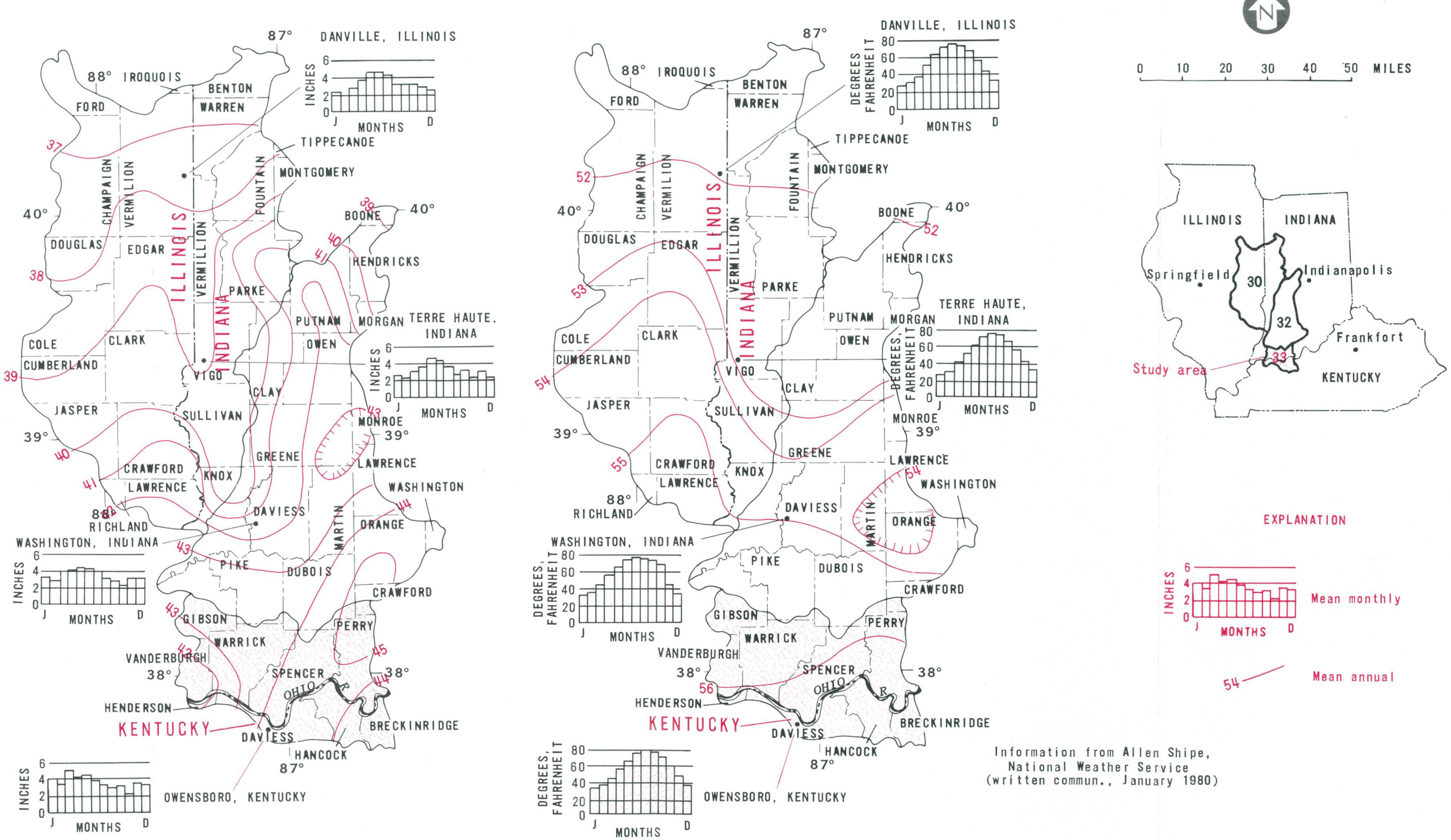
TEMPERATURE AND PRECIPITATION IN THE AREA IS REPRESENTATIVE OF MIDDLE-LATITUDE STATES

Annual temperature averages 56°F (Fahrenheit), and average monthly temperature ranges from 35°F in January to 78°F in July. Annual precipitation averages 44 inches, and average monthly precipitation ranges from 5.1 inches in March to 2.3 inches in October.

Indiana has warm summers and cool winters because of its location in the middle latitudes in the interior of a large continent. Temperature and precipitation are affected by the range in latitude, from 38° to nearly 42°N., and the range in elevation of the State, from 300 to 1,200 feet above NGVD of 1929 (National Geodetic Vertical Datum of 1929). Temperature can change significantly when surges of polar air move southeastward or tropical air moves northeastward but changes more frequently during the winter months than during the summer. A winter may be unusually cold or a summer cool if the influence of polar air is continuous. If tropical air dominates the weather, a winter may be mild and the summer unusually warm. The interaction of tropical and polar air masses of contrasting temperature and density develops low-pressure centers that generally move east through or near Indiana. This interaction normally results in abundant precipitation. Average annual snowfall ranges from 10 inches in the south part of the State to 40 inches in the north. Thunderstorms are generated by storm frontal activity or are formed locally by daytime convective air currents, which is important when evapotranspiration exceeds rainfall. This weather pattern also generates tornadoes, primarily in May and June. Indiana ranks 12th in tornado frequency but States to the south and west rank higher. (Schaal, 1959, and Schaal, 1966, p. 156 to 170.)

The climate of Area 33 differs from that of northern Indiana. The average annual temperature ranges from 50°F for the north to about 56°F for the study area. The average winter temperature ranges from 26°F for the north to 35°F for the study area. The maximum monthly mean temperature at Owensboro, Ky., from 1941 through 1970, was 78°F during July, and the minimum mean monthly temperature was 35°F during January. The average date of the first freezing temperature in the autumn is October 26 in the study area compared with October 7 in northern Indiana. The time of the last freeze in the spring is usually in the first week of April in the study area and in the second week of May in the north. Annual precipitation in the study area averages 44 inches, very little of which is snow. Mean monthly precipitation is generally greatest during spring (5.10 inches in March) and least during autumn (2.30 inches in October). Pan evaporation is about 8 inches at Evansville, Ind., during July compared with 6 to 7 inches at Valparaiso in northern Indiana. In October the evaporation is about 3 to 4 inches at Valparaiso and slightly greater at Evansville. Humidity ranges from 40 to 90 percent in Indiana and is generally higher at the lowest latitudes.

The adjoining maps (fig. 1.3.1) show mean annual precipitation and temperature curves for southwestern Indiana and eastern Illinois, and mean monthly precipitation and air temperature graphs for selected locations within the area.



MEAN ANNUAL PRECIPITATION AND SELECTED MEAN MONTHLY PRECIPITATION
1941-70

MEAN ANNUAL TEMPERATURE AND SELECTED MEAN MONTHLY TEMPERATURES
1941-70

Figure 1.3.1. -- Mean precipitation and air temperature.

RAINFALL FREQUENCY DATA ARE USED IN PROJECT DESIGN

Amounts of precipitation for various storm frequencies and durations are required for the design of many hydrologic projects.

Frequency analyses of point rainfall values are used to compute runoff hydrographs for the design of sewers, culverts, flood control, and other hydrologic projects. The designing of projects to handle maximum runoff events is seldom economical. Rather, projects are designed for 10-, 25-, or 100-year or other floods on the basis of a regulation or an economic balance between average damages attributed to occasional floods and the cost of facilities for protection against larger floods.

Except in mountainous terrain, rainfall intensity and frequency variations over short distances are usually small. Thus, maps of rainfall amounts for various frequencies and durations can be prepared. The maps in figure 1.3.2 show precipitation amounts for frequencies of 10, 25, and 100 years for a 24-hour duration. This information has been made available through a report published by the Indiana Department of Natural Resources (1974). The report shows precipitation amounts for frequencies of 1 to 100 years and durations of 1 to 24 hours. The near straight line relations have been extended into northern Kentucky and eastern Illinois.

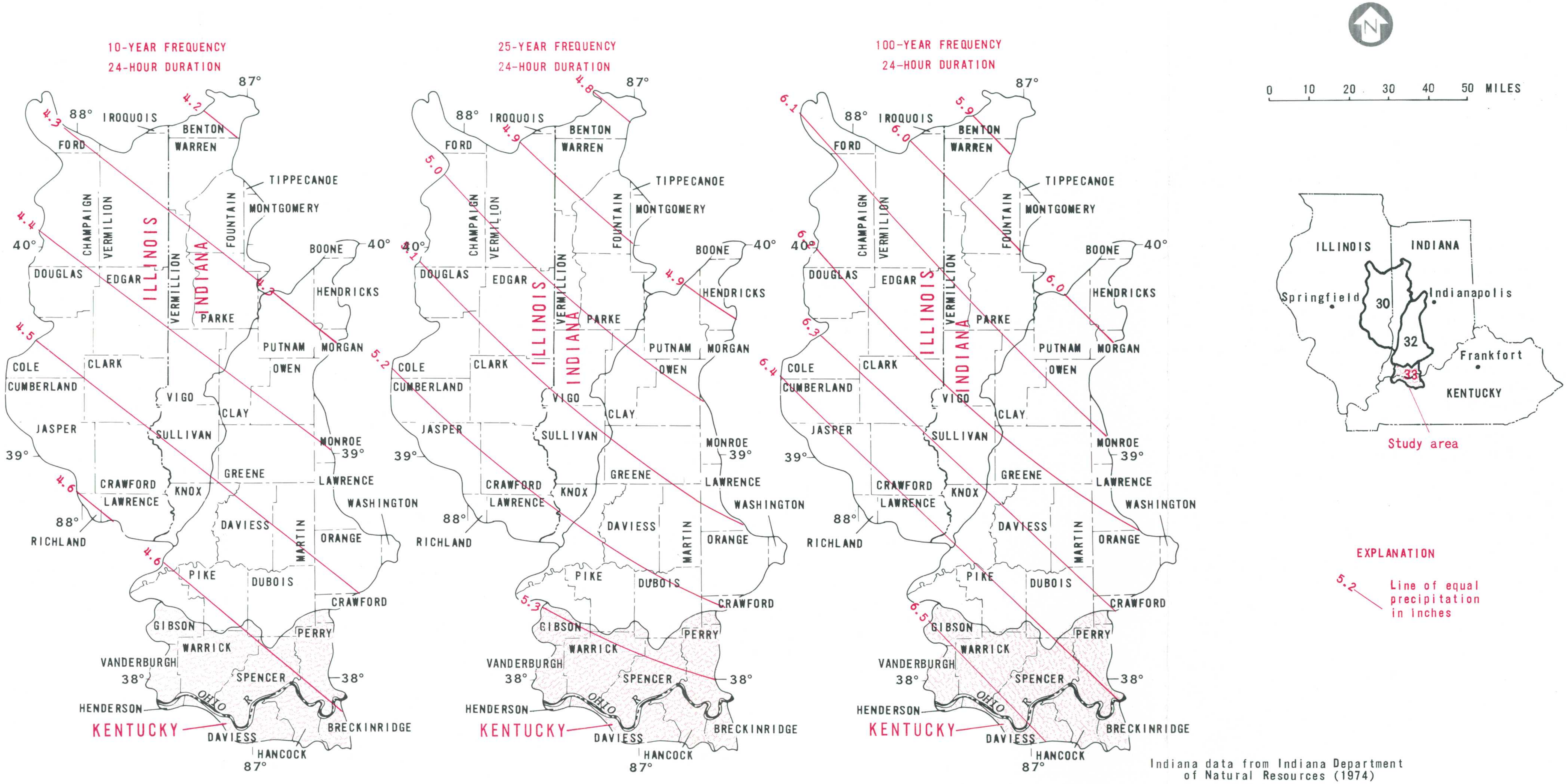


Figure 1.3.2. -- Precipitation magnitude and frequency for 24-hour duration.

DRAINAGE AREAS ARE SMALL AND STREAMS FLOW TO OHIO RIVER

Drainage area ranges from 11.9 to 368 square miles for streams that are gaged. The total drainage area for Area 33, is approximately 1,630 square miles.

Drainage area is useful in analyzing streamflow characteristics for design of hydrologic structures and for evaluating the availability of water. The stream network and locations where drainage areas are reported for the study area are shown on the adjoining map (fig. 1.4). The major streams and tributaries and the drainage areas computed at the mouth of each stream in the network are listed in the following table (Hoggatt, 1975).

Table 1.4 -- Drainage areas

Reference number (See map.)	Location	Drainage area (mi^2)	Reference number (See map.)	Location	Drainage area (mi^2)
1	Pigeon Creek at mouth------------	368	9	Crooked Creek at mouth-------------	72.7
2	Eagle Creek at mouth------------	12.8	10	Anderson River at mouth-------------	258
3	Cypress Creek at mouth------------	65.9	11	Middle Fork Anderson River at mouth----	106
4	Little Pigeon Creek at mouth---	360	12	Deer Creek at mouth-	50.5
5	Lake Drain at mouth·	20.2	13	Pup Creek at mouth--	38.8
6	Honey Creek at mouth------------	19.3	14	Blackford Creek at mouth	113
7	Sandy Creek at mouth------------	27.2	15	Lead Creek at mouth-	19.1
8	Little Sandy Creek at mouth---------	11.9	16	Clover Creek at mouth-------------	87.2

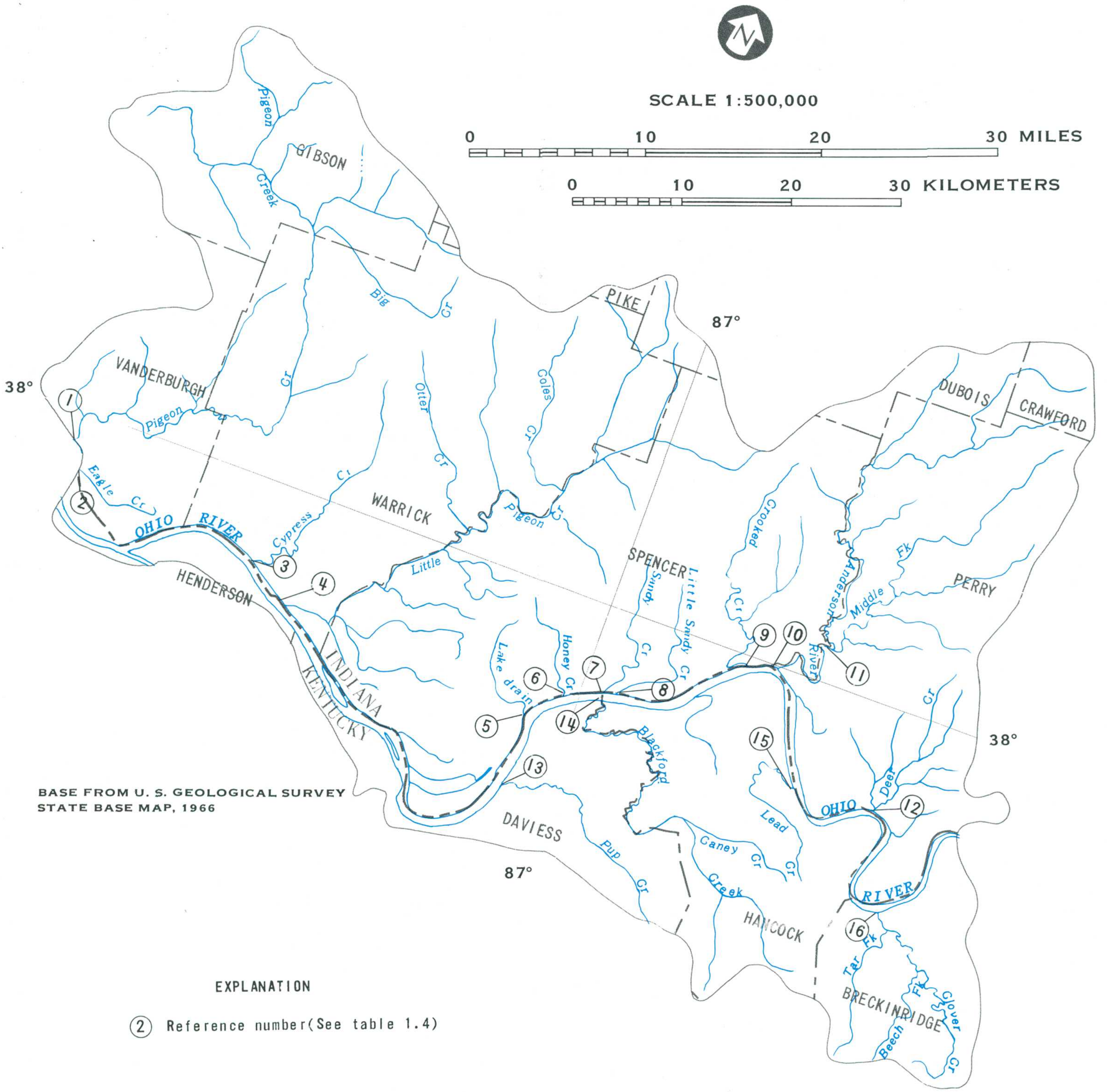


Figure 1.4. -- Stream network.

BEDROCK DISTURBED BY COAL MINING IS PENNSYLVANIAN AGE

Pennsylvanian coal-bearing formations and their mantle of Quaternary unconsolidated deposits make up the geologic deposits disturbed by coal mining and subsequent land reclamation. Pennsylvanian bedrock is composed of shales, claystones, siltstones sandstones, limestones and coals.

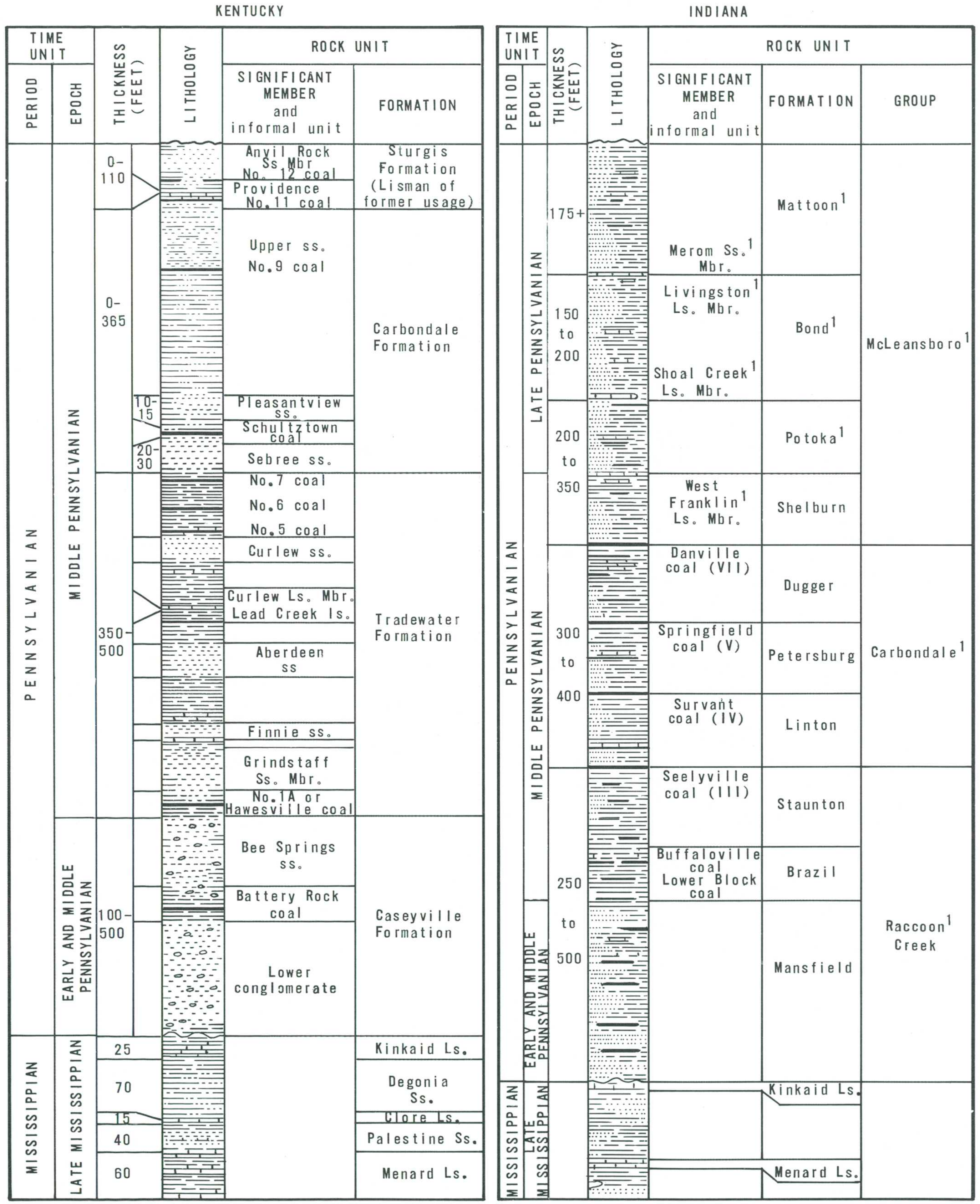
The coal-bearing rocks of Area 33 lie along the eastern edge of the Eastern Coal Region (Illinois basin) of the Interior Coal Province. From the Late Precambrian Era through the Late Pennsylvanian Epoch of the Paleozoic Era, the structural basin subsided and experienced interrupted episodes of sedimentation and landform change.

The Pennsylvanian formations consist of sandstones, siltstones, shales, claystones, thin limestones, and coals deposited within a delta plain that extended into a shallow marine sea. Marine and nonmarine sediments were deposited cyclically as the shoreline oscillated across the study area (Weller, 1930). The coal seams are the result of thick accumulations of peat deposited in nonmarine delta plain swamps. The peat changed to coal as the sediments were consolidated into rock.

Each Pennsylvanian formation consists of lithologically related rock strata whose lateral variations reflect differences in depositional environment. Similarities between formations allow them to be combined into groups in Indiana. The thickness of the Pennsylvanian rocks within the study area ranges from zero on the east to about 1,200 feet on the west.

The strike of the rock strata is generally north-south, and the dip is gently west toward the center of the Illinois basin at an average of about 25 feet per mile. Mississippian rocks are exposed on the east side of the study area, and progressively younger Pennsylvanian rocks are exposed toward the west. Major faulting is not common, but some minor normal faulting has been mapped, especially in the Kentucky part of the study area.

Location of the bedrock geology within the study area is shown in the adjoining figures 1.5.1a and 1.5.1b.



Modified from Devaul and Maxwell (1962)

Modified from Gray and others (1970)

[1] Usage of Indiana Geological Survey

Figure 1.5.1a. -- Generalized stratigraphic columns.

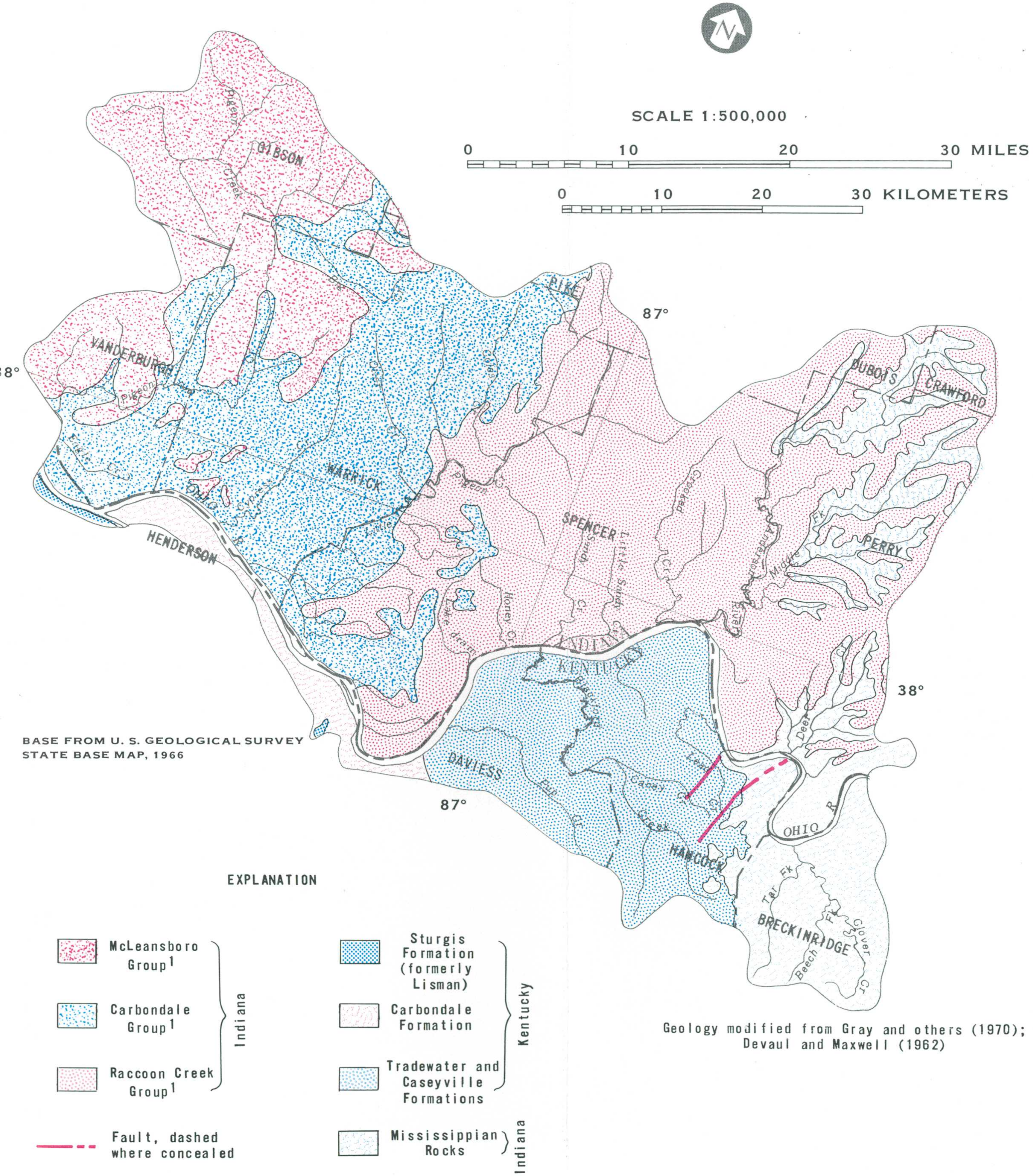


Figure 1.5.1b. -- Bedrock geology.

UNCONSOLIDATED SURFACE DEPOSITS DISTURBED BY COAL MINING ARE QUATERNARY AGE

Variable amounts of unconsolidated Quaternary sediments are disturbed by coal mining and subsequent land reclamation. These sediments have three main sources: (1) Various types of deposits formed during the Ice Age, (2) alluvial deposits formed during the Holocene Epoch, and (3) recent deposits formed by inplace weathering of bedrock. The unconsolidated deposits have highly complex horizontal as well as vertical relationships to each other.

The Pennsylvanian and Mississippian bedrock are covered by a veneer of unconsolidated material of Quaternary age. The thickness ranges from zero to about 150 feet.

The Quaternary is the most recent period in the Earth's history and is divided into the Pleistocene Epoch (the great Ice Age) and the Holocene Epoch. During the Pleistocene Epoch, ice sheets from the north advanced into and retreated from Indiana and surrounding areas. These ice sheets covered only a small part of southwestern Indiana, but their proximity influenced the deposition of sediments (Thornbury, 1950).

Continental glaciers east, north, and west of the study area supplied huge amounts of water and sediments to the surface drainage system. Local streams and rivers were choked with this sediment load. The effect was a change from an eroding drainage system to an aggrading one. The accumulating sediments were the products of several different environments, including:

1. Outwash plain deposits (clays, silts, sands, and gravels) formed as sediments came out of suspension in sediment-choked alluvial plains.

2. Lake deposits (clays, silts, and sands) formed as drainage systems backed up or were dammed by outwash sediments of alluvial plains into which they emptied.

3. Wind-blown sediments (clays, silts, and fine sands) formed as dust-bowl type storms deposited the fine material winnowed from outwash plains during dry periods.

At the end of the Ice Age, streams began to erode into the underlying Pleistocene deposits and bedrock and then to deposit this eroded material as alluvium or valley-train deposits. Alluvium, which consists of layered and cross-bedded gravels, sands, silts, and clays, constantly shifts, erodes, and aggrades in its travel downstream.

Holocene and Pleistocene unconsolidated deposits overlie the bedrock in about one-fourth of the study area, as shown on the facing map (fig. 1.5.2). However, the complexity of the unconsolidated deposits is much greater than that shown here. In many places, bedrock areas are covered by Quaternary unconsolidated deposits that are not shown. These deposits, consisting mainly of thin lake sediments and wind-blown loess, are shown on a more detailed geologic map by Gray and others (1970).

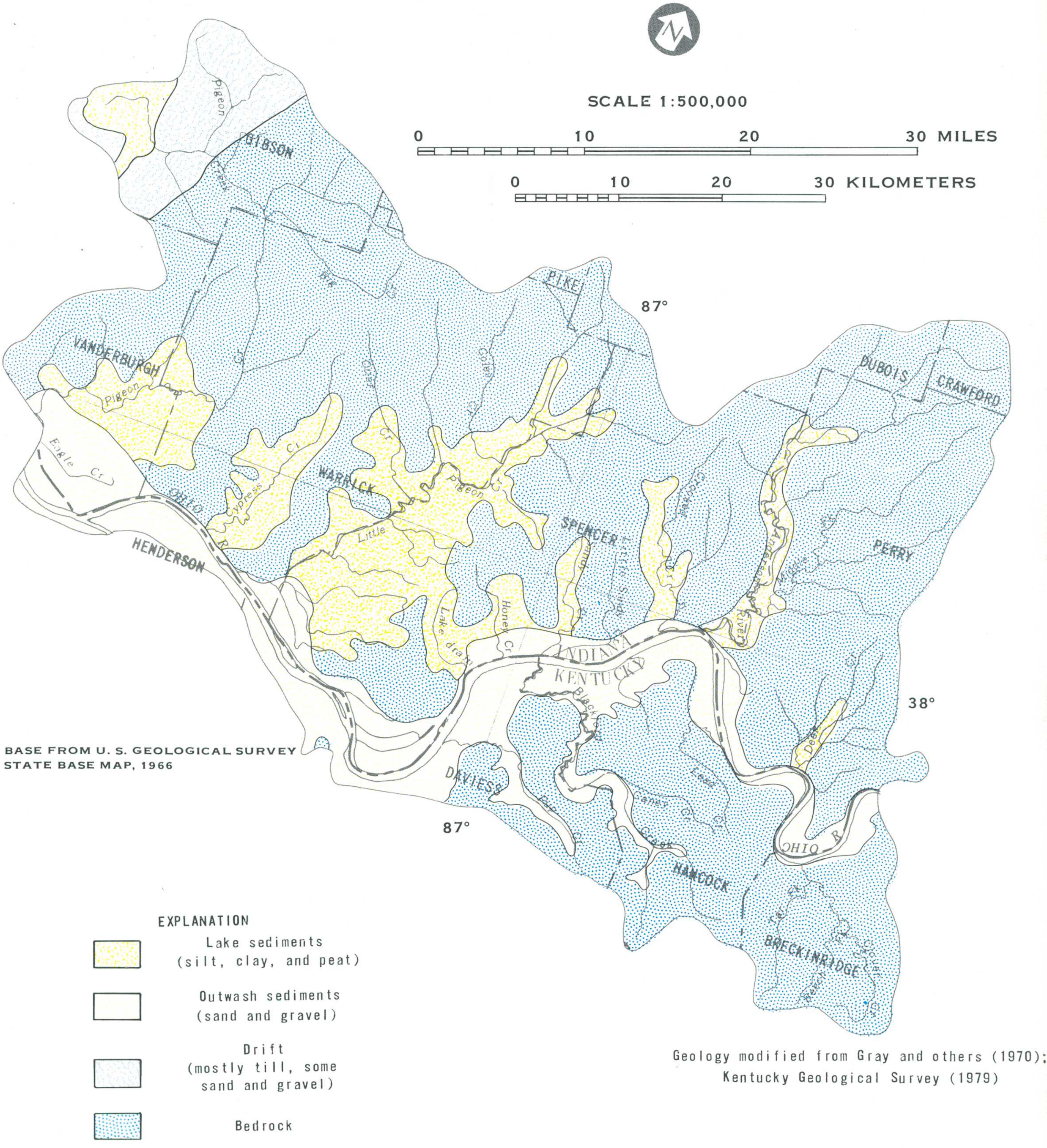


Figure 1.5.2. -- Glacial geology.

SOIL TYPE AND LAND SLOPE VARY WIDELY

The study area contains 15 soil associations that are represented by 27 major soil series and 59 minor soil types. The surface horizons of many of the soils are light colored, silty loams of silty-clay loams underlain by silty clay or silty-clay loam subsoils that may have fragipans. The soils range from poorly drained to well-drained.

The adjoining map (fig. 1.6) shows the soil associations within Area 33, and table 1.6 lists descriptive information for each association. Information is from an Indiana soils association map and a Kentucky soil map published by the U.S. Soil Conservation Service in 1977a and 1975a, respectively. More detailed information is available in county soil surveys that are also published by the Soil Conservation Service in each respective State. Some of these county reports are referenced in section 6.2.

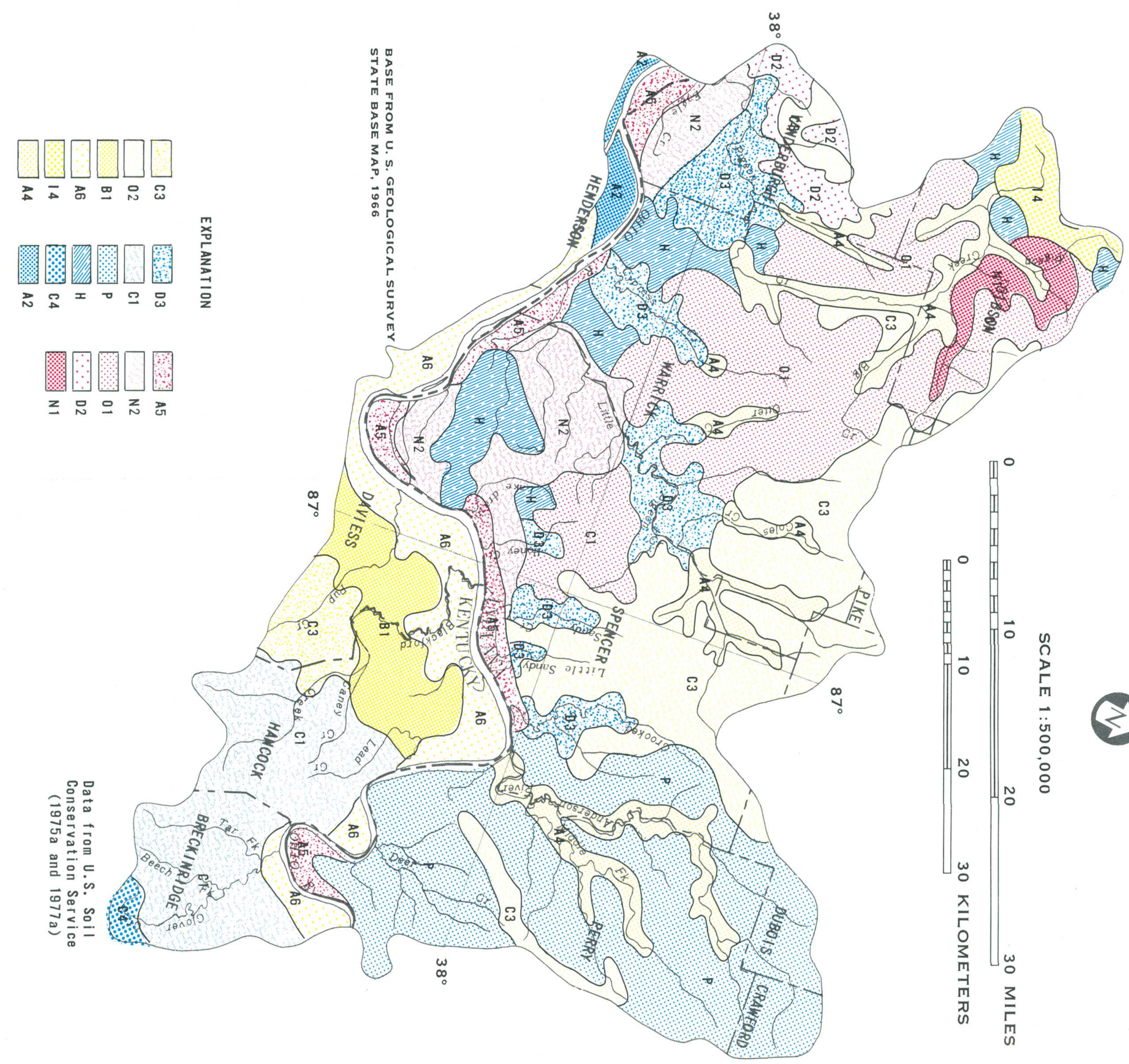


Figure 1.6. -- Soil associations.

Table 1.6. -- Description of soil associations in southern Indiana and northern Kentucky

Indiana soil associations

(Source: U.S. Soil Conservation Service, 1977a)

Soil association: Symbol	Soil association: Major soil series[1]	Soil description: Surface horizons	Soil description: Sub-soils	Soil description: Drainage	Normal slope range (percent)	Remarks
A4	Stendal	Light-colored, silty, loam.	Silty loam or silty-clay loam.	Poorly drained.	Nearly level.	Parent materials neutral to acid silty, alluvial deposits. Located on flood plains. Minor soils are Armiesburg, Cuba, Genesee, Petrolia, and Steff.
	Haymond	do.	do.	Well drained.	do.	
	Wakeland	do.	do.	Poorly drained.	do.	
	Nolin	do.	do.	Well drained.	do.	
A5	Wheeling	Light-colored, silty loam.	Clay loam or silty clay.	Well drained.	0-6	Wheeling on Ohio River terraces, formed from loamy material over sand and silt, high in mica. Huntington/Lindside flood plain formed from neutral silty alluvium. Minor soils are Cuba, Rahm, and Weinbach.
	Huntington	Silty loam.	Silty loam or silty-clay loam.	Well to moderately well drained.	0-2	
	Lindside	do.	do.	do.	0-2	
D3	Zipp	Light-colored, silty clay.	Silty clay.	Very poorly drained.	Nearly level.	Zipp/McGary on nearly level lake plain uplands. Markland on side slopes leading down to streams. Minor soils are Evansville, Henshaw, Montgomery, Patton, and Steff.
	Markland	Light-colored, silty loam.	Silty clay.	Well drained.	2-12	
	McGary	do.	do.	Poorly drained.	Nearly level.	
H	Alford	Light-colored, silty loam.	Silty-clay loam.	Well drained.	2-18	Parent material leached loess more than 5 feet thick.
I4	Reesville	Light-colored, silty loam.	Silty-clay loam.	Somewhat poorly drained.	Nearly level.	Developed entirely in Wisconsinan loess. Minor soils are Alford, Fincastle, and Iva.
	Ragsdale	Dark-colored, silty loam or silty-clay loam.	Silty-clay loam.	Very poorly drained.	Nearly level.	
N1	Bartle	Light-colored, silty loam.	Silty-clay loam.	Poorly drained.	Nearly level.	Acid, silty parent materials located on lacustrine plains and slack-water terraces. Minor soils are Hosmer and Robinson.
	Peoga	do.	do.	do.	do.	
	Dubois	do.	do.	do.	do.	
N2	Weinback	Light-colored, silty loam.	Silty-clay loam with fragipans.	Poorly drained.	Nearly level.	Loamy outwash parent materials over acid sands and silts. Located on Ohio River terraces. Minor soils are Ginat and Sciotoville.
	Wheeling	do.	Clay loam.	Well drained.	0-6	
O1	Hosmer	Light-colored, silty loam.	Silty clay with fragipan.	Well drained.	2-12	Leached loess deposits usually 4-6 ft thick on rolling landscapes. Minor soils are Alford and Cincinnati.
O2	Zanesville	Light-colored, silty loam.	Silty clay with fragipan.	Well drained.	2-18	Weathered, acid parent materials of Pennsylvanian siltstone, shale and sandstone and overlying loess on gently sloping unglaciated areas. Minor soil is Muskingum.
	Wellston	do.	Silty clay but lack fragipans.	do.	12-25	
	Tilsit	do.	Silty clay with fragipans.	Moderately well drained.	2-10	

Indiana soil associations--Continued

Soil association: Symbol	Soil association: Major soil series[1]	Soil description: Surface horizons	Soil description: Sub-soils	Soil description: Drainage	Normal slope range (percent)	Remarks
P	Wellston	Light-colored, silty loam.	Silty-clay loam.	Well drained.	12-25	Soil parent materials are weathered acid Mississippian and Pennsylvanian siltstone, sandstone, and shale. Many of these are covered by a thin layer of loess. Located on steep slopes of unglaciated areas. Minor soils are Gilpin and Muskingum.
	Zanesville	do.	Silt-clay loam with fragipan.	do.	2-18	
	Berks	Loam and silty loam with shale.	Loam and silty loam with shale.	do.	18-35	

Kentucky soil associations

(Source: Kentucky Soil Conservation Service, 1975)

Soil association: Symbol	Soil association: Major soil series[1]	Soil description: Surface horizons	Soil description: Sub-soils	Soil description: Drainage	Normal slope range (percent)	Remarks
A2	Huntington	Dark-colored, silty loam.	Fine silty loam.	Well drained.	0-2	Located on the Ohio River flood plain and terraces. Minor soils are Ashton, Newark, Nolin, Otwell, Weinbach, and Wheeling.
	Melvin	Silty loam.	Silty-clay loam.	Poorly drained.		
A6	Elk	Dark-colored, silty loam.	Silty-clay loam.	Well drained.	0-12	Minor soils are Huntington, Licking, McGary, Newark, Otwell, Sciotoville, and Wheeling.
	Weinbach	Light-colored, silty loam with fragipan.	Dark brown, somewhat compacted silt loam.	Poorly drained.	0-2	
	Melvin	Silty loam.	Silty-clay loam.	Poorly drained.	0-2	
B1	Memphis	Silty loam.	Firm, silty-clay loam.	Well drained.	2-30	Formed in loess, extensive on broad ridges and side slopes. Strongly acidic soils. Minor soils are Calloway, Collins, Falaya, Grenada, and Wellston.
	Loring	Silty loam.	Slightly sticky, silty clay loam with fragipan.	do.	2-12	
C1	Zanesville	Silty loam.	Firm, silty-clay loam with fragipans.	Well drained.	2-12	Formed in a thin layer of loess and in material weathered from sandstone and siltstone. Located on undulating broad ridge tops and steep side slopes. Minor soils are Belknap, Clifty, DeKalb, Johnsburg, Sadler, Stendal, Weikert, and Wellston.
	Frandorf	Strongly acid, silty loam.	Strongly acid, silty-clay loam.	do.	6-50	
C3	Loring	Silty clay loam.	Compact, silt loam with fragipan.	Well drained.	2-12	Formed in loess on rolling upland plain and is dissected by many small streams. Minor soils are Belknap, Collins, Frandorf, and Memphis.
	Wellston	Heavy silty loams.	Light, silty-clay loam.	do.	6-30	

[1] Major soils listed represent soil associations.

COAL PRODUCTION AND ESTIMATED RESERVES

Coal production in Indiana in 1978 totaled nearly 24 milllion tons,[1] and in Kentucky nearly 137 million tons.[2] In 1978, 64 percent of the coal produced in Indiana was mined in the seven counties represented in Area 33. Only about 1 percent (1.9 million tons) of Kentucky's total production was from the four counties within the study area. As of 1978, more than 400 million tons of coal had been mined from the southwestern Indiana counties, and 6.3 million tons had been mined from the Kentucky counties. In 1978, reserves in Area 33 were estimated to be nearly 6.5 billion tons.[3]

According to Carter and others (1974, p. III-6), commercial coal mines were opened in Kentucky in 1790 and in Indiana in 1812. Small strip-mine operations using horse-drawn scrapers worked outcrop areas overlain by only a few feet of loose, unconsolidated overburden. In 1840, strip mines produced 9,682 tons of coal in Indiana. As production demands increased, the industry turned to underground mines. By 1860 the industry was producing 100,000 tons of coal per year in Indiana. By the late 1930's the development of large excavating equipment and the increased efficiency of explosives had caused a resurgence of surface mining to a point where more than 50 percent of the coal produced in Indiana came from surface mines. In 1978, about 98 percent of the coal produced in Indiana came from surface mines. There were only 4 underground mines in Indiana in 1978 (Indiana Bureau of Mines and Mining, 1979) compared with about 500 in 1920 (Carter and others, 1974, p. III-7).

In Indiana, there are nine major coal seams in Pennyslvanian rock (Carter and others, 1974, p. III-10). The average thickness of the seams is 4.4 feet. Nearly half of the coal produced in Indiana is from Coal V (Springfield coal). In Kentucky there are 31 different coal seams, but only about 6 are commercially significant. About 50 percent of the coal produced in Kentucky is removed from multiseam beds. Eighty percent of the coal removed from single seams is Number 9 coal in the Carbondale Formation whose thickness average just under 5 feet. The coals in Indiana and Kentucky are generally high in sulfur and are highly volatile bituminous type B or C coals.

Coal production and estimated coal reserves by county for Area 33 from 1790 through 1978 are listed in table 1.7. Estimates of coal reserves are subject to revision, owing to advances in mining technology. Carter and others (1974, p. III-11), Currens and Smith (1977), and Wier (1973, p. 21) summarized the coal production figures through 1971. Data from 1972 through 1978 are from annual reports of the Indiana Bureau of Mines and Mining (1973-79) and the Kentucky Department of Mines and Minerals (1973-79). Maps showing locations of active surface and underground coal mines in some of the counties in southwestern Indiana are available from the Indiana Department of Natural Resources (1980). Maps showing locations of areas strip mined for coal (Powell, 1976) and of active mines (Powell, 1977) are also available for southwestern Indiana.

[1] Indiana Bureau of Mines and Mining, 1979.
[2] V. Norris, Kentucky Department of Mines and Minerals, written commun., March 1980.
[3] D. Eggart, Indiana Geological Survey, written commun., March 1980; and, for Kentucky, Carter and others, 1974, p. IV-38.

Table 1.7.--Coal production and estimates of reserves in southern Indiana (1812-1978) and northern Kentucky (1790-1978)

[Source of data: Indiana--Donald L. Eggart, Indiana Geological Survey, written commun., March 1980; and Kentucky--Carter and others, 1974, p. IV-38]

Counties	Coal produced in Indiana 1812-1978[1] (tons)	Estimates of recoverable reserves (thousand tons)[2]		
		Strippable reserves	Underground reserves	Total
Dubois	994,051	3,963	3,978	7,964
Gibson	45,393,580	0	2,231,226	2,231,226
Perry	1,580,548	0	27,956	27,956
Pike	152,388,298	188,469	369,699	558,168
Spencer	3,776,313	48,484	0	48,484
Vanderburgh	11,286,000	0	1,083,455	1,083,455
Warrick	186,777,998	231,504	515,431	746,935

Counties	Coal produced in Kentucky 1790-1978[1] (tons)	Estimated recoverable reserves (thousand short tons)[2]		
		Strippable reserves	Underground reserves	Total
Breckinridge	75	0	0	0
Daviess	35,024	57,813	76,661	134,474
Hancock	3,585	13,062	1,224	14,286
Henderson	24,247	165,153	1,157,594	1,322,747

1 The tonnages represent coal production by county and, therefore, should not be totaled to represent production within the study area. Several counties are represented within more than one study area, and their production is also listed in other study area reports.

2 These tonnages are subject to revision as mining techniques change. The current figures are based on removing 90 feet of overburden. Present technology allows for removal of as much as 150 feet of overburden. As technology and equipment are improved, thickness of overburden removed the amount of strippable reserves will increase. Also, the techniques for calculating coal reserves are improving and the number and the depth of test wells are increasing.

MOST OF LAND IS FARMED OR FORESTED

The principle uses of land within the study area are agricultural (51 percent) and forested (42 percent). Land disturbed by mining activities accounts for less than 1 percent of the total land area. Nearly one-half the total area disturbed by mining is Warrick County.

General land-use categories by area and percent of total area for the 12 counties discussed in this report are listed in the adjacent table 1.8. Land-use categories are described in the list that follows.

Agriculture--row crop, pasture, small grains, and barren rural lands.
Urban--residential, commercial, industrial, institutions, and recreational.
Forested--comercial forest, and wooded farm lots.
Water--lakes, ponds, and rivers.
Wetland--marsh or bog areas.
Mined--surface area disturbed by strip or underground mines.
Other--miscellaneous land uses not generally catergorized.

Land-use maps are available for most of the counties in Indiana through the Indiana State Board of Health Stream Pollution Control Board (1980), at a scale of 1:250,000.

Limits on the mining of prime farmland (land best suited for producing food, fiber, forage, and oil seed crops) are given in paragraph 779.27 of the Surface Mining Control and Reclamation Act. The adjacent map (fig. 1.8) shows areas of prime farmland (U.S. Soil Conservation Service, 1977b).

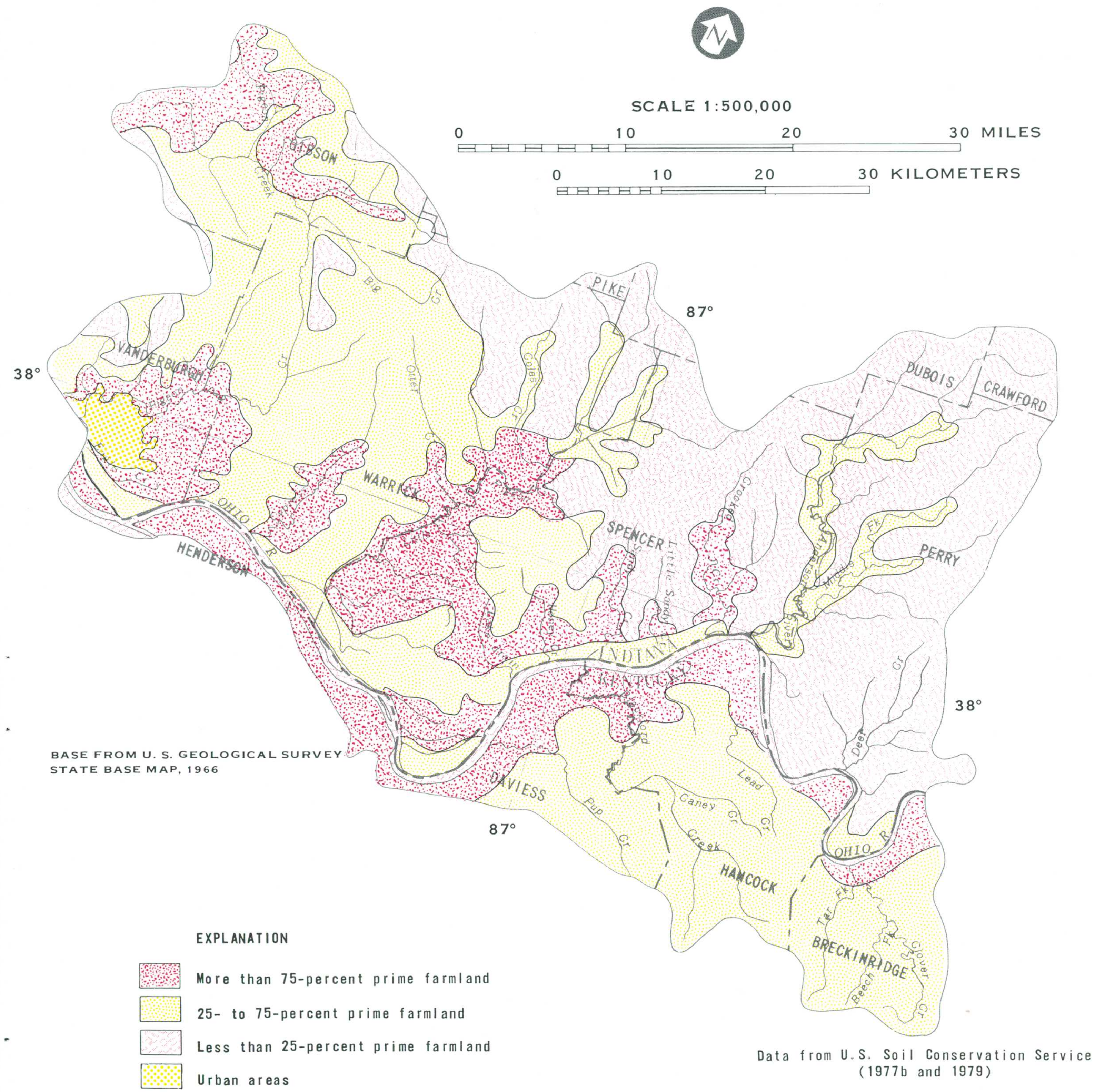


Figure 1.8. -- Prime farmland.

Table 1.8.--Land use by county for southwestern Indiana and northern Kentucky

[Land use, in acres/percent; A, less than 0.1 percent; B, no data compiled]

County	Agriculture	Urban	Forested	Water	Wetland	Mined	Other	Total (acres)
	acres/percent							
Crawford[1]	76,744 38.4	10,783 5.4	108,813 54.5	2,357 1.2	9 A	1,047 0.5	90 A	199,743
Dubois[1]	175,283 63.2	10,405 3.8	84,251 30.4	3,969 1.4	203 .1	347 .1	2,663 1	277,121
Gibson[1,2]	222,722 69.8	9,570 3.0	78,443 24.6	3,103 1	2,140 .7	177 A	2,757 .9	318,912
Perry[1]	87,209 35.5	1,888 .8	153,799 62.6	1,441 .6	21 A	384 .1	1,018 .4	245,760
Pike[1,2]	76,934 35.9	15,356 7.2	116,285 54.2	395 .2	706 .3	3,792 1.8	935 .4	214,403
Spencer	189,340 74.8	5,096 2	55,570 21.9	1,098 .4	212 .1	1,671 .6	581 .2	253,568
Warrick[1,2]	94,216 37.6	11,498 4.6	125,352 50.1	3,090 1.2	675 .3	13,228 5.3	2,184 .9	250,243
Vanderburgh[1,2]	79,242 51.4	29,730 19.3	43,260 28	B	B	B	2,008 1.3	154,240
Breckinridge[3]	75,012 20.8	6,561 1.8	273,708 75.8	2,066 0.6	B	B	3,613 1	360,960
Daviess[4]	197,691 64.5	15,794 5.1	81,683 26.6	8,178 2.7	870 .3	1,207 .4	1,367 .4	306,790
Hancock[4]	42,231 33.3	665 .5	78,354 61.9	4,693 3.7	371 .3	241 .2	178 .1	126,733
Henderson[4]	212,069 70.8	11,965 4.0	52,996 17.7	15,630 5.2	2,931 1.0	2,321 .8	1,374 .5	299,286
Total	1,528,593 50.9	129,311 4.3	1,252,514 41.6	46,020 1.5	8,138 .3	24,415 .8	18,768 .6	3,007,759

[1]Kris Kothe, Indiana State Planning Services Agency, written commun., December 1979.
[2]Marcia A. Werling, Southwest Indiana and Kentucky Regional Council of Governments, written commun., December 1979.
[3]Wayne Kimbell, Lincoln Trail Area Development District, Kentucky, written commun., February 1980.
[4]Rick Hiten, Green River Area Development District, Kentucky, written commun., February 1980.

DESCRIPTION OF U.S. GEOLOGICAL SURVEY GAGING STATIONS

Discharge data have been collected at 4 gaging stations, 5 low-flow partial-record stations, 4 crest-stage partial-record stations, and 58 miscellaneous measurement sites.

Discharge data analyzed for this report have been collected at 4 gaging stations, 5 low-flow partial-record stations, 4 crest-stage partial-record stations, and at 58 miscellaneous measurement sites. Data from miscellaneous measurements are available from the Geological Survey office in Indianapolis.

The gaging station on the Middle Fork Anderson River at Bristow (03303300) recorded three separate periods of hydrologic record. From August 1961 to June 1967, the flow was unregulated; from June 1967 to October 1972, the flow was affected by construction of three dams by the U.S. Forest Service and the U.S. Soil Conservation Service at sites upstream from the gage; from October 1972 to the present (1981) time, the flow has been regulated by the reservoirs. Discharge data for the water years 1962 through 1966 and 1972 through 1979 were analyzed for this report.

Flow in Pigeon Creek at Evansville (03322100) is partially affected by backwater from the Ohio River, which results in periods of negative flow. Therefore, the analyses are only representative of the flow conditions at the gaging station and have little transfer value.

The gaging station on Little Pigeon Creek near Tennyson (03304000) was established in October 1943 and was discontinued in September 1947. Owing to the short length of record, only an analysis of low flow was made at this station. Further information on this location is available in U.S. Geological Survey Water-Supply Paper 1305 (Wells, 1957, p. 523).

The Ohio River is probably not representative of the hydrology for the area discussed in this report. Therefore, analyses for the river are not included. Discharge data for the river can be obtained from U.S. Geological Survey annual reports entitled, "Water Resources Data for Indiana" and "Water Resources Data for Kentucky." Miscellaneous information for the Geological Survey gaging stations and crest-stage gages is presented in the adjoining table 2.1. Locations of the stations are shown on the following map (fig. 2.1).

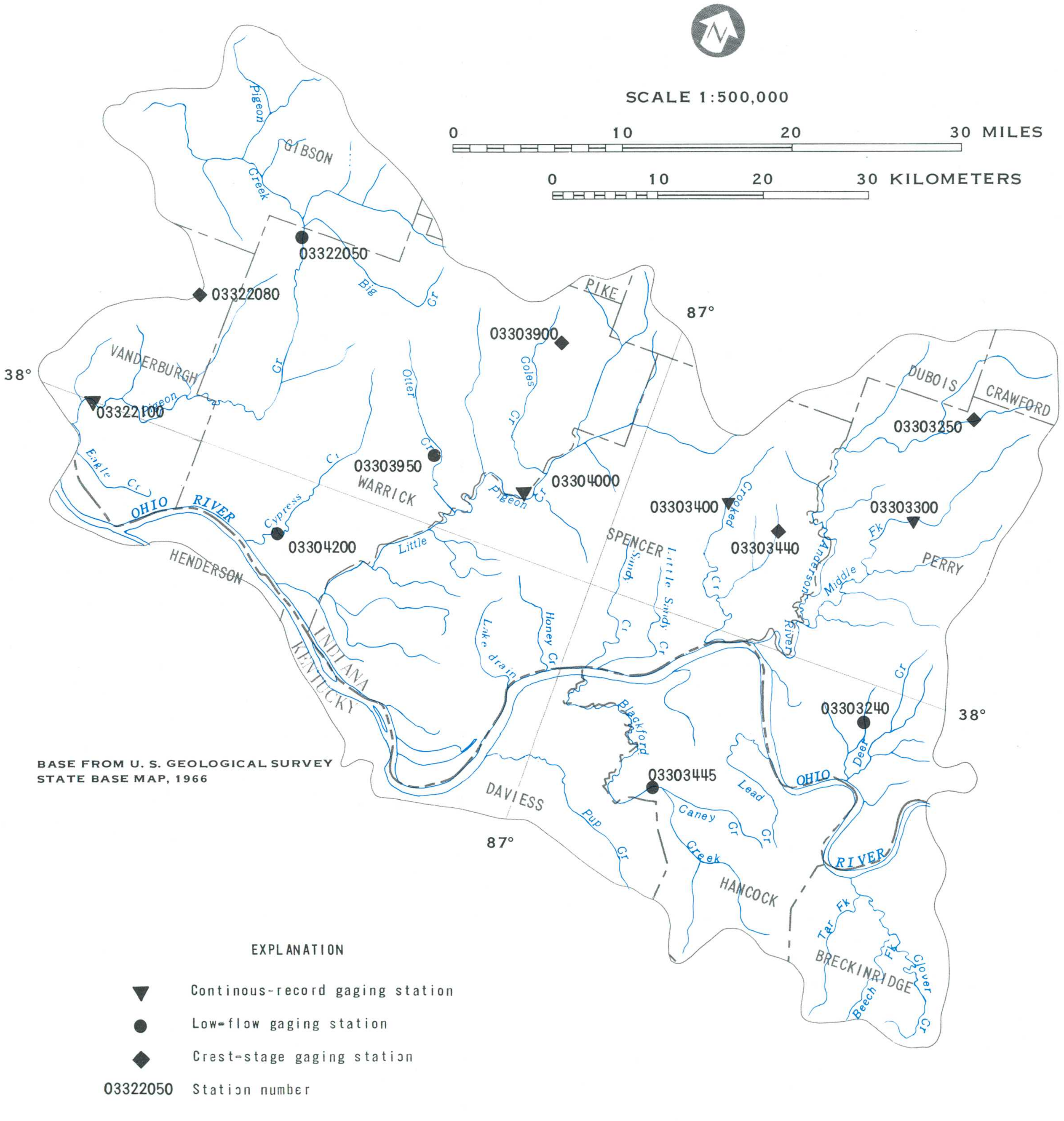


Figure 2.1. -- Gaging stations.

Table 2.1.--Gaging stations

Station name	Station number	Drainage area (mi^2)	Period of record	Station type
Middle Fk Anderson River at Bristow, Ind.	03303300	39.8	1961 to present	Continuous.
Crooked Cr nr Santa Claus, Ind.	03303400	7.86	1969 to present	Do.
Pigeon Cr at Evansville, Ind.	03322100	323	1960 to present	Do.
Little Pigeon Cr near Tennyson, Ind.	03304000	150	1943 to 1947	Do.
Blackford Cr near Hawsville, Ky.	03303445	71.8	1975 to present	Low flow.
Deer Cr near Cannelton, Ind.	03303240	8.7	1974 to 1979	Do.
Otter Cr near DeGonia Springs, Ind.	03303950	30.1	do.	Do.
Cypress Cr near Newburg, Ind.	03304200	56	1972 to 1974	Do.
Pigeon Cr near Buckskin, Ind.	03322050	184	1961 to 1969	Do.
Sigler Cr trib at Uniontown, Ind.	03303250	.15	1973 to present	Crest stage.
E. Fk Crooked Cr trib near Fulda, Ind.	03303440	.26	do.	Do.
Little Red Cr trib near Heilman, Ind.	03303900	.25	do.	Do.
Bluegrass Cr trib near Daylight, Ind.	03322080	.42	1973 to 1978	Do.

ESTIMATES OF 7-DAY, 10-YEAR LOW FLOW PRESENTED FOR NINE STATIONS

The 7-day, 10-year low flow is defined as the lowest average rate of flow for 7 consecutive days to which streamflow can be expected to decline in 1 year out of 10. The 7-day, 10-year low flow is commonly zero because surficial aquifers are minimal and their yields are commonly very low.

Estimates of the 7-day, 10-year low flow are presented for the study area. Two types of analyses were used for this report. Where sufficient continuous record was available, a Geological Survey computer program (Hutchison, 1975) was used for a statistical analysis. The program fits the low-flow values to a log-Pearson Type III frequency distribution. For partial-record stations, the frequency was estimated by correlating the measured flows with concurrent flows at a long-term, continuous-record index site where the low-flow frequency curve has been defined. Streamflow for partial record sites was measured during periods of base flow, when flow is primarily from ground-water storage.

The Wabash Lowland is underlain by siltstone and shale beds and is capped by a layer of glacial till in the north section (Schneider, 1966). Surficial aquifers in the area are minimal. Therefore, the 7-day, 10-year low flow of the streams in the area is commonly zero, except in the outwash areas along the major streams.

Locations of the sites where streamflow data have been used to calculate 7-day, 10-year low flow are shown on the following map (fig. 2.2). The calculated values are listed in the adjoining table 2.2.

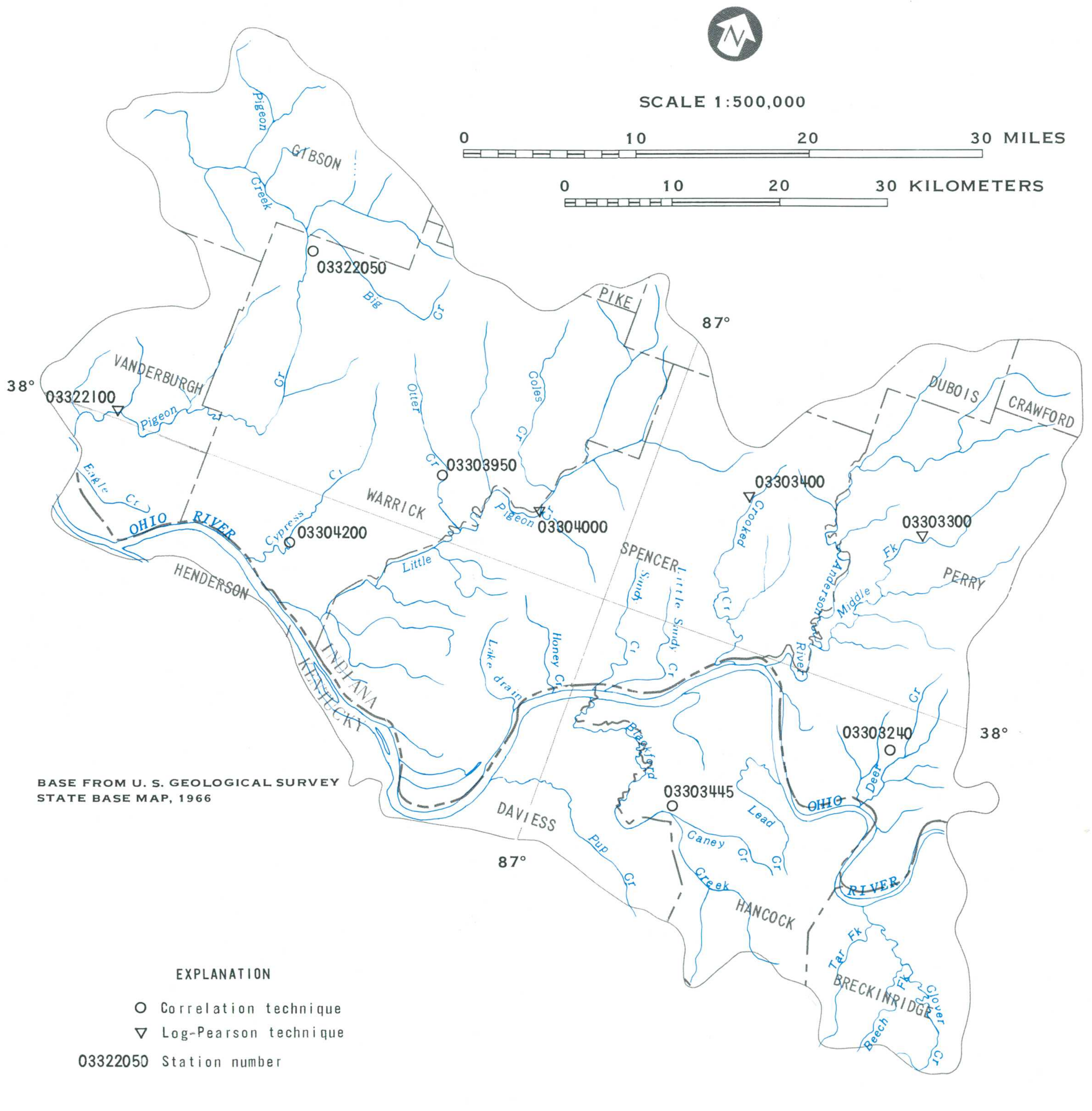


Figure 2.2.-- Data sites for 7-day, 10-year low-flow calculations.

Table 2.2.--Seven-day, 10-year low flow

Station name	Station No.	Drainage area (mi^2)	Q7,10 (ft^3/s)
Log-Pearson technique			
Crooked Cr nr Santa Claus, Ind.	03303400	7.86	0
Pigeon Cr at Evansville, Ind.	03322100	323	[1]0
Middle Fk Anderson R at Bristow, Ind.	03303300	39.8	0
Little Pigeon Cr nr Tennyson, Ind.	03304000	150	0
Correlation technique			
Blackford Cr nr Hawsville, Ky.	03303445	71.8	(2)
Deer Cr nr Cannelton, Ind.	03303240	8.7	0
Cypress Cr nr Newburg, Ind.	03304200	56	(2)
Otter Cr nr DeGonia Springs, Ind.	03303950	30.1	.07
Pigeon Cr nr Buckskin, Ind.	03322050	184	0

[1]Affected by backwater from the Ohio River.
[2]Insufficient data to establish 7-day, 10-year low flow.

FLOOD FREQUENCIES ESTIMATED FOR SELECTED GAGING STATIONS

Flood magnitude is primarily dependent on the net precipitation in a drainage basin. The net precipitation, also referred to as precipitation index, indicates that flood magnitudes in the study area would be greater than those in other parts of Indiana.

The 10-, 25-, 50-, and 100-year floods are floods of a magnitude that are expected to be equaled or exceeded once during any 10-, 25-, 50-, or 100-year recurrence interval. These floods have a 10-, 4-, 2-, or 1-percent chance, respectively, of being equaled or exceeded during any year.

Estimates of the 10-, 25-, 50-, and 100-year flood frequency recurrence interval are presented for selected gaging stations. The recurrence interval of the flood frequency represents the long-term average period between floods of a specific magnitude; however, floods of a higher magnitude can occur at a shorter interval or even within a given year.

Discharge records of less than 5 years are insufficient to compute flood peaks. Where 5 to 10 years of discharge records were available, the 10-year flood was computed. Where records for more than 10 years were available, flood frequencies of 10-, 25-, 50-, and 100-year were computed.

Davis (1974) and Gold (1980) prepared manuals that provide methods for estimating the magnitude and frequency of floods on unregulated and unurbanized Indiana streams. Additional methods are provided by the U.S. Soil Conservation Service (1975b) for areas less than 2,000 acres. Davis (1974) and Gold (1980) found that precipitation minus snowfall and evapotranspiration is the controlling factor on flood magnitude in the study area. The precipitation index is greater in this area than in most other parts of Indiana (Davis, 1974). Therefore, flood magnitudes estimated with the precipitation index would also be greater than those in other parts of the State.

Locations of the six gaging stations used to compute flood peaks within the study area are shown on the following map (fig. 2.3a), and computed flood peaks are listed in the adjoining table 2.3. The relation between discharge and drainage area for four creeks (fig. 2.3b) and one ditch (fig. 2.3c) is shown in the adjoining illustrations.

Data were provided by William J. Andrews, Indiana Department of Natural Resources (written commun., August 1979).

Table 2.3 -- Estimates of flood peaks at selected gaging stations

[Ir, insufficient record, *, record reflects regulated condition (1972-79)]

Station name	Station No.	Drainage area (mi^2)	Years of record	Flood peaks (ft^3/s) 10 yr	25 yr	50 yr	100 yr
E. Fk Crooked Cr trib nr Fulda, Ind.	03303440	0.26	7	232	Ir	Ir	Ir
Sigler Cr trib at Uniontown, Ind.	03303250	.15	7	111	Ir	Ir	Ir
Little Red Cr trib nr Heilman, Ind.	03303900	.25	7	110	Ir	Ir	Ir
Blue Grass Cr trib nr Daylight, Ind.	03322080	.42	6	208	Ir	Ir	Ir
Crooked Cr nr Santa Claus, Ind.	03303400	7.86	10	2,440	3,170	3,730	4,300
Middle Fk Anderson R at Bristow, Ind.	03303300	39.8	*8	2,300	Ir	Ir	Ir

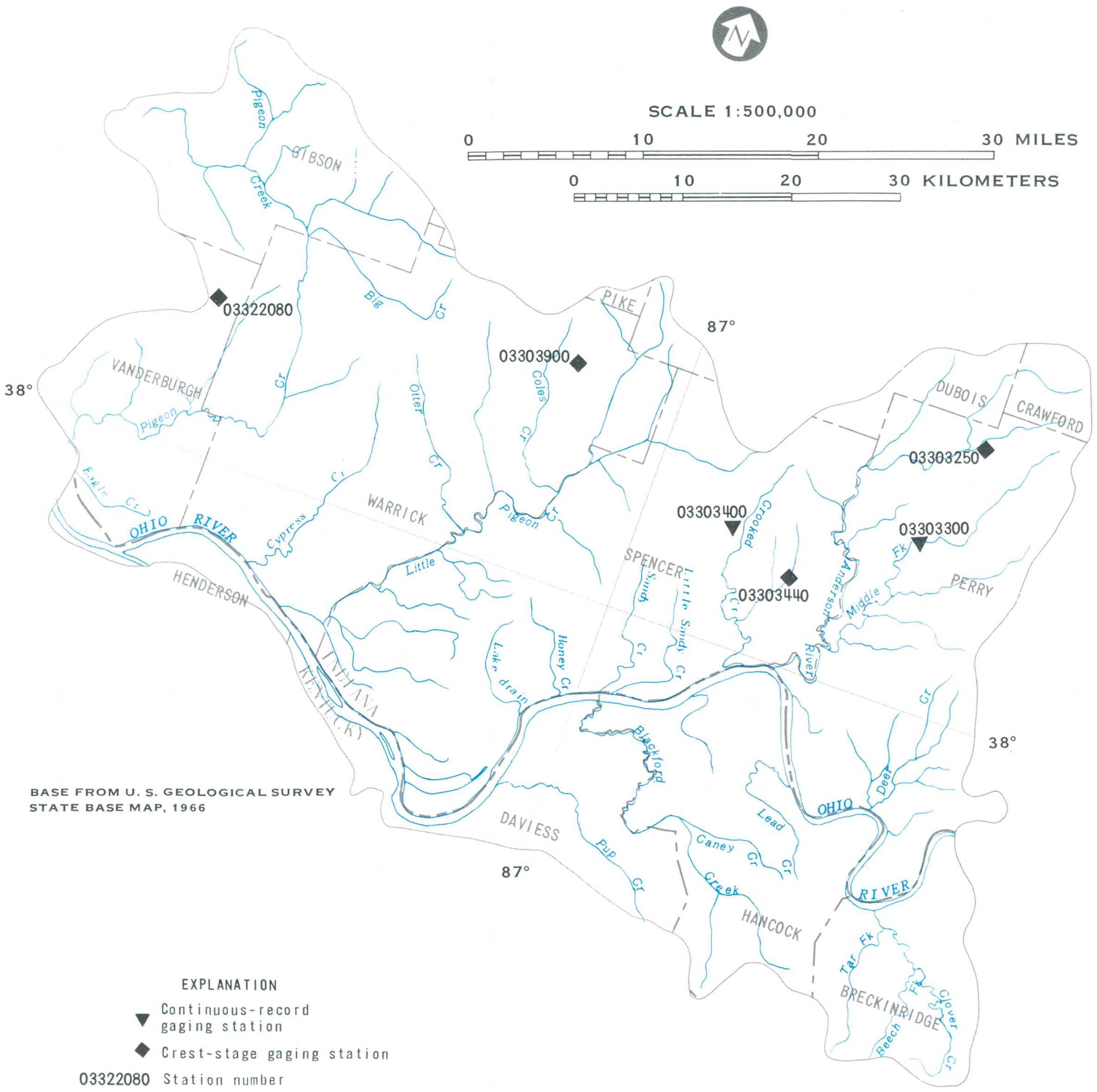
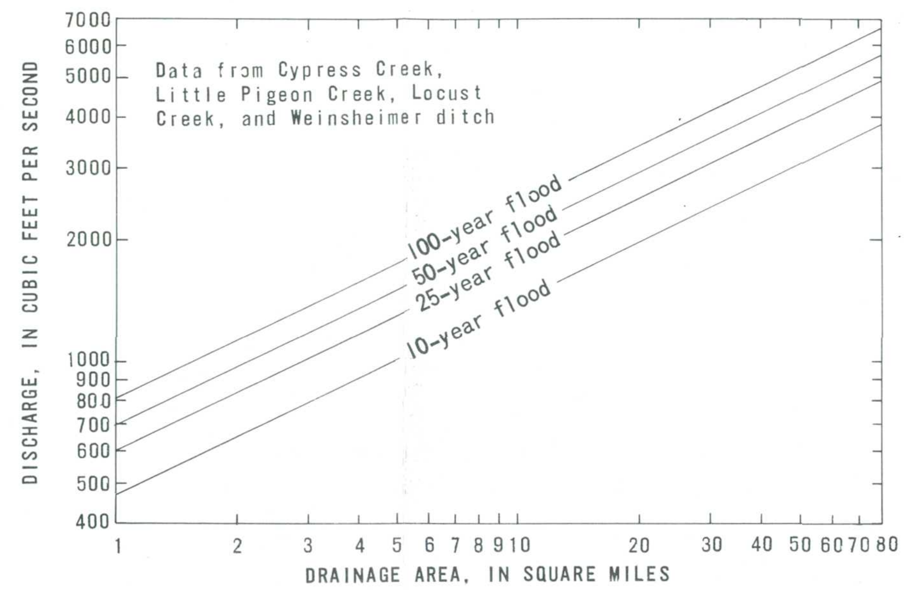
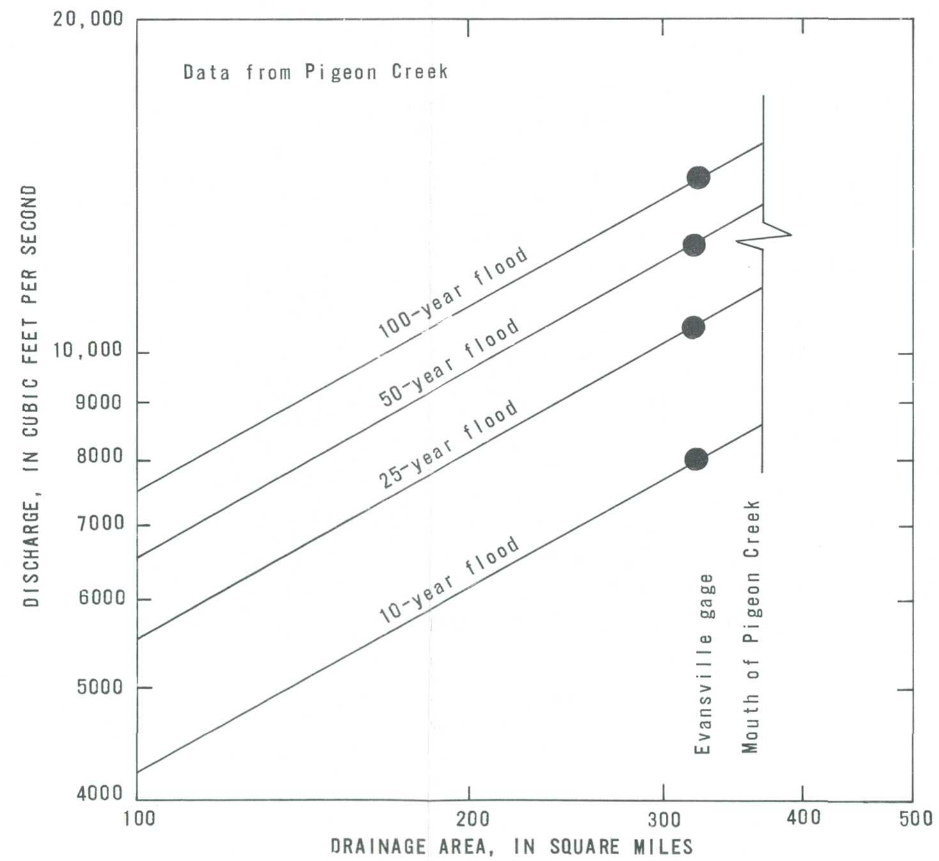


Figure 2.3a.-- Data sites for flood-frequency calculations.





Data from Indiana Department of Natural Resources (1979)

Figure 2.3b and 2.3c.-- Drainage-area discharge curves.

DURATION CURVES FOR SELECTED LOCATIONS INDICATE THAT FLOW IS NOT WELL SUSTAINED

Flow-duration curves show the percent of time specified discharge were equaled or exceeded during a given period of record. Curves developed for the Middle Fork Anderson River, Crooked Creek, and Pigeon Creek show that streamflow in the study area is not well sustained.

Duration curves are presented for three gaging stations whose locations are shown on the adjoining map (fig. 2.4a). Two curves were developed for the Middle Fork Anderson River at Bristow (03303300), one for 1962-66, before reservoir construction, and a second curve for 1972-79 after construction (fig. 2.4b). The duration curve for Crooked Creek near Santa Claus (03303400) was developed for the period of record 1970-79, and the duration curve for Pigeon Creek at Evansville (03322100) was developed for the period of record 1962-78. Because the gaging station on Pigeon Creek is often affected by backwater from the Ohio River, the duration curve for Pigeon Creek only represents flow conditions at the gage and is not transferable to other sites.

A Geological Survey computer program (Hutchison, 1975) was used to compute flow duration by a magnitude-frequency analysis of daily discharges. The computed values were used to construct the duration curves shown in the adjoining illustration (fig. 2.4b). The steep slopes at the lower end of the flow-duration curves indicate that streamflow is not sustained and that runoff is primarily a response to precipitation. These conditions are due to the nature of the surficial aquifers, which are minimal and are usually of very low yield.

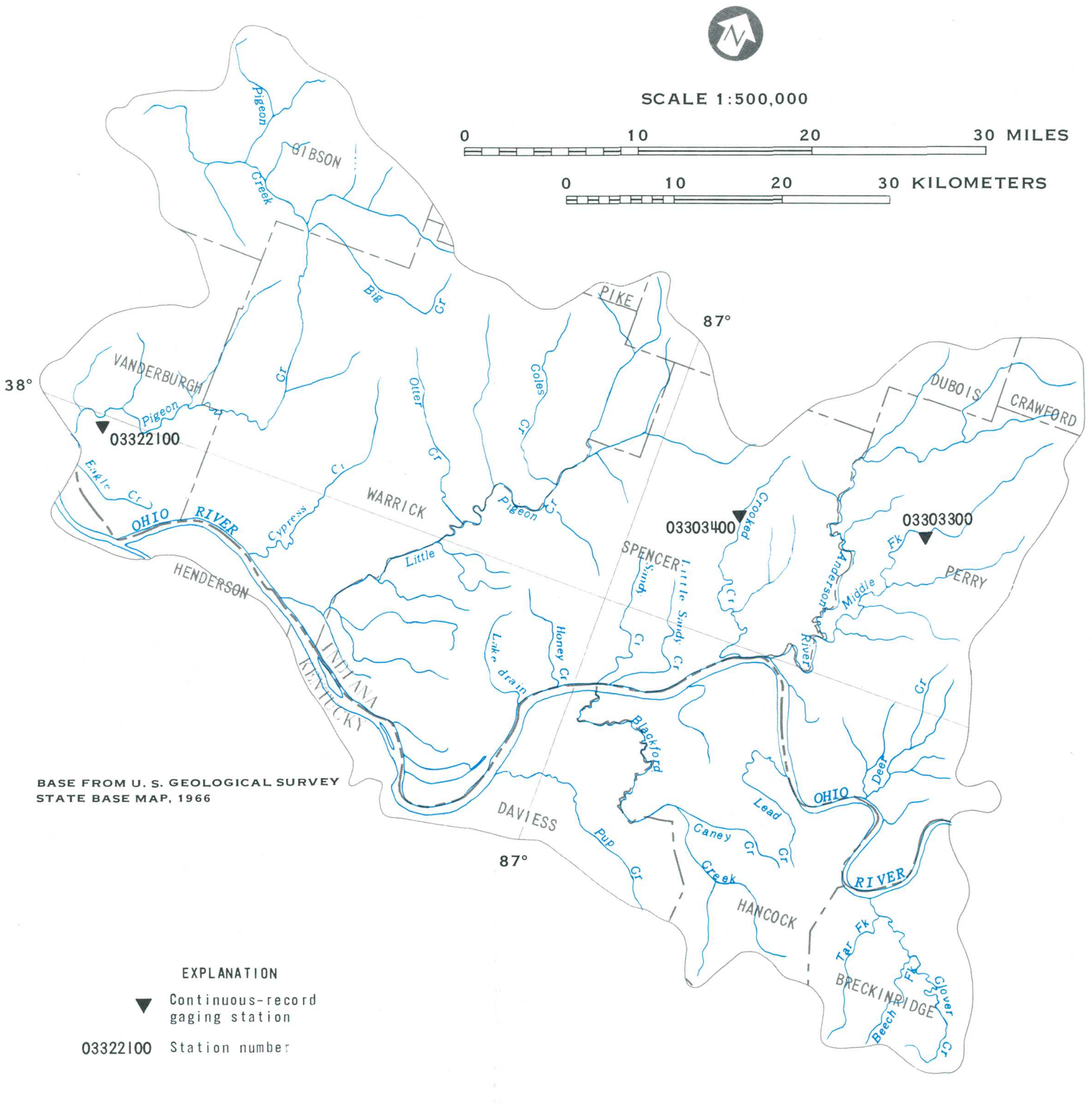


Figure 2.4a.-- Data sites for computation of duration curves.

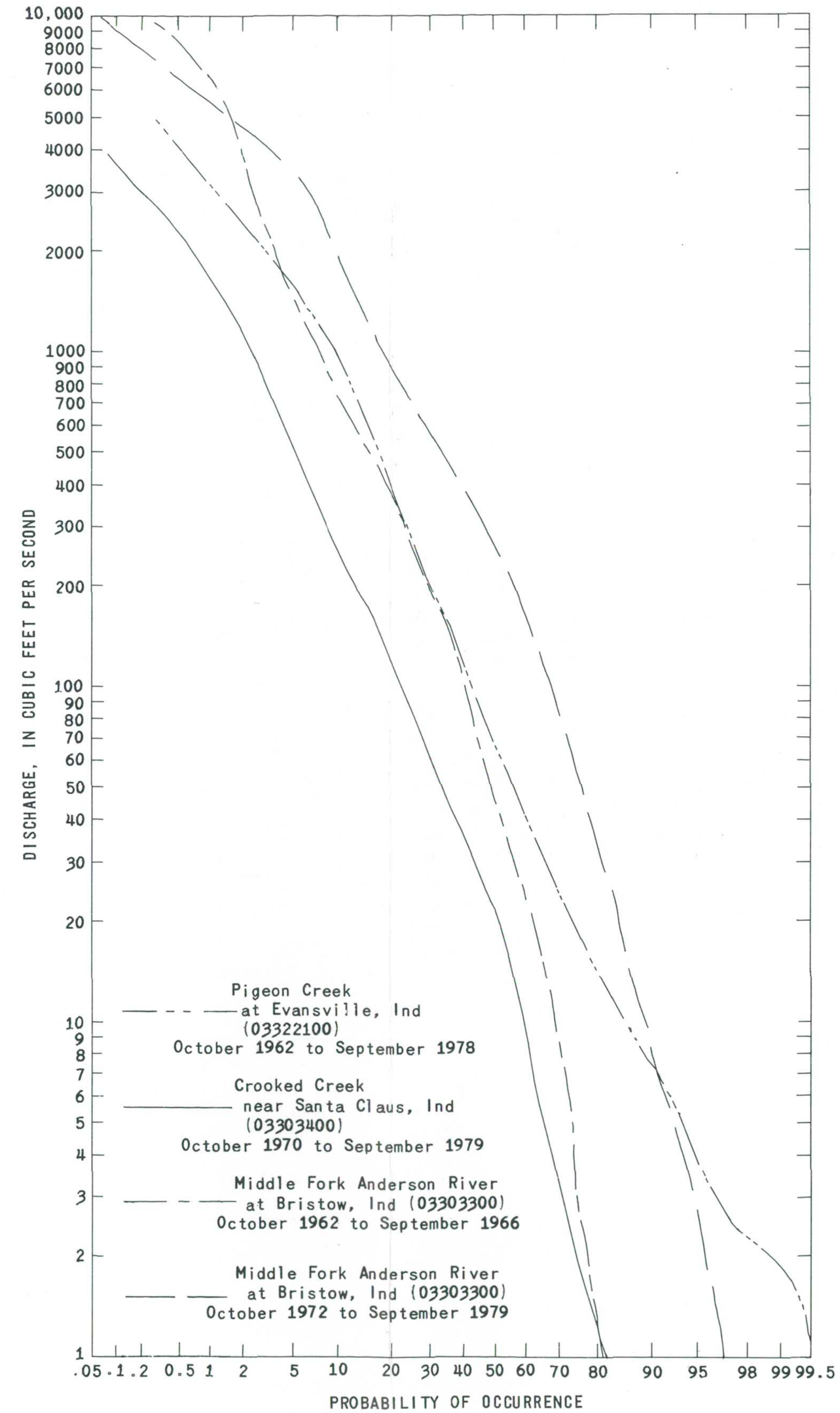


Figure 2.4b.-- Duration curves.

AVERAGE ANNUAL FLOW TENDS TO BE LOW, AND AVERAGE MONTHLY FLOWS AT TIMES ARE ZERO OR NEAR ZERO

Average annual flow for the area tends to be low, and mean monthly is commonly near zero. Streamflow is primarily the result of precipitation. There is little sustained flow because stream slopes are steep and surficial aquifers are minimal and usually have very low yield.

Average discharges at three gaging stations are presented in the adjoining illustration (fig. 2.5b). A Geological Survey computer program (Hutchison, 1975) was used to calculate monthly and annual average flows from daily discharges. The computed values were used to construct bar graphs for the Middle Fork Anderson River at Bristow (03303300), Crooked Creek near Santa Claus (03303400), and Pigeon Creek at Evansville (03322100) that show mean monthly discharges, the highest and lowest mean discharge by month, and the mean annual discharge for the periods of record (fig. 2.5b). Locations of the stations are shown on the following map (fig. 2.5a). Two periods of record were used for the Middle Fork Anderson River (03303300), one before reservoir construction (1962-66) and one after construction (1972-79). Average flow for Crooked Creek near Santa Claus (03303400) was computed for the period of record from 1970 through 1979, and average flow for Pigeon Creek at Evansville (03322100) was computed for the period of record from 1962 through 1978. Because backwater from the Ohio River affects the Pigeon Creek gage, the average flows only represent that site and are not transferable to other sites.

Average flows in the area tend to be low. Near zero monthly mean flows have been recorded in almost every month at all gaged sites. The low streamflow is primarily due to precipitation events. There is little sustained flow because stream slopes are steep and surficial aquifers are minimal and usually have very low yield.

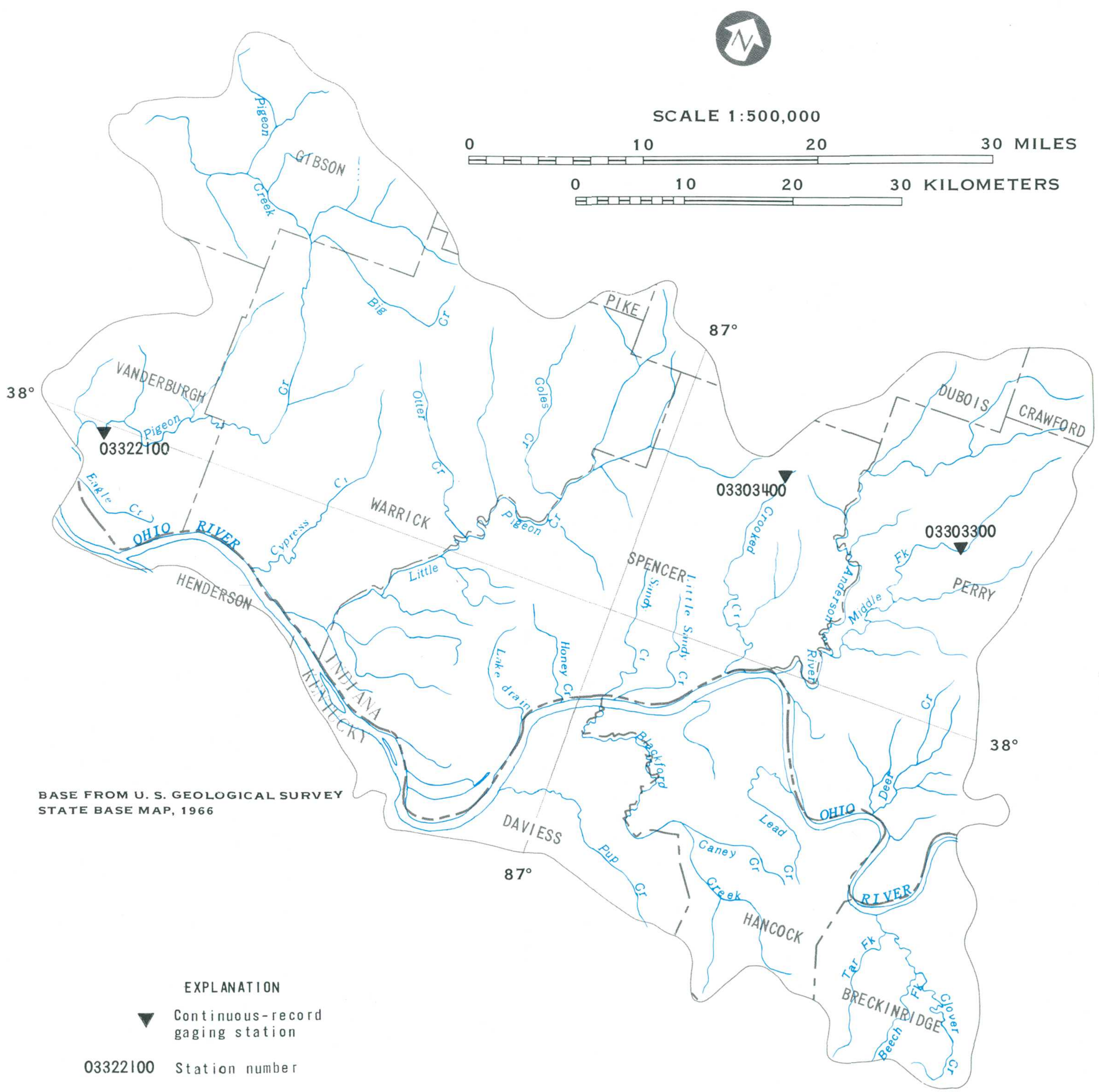


Figure 2.5a.-- Data sites for average-flow calculations.

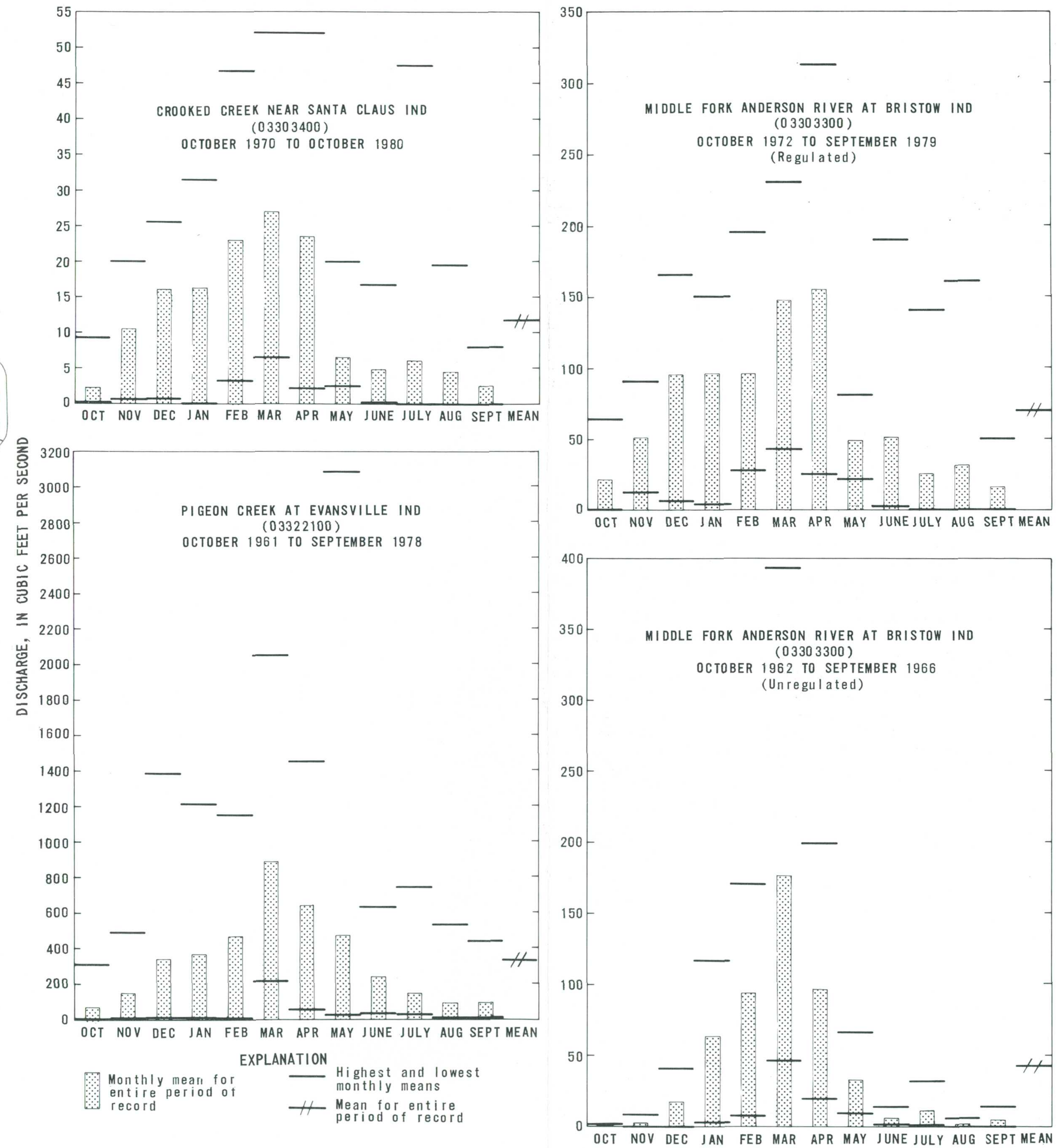


Figure 2.5b.-- Average flows.

THREE MAJOR AQUIFERS IN SOUTHWESTERN INDIANA AND NORTHERN KENTUCKY

The bedrock (sandstone) aquifer is the most extensive aquifer of Pennsylvanian System. The alluvial aquifer associated with the Ohio River is less extensive that the sandstone aquifer but yields more water. Sand and gravel aquifers in bedrock valleys tributary to the Ohio River yield less water than the sandstone and alluvial aquifers.

Rocks of Pennsylvanian age are composed of sandstone, shale, and limestone. The major water-bearing formations are the discontinuous sandstone units in the McLeansboro, Carbondale, and Raccoon Creek Groups (as used by the Indiana Geological Survey). Limestone and shale are usually denser than sandstone and are more like confining layers than aquifers (Pettijohn and Reussow, 1969). The Pennsylvanian System dips generally westward at 20 to 30 feet per mile. Aquifer thickness is not known, but sandstone formations in Vanderburgh County are commonly 20 to 60 feet thick.

Deposition of the Ohio River alluvial aquifer, a graded outwash, eroded the bedrock to form a valley that laterally confines the aquifer. The sediments grade from gravel and cobbles at the bottom of the aquifer to a layer of fine sand, silt, and clay at the top that may confine the aquifer in places. Throughout the study area, saturated thickness of the alluvial aquifer ranges generally from 60 to 140 feet. The saturated thickness is often controlled by navigational dams on the Ohio River. According to Gallaher and Price (1966), the water behind the dam at Cannelton, Ind., raised the saturated thickness of the aquifer by 25 feet. Near the edge of the outwash, the aquifer thins and the deposits become fine grained. The extent of the aquifer is shown in the adjoining map (fig. 3.1a).

Minor amounts of sand and gravel are found in some bedrock tributary valleys draining into the Ohio River bedrock valley. These aquifers are associated with lacustrine deposits that developed along with the alluvial outwash aquifer. The lacustrine clays and silts confine the sand and gravel into scattered aquifers that are finer textured, thinner, and narrower in extent than the alluvial aquifer.

Relative locations and thickness of the aquifers are shown in the adjoining generalized cross section (fig. 3.1b).

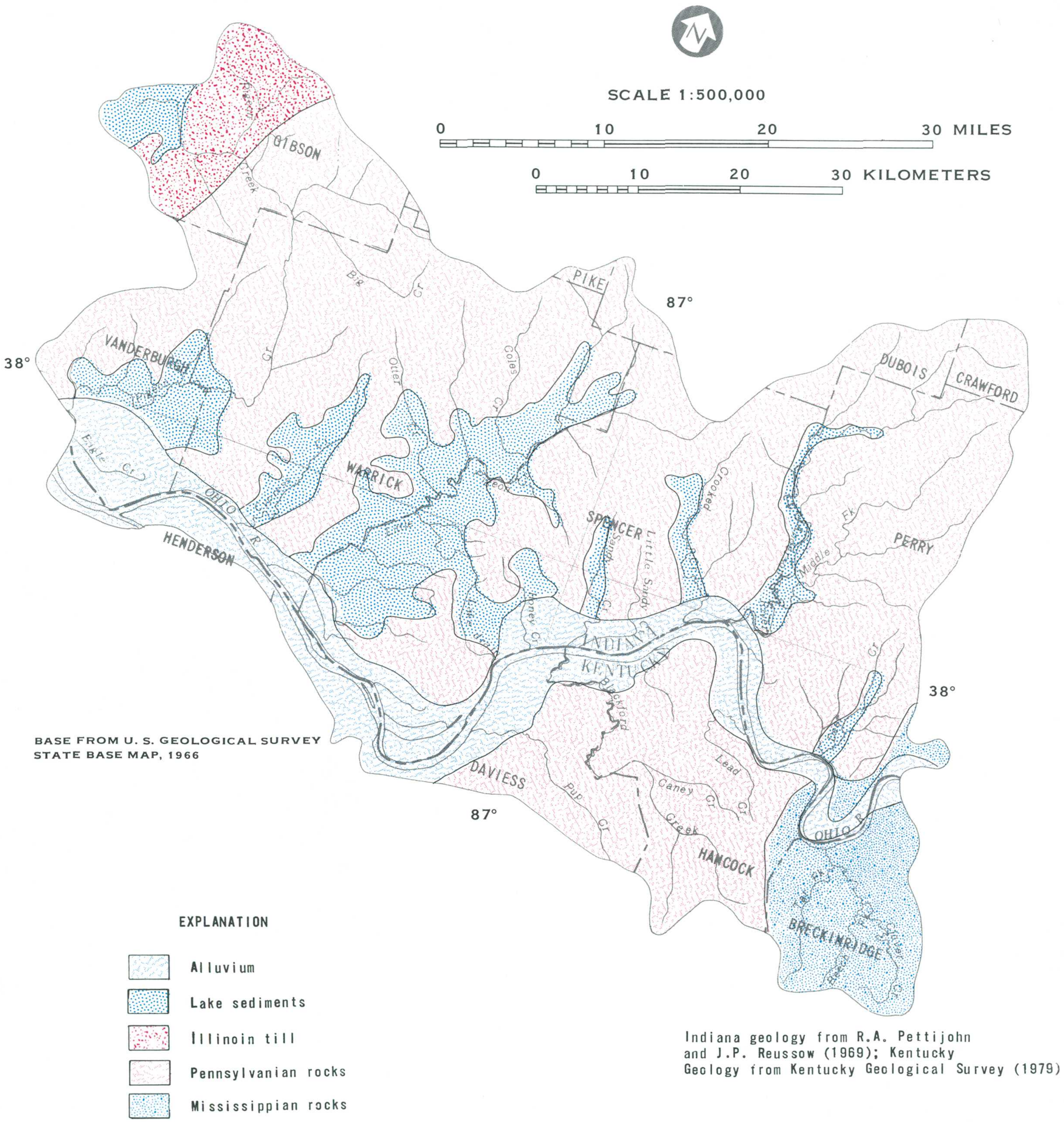


Figure 3.1a.-- Extent of potential water-yeilding formations.

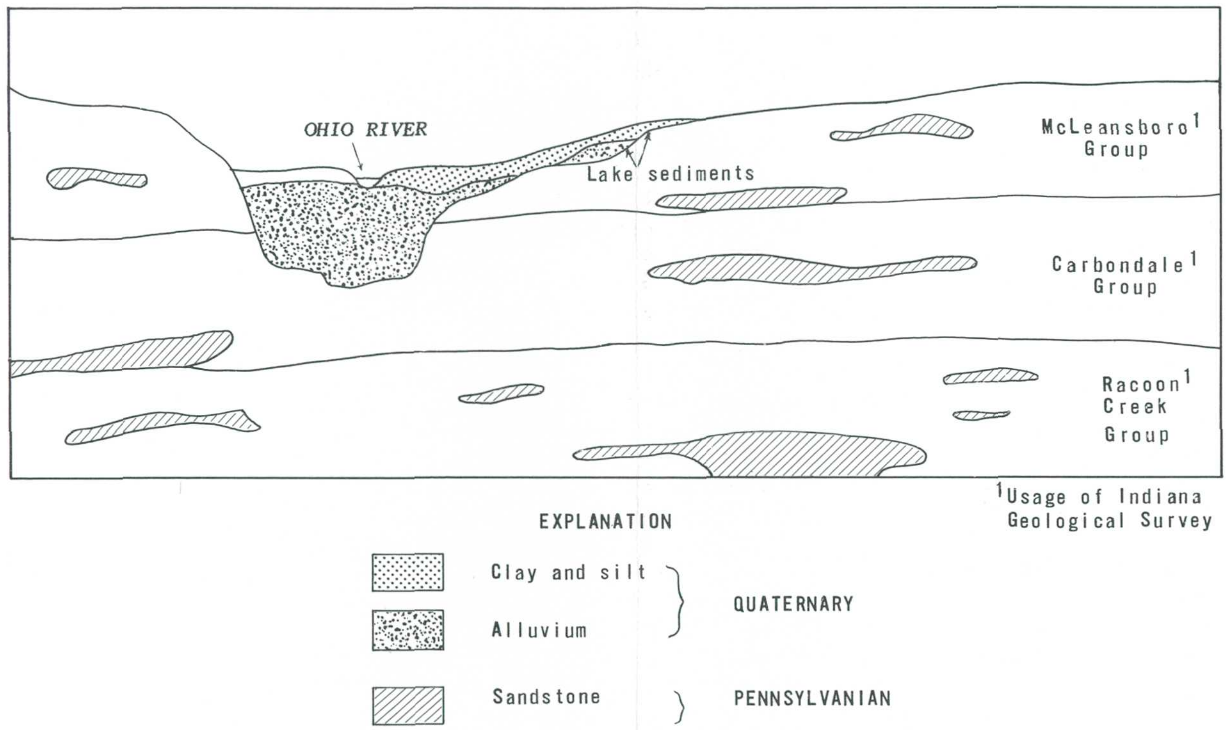


Figure 3.1b.-- Generalized cross section of aquifers.

ALLUVIAL AQUIFERS YIELD MORE THAN BEDROCK AQUIFERS BECAUSE OF DIFFERENT HYDRAULIC CHARACTERISTICS

The difference in hydraulic characteristics of the two aquifers is indicated by the range of well yields. In the bedrock aquifers of Pennsylvanian age, yield typically ranges from 1 to 30 gallons per minute, whereas in the Ohio River alluvial aquifer yields are as much as 3,000 gallons per minute and in the finer grained sand and gravels in tributary valleys near the Ohio River as much as 300 gallons per minute.

Two factors contribute to the low yield and potential dewatering of the aquifer: (1) the cemented structure of the sandstones and (2) the numerous layers of confining shale and limestone. These factors lower the hydraulic conductivity and lessen the vertical leakage to the sandstone aquifers. Cable and Wolf (1977) reported that hydraulic conductivity and maximum transmissivity in Vanderburgh County, Ind., are 10 (gal/d)/ft^2 and 1,000 (gal/d)/ft, respectively. Davis and others (1974) reported that the storage coefficient ranges from 4 x 10^{-5} to 9 x 10^{-4} for bedrock aquifers of Pennsylvanian age in the Western Coal Field region of Kentucky, which includes the south part of the study area.

The hydraulic conductivity and transmissivity of the alluvial aquifer along the Ohio River vary areally, but Gallaher and Price (1966) reported that the median hydraulic conductivity is 460 (gal/d)/ft^2. Storage coefficients may vary by several orders of magnitude, depending on whether the aquifer is confined or unconfined. Well yields may range from about 20 gallons per minute at the margin of the aquifer to about 3,000 gallons per minute in the areas of greatest saturated thickness (Pettijohn and Reussow, 1969).

Little information is available on the hydraulic characteristics of the tributary alluvium, but the characteristics are probably similar to those of the Ohio River outwash, only the values may be somewhat lower. Pettijohn and Reussow (1969) reported a potential well yield of 300 gallons per minute from the outwash.

Hydraulic characteristics for the different formations are listed in table 3.2.

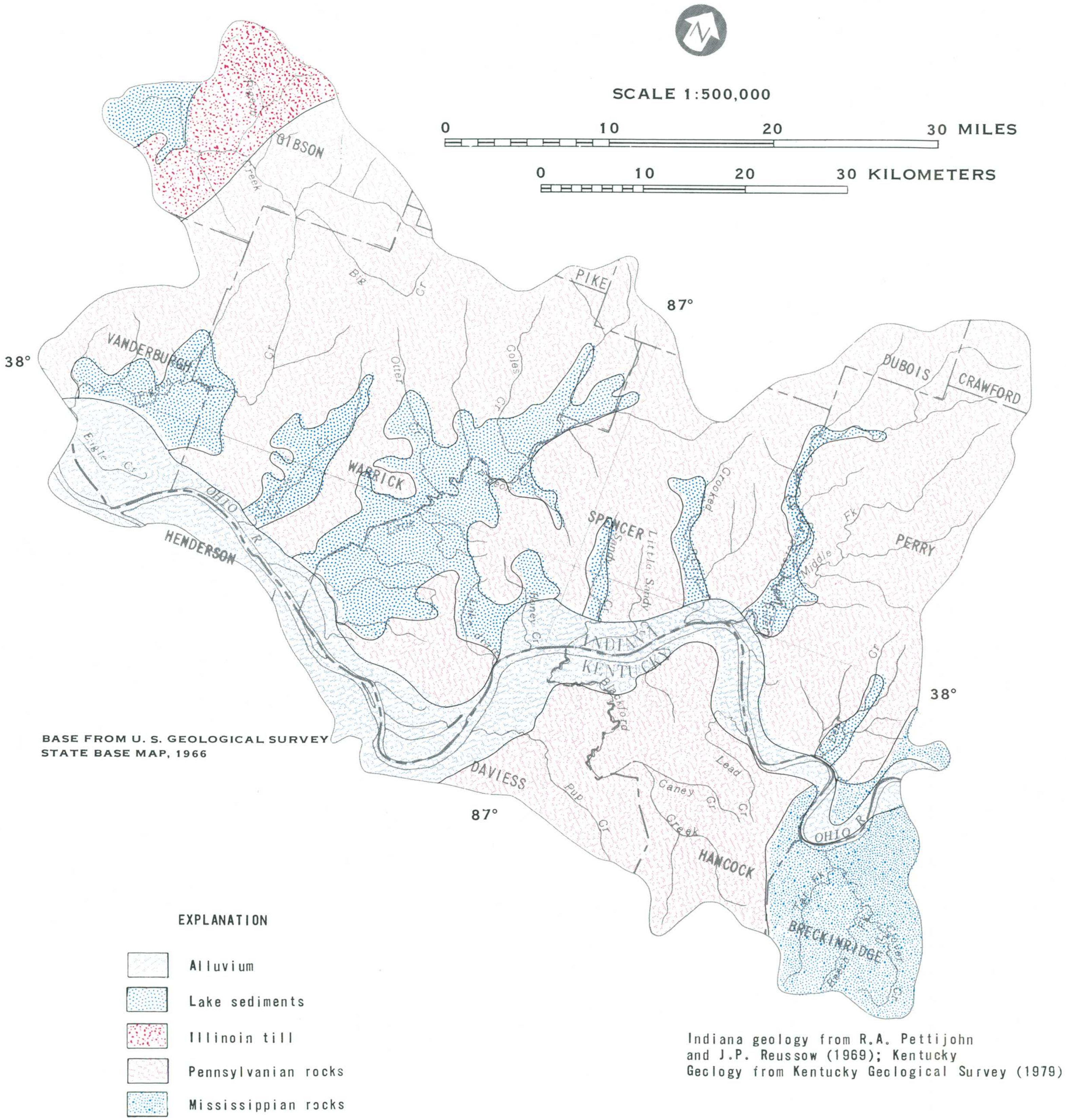


Figure 3.2. -- Extent of potential water-yielding formations.

Table 3.2.--Hydraulic characteristics of aquifers

Source	Location	Aquifer	Hydraulic conductivity [(gal/d)/ft^2]	Transmissivity [(gal/d)/ft]	Storage coefficient	Well yields (gal/min)
Pettijohn and Reussow (1969)	Indiana part of the Ohio River basin	Bedrock	12	300	-----	$\leq$75
Cable and Wolf (1977)	Vanderburgh County	do.	10	1,000 (maximum)	-----	$\leq$20
Do.	do.	Ohio River alluvial outwash	2,000	[1]185,000	[1]0.0014	$\leq$1,000
Gallaher and Price (1966)	Kentucky part of the Ohio River basin	do.	[2]310 [2]570 [2]380	207,650	-----	------

[1]From aquifer test data near Evansville.
[2]Values are medians of data from three sections of the alluvial outwash aquifer in the study area.

GROUND-WATER FLOW IS GENERALLY TOWARD THE OHIO RIVER

Flow in the bedrock and outwash aquifers is toward the Ohio River levels associated with the flow show some seasonal and long-term trends.

The Ohio River is the main discharge area for the outwash and probably for the bedrock aquifers as well. The amount of water flowing from the bedrock to the Ohio River depends on the hydraulic connection between the bedrock water-bearing formations and the river. In some areas, erosion of the Ohio bedrock valley has exposed some of the formations. For these formations, discharge would be directly to the river. Formations lower than the bedrock valley floor still have confining layers that limit the flow to the river. The amount of vertical fracturing through the confining layers probably controls this flow. Nonfractured bedrock might limit flow in one formation so that most of the flow discharges to another area.

Seasonal and long-term trends of water levels in the Ohio River alluvium and sandstone aquifers are shown in the adjacent hydrographs (fig. 3.3a). Rate of recharge was maximum in late winter and early spring. The annual fluctuation in the water levels generally ranged from 2 to 30 feet. Fluctuations were greater in the outwash than in the bedrock aquifers.

Continous water-level records available for observation wells in or near Area 33 are listed in table 3.3. Locations of the wells listed in the table and the four ground-water observation wells for which hydrographs were plotted are shown on the adjoining map (fig. 3.3b).

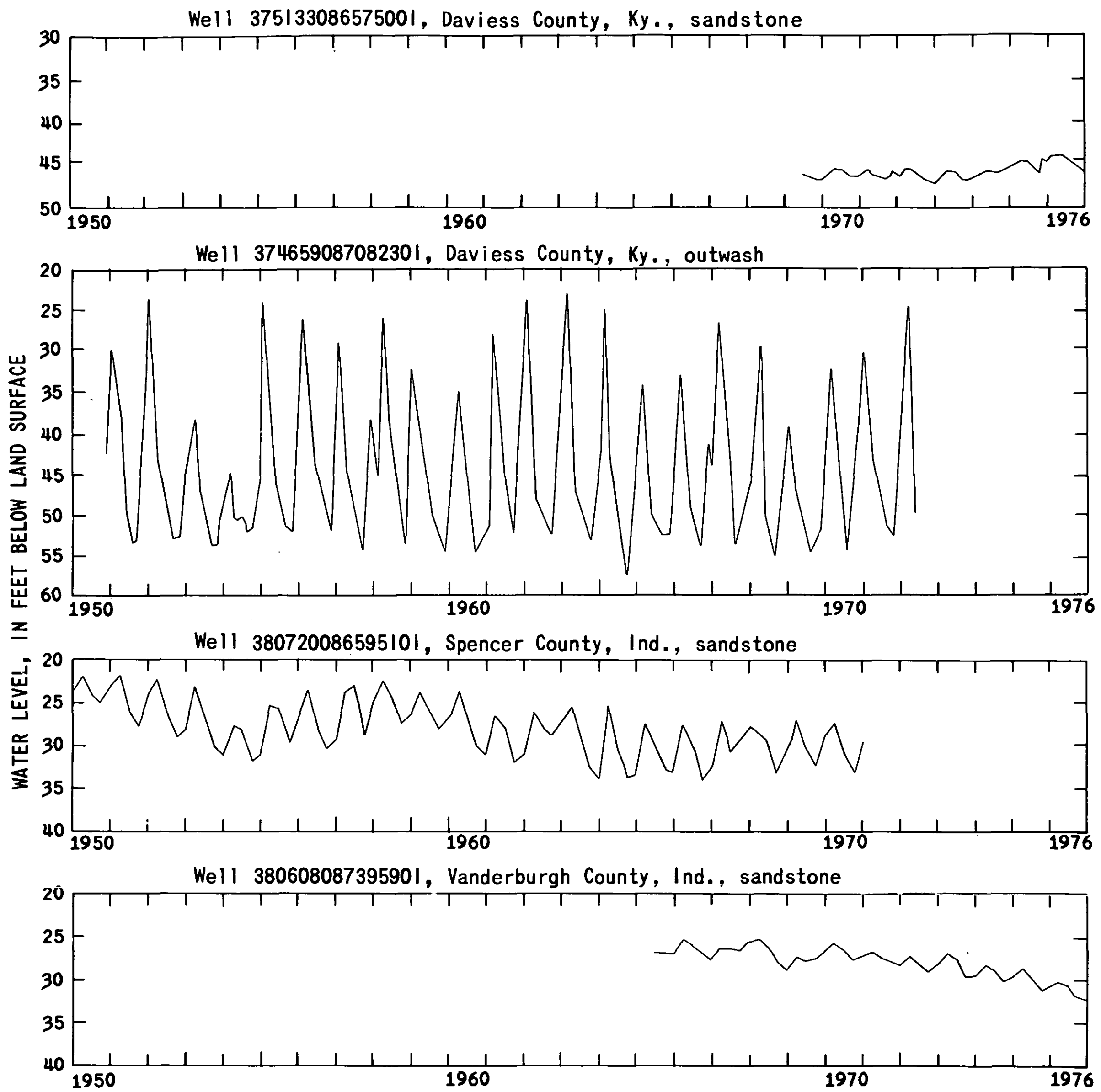
Table 3.3-- Continuous-record observation wells in or near Area 33

Well	County, State	Water-bearing unit
[1]380608087395901	Vanderburgh, Ind.	Rocks of Pennsylvanian age.
374638087054101	Daviess, Ky.	Glacial sand and gravel.
374700087082001	do.	Do.
374914087141501	do.	Do.
[2]374659087082301	do.	Do.
375133086575001	do.	Carbondale/Raccoon Creek Groups[3].
[1]375152087311501	Henderson, Ky.	Carbondale Group[3].
[1]375200087342901	do.	Do.
[2]380720086595101	Spencer, Ind.	Raccoon Creek Group[3].

[1]Wells outside study area.

[2]Discontinued record.

[3]Usage of the Indiana Geological Survey.



Kentucky hydrographs from Whitesides and others(1979)

Indiana hydrographs based on U.S. Geological Survey data

Figure 3.3a.-- Hydrographs of selected wells.

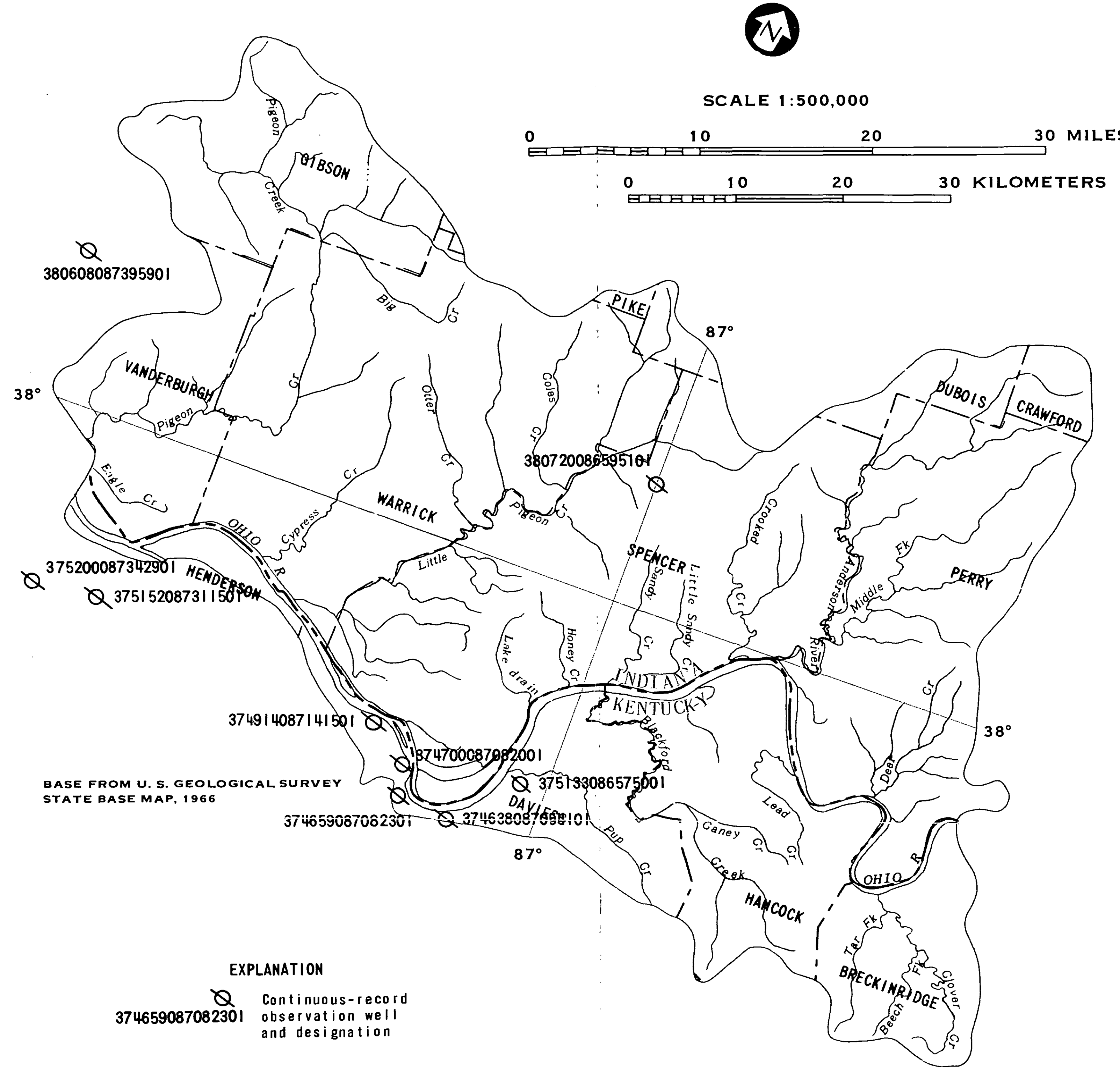


Figure 3.3b.--Observation wells.

RECHARGE DEPENDS ON THE TYPE OF AQUIFER

The bedrock aquifers are recharged mainly at their out-crop areas, whereas the outwash aquifers are recharged vertically through their confining layers. Amounts of recharge or discharge from the systems are not known.

The outcrop areas of the bedrock units serve as recharge zones. Discharge occurs along streams in the out-crop area. Outcrop areas of rock groups and associated coal beds are shown on the adjoining map (fig. 3.4).

The outwash aquifers of the Ohio River and the alluvium in tributary valleys receive recharge vertically from the confining beds. Recharge can occur over the entire aquifer, although the rate may not be uniform.

Discharge from the ground-water flow system provides streamflow during low-flow periods. Streamflow at the 80-percent flow duration is primarily from ground-water discharge. The 80-percent flow durations for the Middle Fork Anderson River at Bristow (03303300), Pigeon Creek at Evansville (03322100), and Crooked Creek near Santa Claus (03303400), 3.2, 14, and 0.12 ft^3/s, respectively, are based on current records.

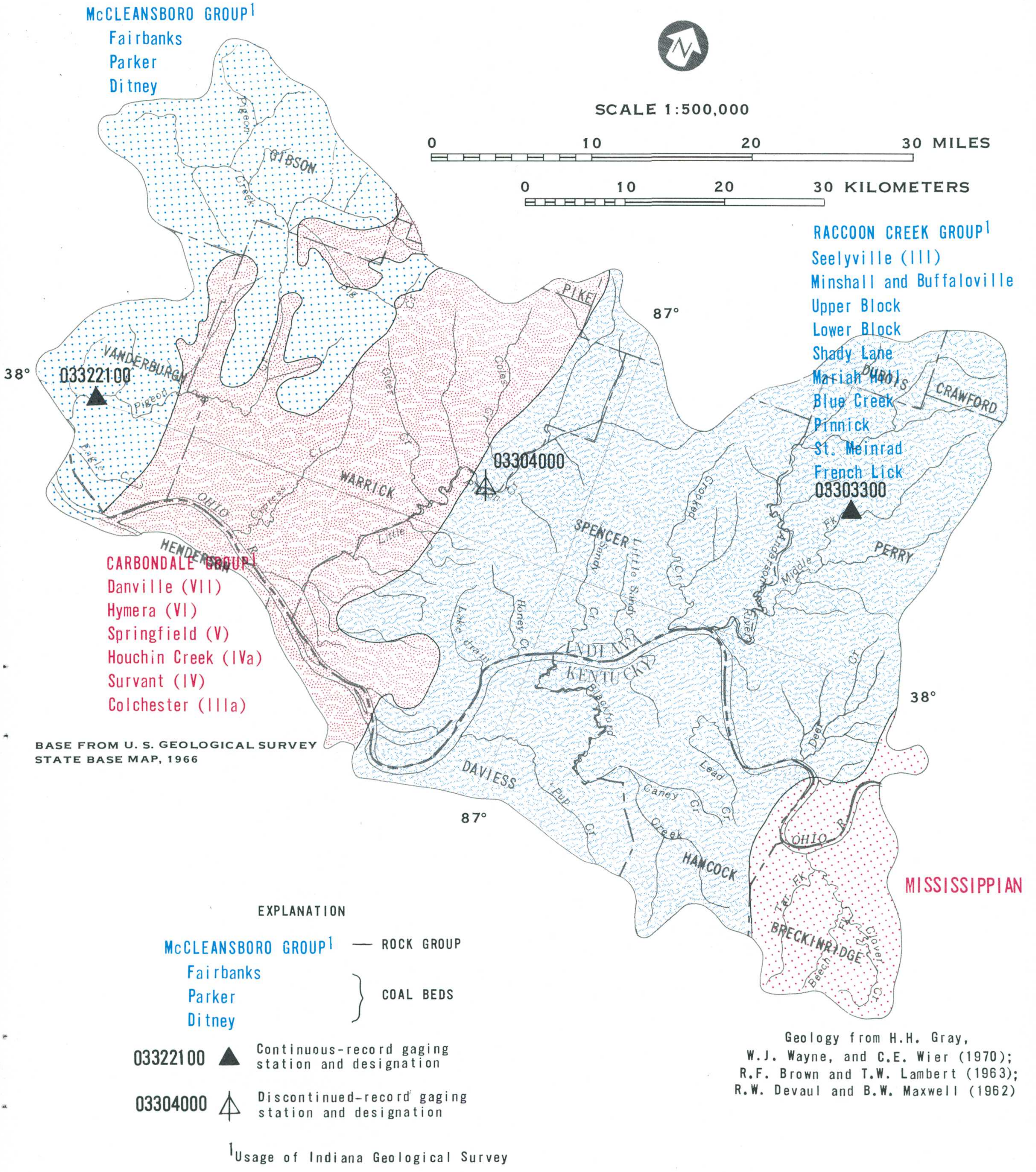


Figure 3.4.-- Outcrop areas of rock groups and associated coal beds.

4.0 WATER QUALITY
4.1 Surface Water
4.1.1 Introduction

WATER-QUALITY DATA ARE REQUIRED FOR COAL-MINE PERMIT APPLICATIONS

Section 507(b)(11) of the Surface Mining Control and Reclamation Act requires that extensive information about the probable hydrologic consequences of mining and reclamation be included in permit applications. Water quality data are essential hydrologic information in making such assessments. As a minimum, water-quality constituents and properties to be monitored are dissolved solids, suspended solids, acidity, pH, total iron, dissolved iron, and total manganese.

Surface mining and reclamation have seriously affected surface-water quality in much of the United States, and their impact, especially in coal-mining areas, is well documented in the literature (Dyer and Curtis, 1977; Hoehn and Sizemore, 1977; King and others, 1974; and Letterman and Mitsch, 1978). Acid-mine drainage in older mining areas results from the oxidation of pyrite and marcasite. In Indiana, these areas were mined before passage of the Indiana Reclamation Law of 1968 (Indiana Code 13-46), which mandates that spoil piles be graded and a cover crop be established. Although acid-mine drainage has been reduced by current mining operations as a result of the preferential burial of pyrite, acid production from the older mining operations continues to be a water-quality problem.

Acid mine drainage is not the only water-quality problem. Concentrations of many dissolved and suspended constituents, including iron and aluminum, are higher in both old and new mining areas than in streams unaffected by mining. Erosion from unreclaimed areas of old mines or unvegetated areas in new mines can substantially increase suspended-sediment concentration in streams (Dyer and Curtis, 1977).

Few water-quality data for the coal-mining region of southwestern Indiana and northern Kentucky are available. The need for these data has become critical since enactment of the Surface Mining Control and Reclamation Act of 1977. Section 507(b)(11) of the Act requires that extensive information about the probable hydrologic consequences of mining and reclamation be included in permit applications so that the regulatory authority can determine the probable cumulative impact of mining on the hydrology of the area. Hydrologic information on the general area is to be made available to applicants for mining permits from an appropriate Federal or State agency before mining permits are issued. The Act provides little information on water-quality constituents that should be monitored. Paragraph 779.16 of the Federal regulations concerning reclamation (Office of Surface Mining, 1979) states that, in general, local water-quality standards are applicable, but, as a minimum, impact determinations should consider the following: (a) dissolved solids, (b) suspended solids, (c) acidity, (d) pH, (e) total and dissolved iron, and (f) total manganese. Other water-quality properties or constituents that might be affected by surface mining include specific conductance, alkalinity, sulfate, and aluminum.

Dissolved and suspended solids have several affects of water: (1) Water with a high dissolved-solids concentration generally does not taste good, and may cause unfavorable physiological reactions in some people; (2) highly mineralized water requires costly chemical treatment before domestic and some industrial uses; (3) water with high suspended-sediment concentrations is unsatisfactory for bathing and recreation; (4) suspended-sediment particles adsorb and transport metal ions, pesticides, and nutrients in streams; (5) high suspended-sediment concentrations in streams can adversely affect the biological communities; and (6) sediments deplete the storage capacity of reservoirs, reduce channel capacities, and may increase both the frequency of flooding and flood stages.

Specific conductance is a measure of the ability of water to conduct an electrical current. The magnitude of specific conductance depends on the total concentration of ionized substances in the water and the temperature at which the measurement is made. Specific conductance is often used as an indicator of the dissolved-solids concentration of water.

The pH of a solution refers to its hydrogen ion activity and is expressed as the logarithm of the reciprocal of the hydrogen ion activity in moles per liter at a given temperature. The pH of most surface waters in the United States is within the range from 6.5 to 8.5 (Hem, 1970, p. 93). Most streams in the study area are slightly basic (pH >7.0) because of their carbonate and bicarbonate concentrations. A departure from a normal pH can be caused by acidic or alkaline industrial wastes, coal-mine wastes, or, for poorly buffered waters, fluctuations in algal photosynthesis.

Acidity is the capacity of a solution to neutralize a strong base (American Public Health Association and others, 1976, p. 273). It is a measure of a gross property and can be interpreted in terms of specific substances only when the chemistry of the sample is known. Strong mineral acids such as sulfuric, weak acids such as carbonic and acetic, and hydrolyzing salts such as ferrous or aluminum sulfates may contribute to the measured acidity, depending on the method of determination. The acidity of water is important because acids corrode metals and influence certain chemical and biological processes.

Alkalinity of water is its quantitative capacity to neutralize an acid. Because the alkalinity of surface water is primarily due to the carbonate and bicarbonate ions (Hem, 1970, p. 152), alkalinity is an indication of the concentrations of these constituents. Alkalinity may also include borate, hydroxide, phosphate, or silicate.

Iron and manganese are common components of rocks and soils and, in water, may originate from leaching of rocks and minerals. Other sources of these elements in water include industrial wastes, municipal wastes, corroded metal, and acid-mine drainage.

Uncomplexed iron in equilibrium with atmospheric oxygen is extremely insoluble. Therefore, in most water, truly soluble iron is a complex ion. Manganese in water may be in solution in the divalent state, or as a stable, soluble complex in the trivalent state, or in suspension in the quadrivalent state.

Iron and manganese concentrations of less than 1 mg/L are nontoxic to freshwater aquatic life (U.S. Environmental Protection Agency, 1976, p. 152, and McKee and Wolf, 1963, p. 215, respectively) and are essential to certain physiological functions of that life. The iron and manganese concentration limits recommended for drinking water by the Environmental Protection Agency (1976) are based on the tendency of these elements to stain clothing and plumbing. In addition, iron can impart a bittersweet astringent taste detectable by some persons at levels greater than 1 or 2 mg/L (American Public Health Association and others, 1976, p. 207).

Sulfate is widely distributed in nature and may be present in natural water in concentrations ranging from a few to several thousand milligrams per liter. Mine-drainage wastes may contribute high sulfate concentrations to streams as a result of the oxidation of pyritic material.

WATER-QUALITY DATA COLLECTED BY FOUR AGENCIES ARE STORED IN WATSTORE AND STORET

The U.S. Geological Survey has collected water-quality data at 4 monitoring stations and 121 miscellaneous sites in the study area and has published data in water-quality assessments of 4 smaller watersheds within Area 33. Other organizations who have collected data in the study area are the U.S. Forest Service, at four monitoring sites; the Ohio River Valley Water Sanitation Commission at one monitoring site; and the Indiana State Board of Health, at one miscellaneous site. All the data are stored in the Geological Survey's WATSTORE and the U.S. Environmental Protection Agency's STORET computer files.

Water-quality data for the study area may be grouped by (1) the agency responsible for publishing the data and (2) the type of water-quality monitoring program. The water-quality data discussed in this report were collected by the Geological Survey at 4 monitoring stations and 121 miscellaneous sites; by the Forest Service at 4 monitoring stations; and by the Ohio River Valley Water Sanitation Commission at 1 monitoring station. Water-quality data from the Geological Survey and from the Indiana State Board of Health represent miscellaneous water-quality measurements from several different studies and sampling programs in the area having a variety of objectives.

Part of the data collected by the Geological Survey was collected during intensive water-quality assessments of four different watersheds: Anderson River in Crawford, Dubois, Perry, and Spencer Counties, Ind. (Ayers and Shampine, 1975); Anderson River in Crawford and Perry Counties, Ind. (Ayers, 1978); Cypress Creek in Warrick County, Ind. (Bobo and Peters, 1980); and East Fork Little Pigeon Creek in Spencer County, Ind. (John S. Zogorski and others, written commun., January 1980). Their locations are shown on the adjoining map (fig. 4.1.2).

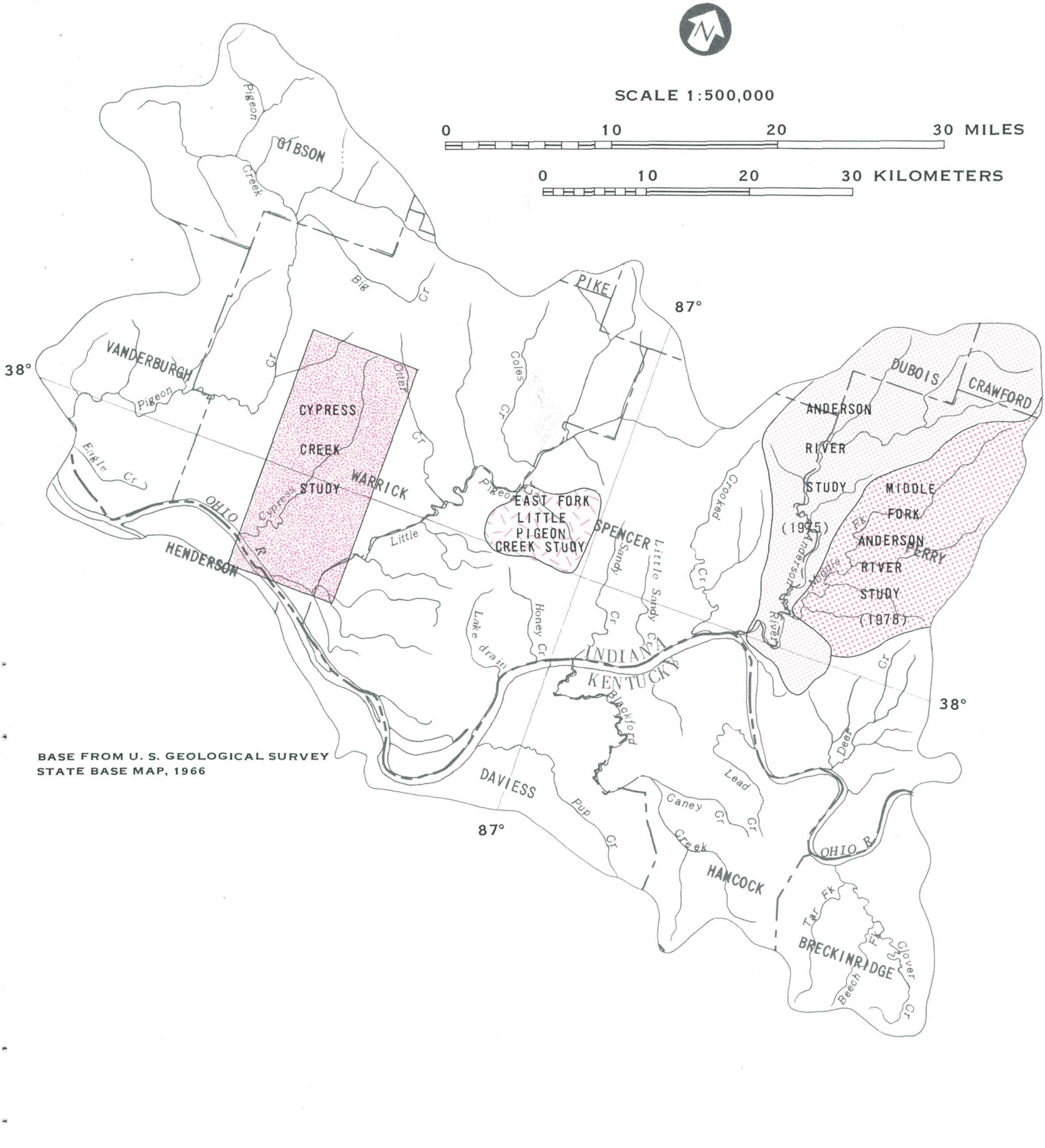


Figure 4.1.2.-- U.S. Geological Survey water-quality studies.

4.0 WATER QUALITY

4.1 SURFACE WATER

4.1.2 SUMMARY OF WATERSHED ASSESSMENTS

WATER-QUALITY OF THE ANDERSON RIVER WATERSHED, CRAWFORD, DUBOIS, PERRY, AND SPENCER COUNTIES, INDIANA

Coal-mine drainage has affected the water quality of Lanman Run; Meinrad Hollow, and Swinging Creek, tributaries of the Anderson River. Alkalinity (as calcium carbonate) and pH are lower in these streams that receive mine drainage than in streams unaffected by mine drainage. Also, specific conductance and concentrations of sulfate, total iron, manganese, and aluminum are higher for 'these streams than for streams unaffected by mine drainage.

A water-quality assessment of the Anderson River was done by the Geological Survey during January 1974 (Ayers and Shampine, 1975). The study area is shown on the adjoining map (fig. 4.1.2.1). The purpose of the study was to delineate existing and (or) potential water-quality problems in the watershed, particularly in areas of potential development. A summary of the results of the study follows.

Eighteen stream sites and one tile drain were sampled within the Anderson River watershed. The location of the sample sites is shown on the adjoining map. According to Ayers and Shampine (1975), the water quality of most streams in the watershed is good. However, coal-mine drainage into Lanman Run, Meinrad Hollow, and Swinging Creek seems to have caused significant changes in the chemical, physical, and biological characteristics of these streams.

In streams unaffected by coal mine drainage, pH ranged from 6.7 to 7.4, whereas, in streams affected by coal mine drainage, pH ranged from 3.8 to 6.5 during the study. Alkalinity ranged from 0 to 130 mg/L and was lowest in streams affected by acid mine drainage.

Specific conductance and dissolved-solids concentration of streams unaffected by coal mine drainage ranged from 105 to 285 μmho/cm at 25°C and from 82 to 152 mg/L, respectively. In comparison, the specific conductance of water from a small tributary draining a strip mine was 520 μmho/cm; the dissolved-solids concentration was not measured in this tributary during the study.

Sulfate concentrations of streams unaffected by coal mine drainage ranged from 29 to 46 mg/L, whereas sulfate concentration for Meinrad Hollow and Lanman Run were 55 and 51 mg/L, respectively.

Total concentrations of iron, manganese, and aluminum were also higher for streams that received coal-mine drainage than for those that did not. The ranges of concentration for these metals in streams receiving coal-mine drainage were: total iron 1,200 to 8,200 μg/L, total manganese 100 to 4,800 μg/L, and total aluminum 390 to 8,200 μg/L. In comparison, the ranges of concentration for these metals in streams that did not receive coal-mine drainage were: total iron 590 to 1,600 μg/L, total manganese (less than the detection limit of 0.01 μg/L to 70 μg/L), and total aluminum (50 to 230 μg/L). Four of the samples were analyzed for both total and dissolved metals. These analyses indicated that more than 80 percent of the total iron was associated with suspended particulates. For manganese, in three of the four samples analyzed, more than 75 percent of the total concentration was in the dissolved phase.

Suspended-sediment concentration of the Anderson River ranged from 11 to 69 mg/L. High suspended-sediment concentrations were attributed by Ayers and Shampine (1975) to local highway construction activities.

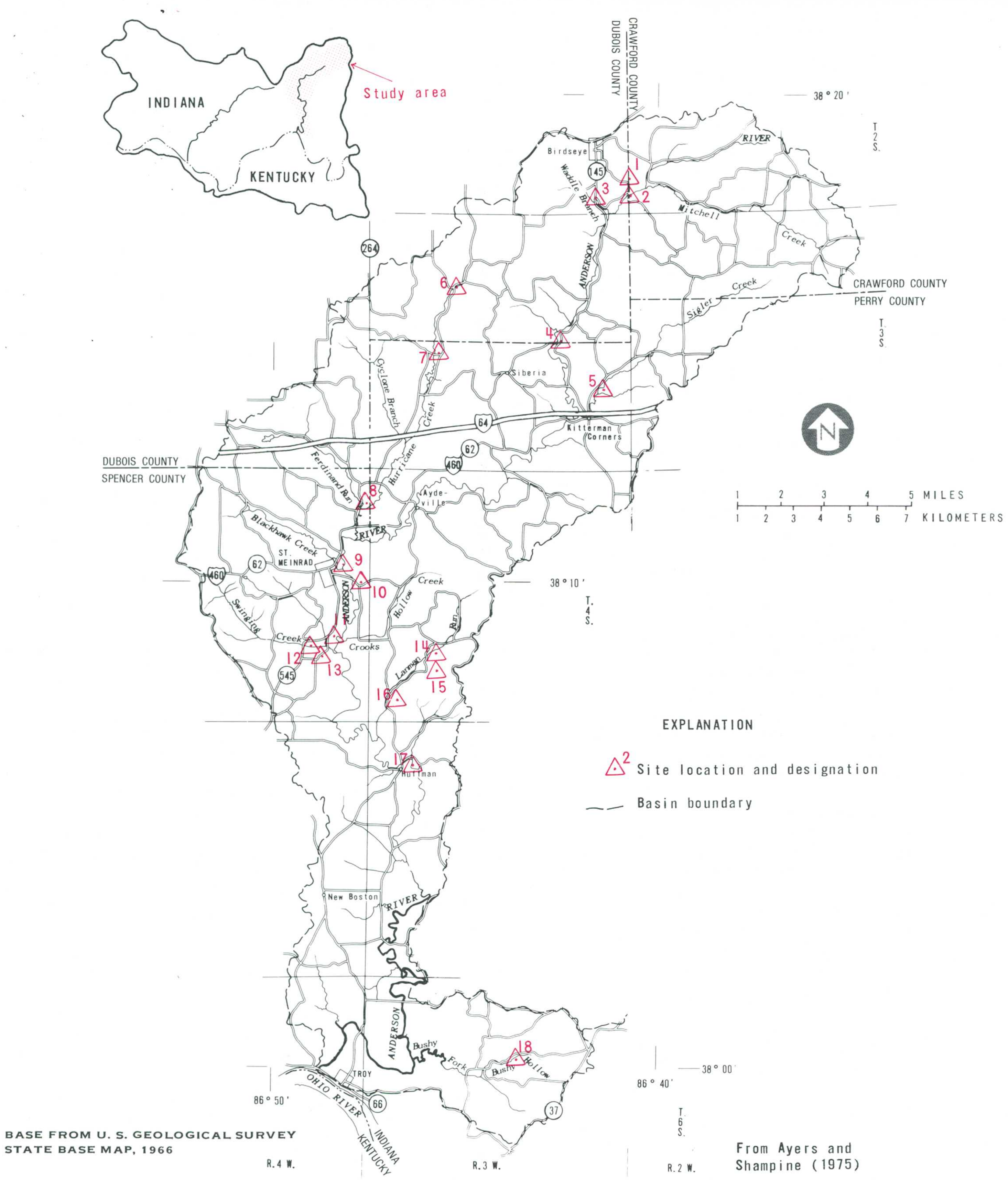


Figure 4.1.2.1.-- Sampling sites in Crawford, Dubois, Perry, and Spencer Counties.

WATER-QUALITY OF THE MIDDLE FORK ANDERSON RIVER WATERSHED, CRAWFORD AND PERRY COUNTIES, INDIANA

Variations in water quality were attributed by Ayers (1978) to bedrock mineralogy, control of the streams by resevoirs, and organic acid in the streams within the watershed. No indications of coal-mine drainage were observed.

Five water-quality surveys of the Middle Fork Anderson River were done by the Geological Survey during 1975 and 1976 (Ayers, 1978). The locations of sampling sites are shown on the adjoining map (fig. 4.1.2.2). The objectives of the surveys were to (1) define the variation in concentrations of nutrients, inorganic constituents, suspended sediment, bacteria, and phytoplankton in surface water and chlorinated hydrocarbons in bed materials; (2) identify sources and areas of water-quality problems in the watershed; and (3) determine the effects of flood-retarding structures on water quality. A summary of the results of the study follows.

According to Ayers (1978), surface-water quality of the watershed was generally good. No indications of coal-mine drainage within the study area were observed.

The water type for most of the streams was calcium bicarbonate. The range of pH in streams in 1975 and 1976 (from 6.6 to 8.5) is normal for most surface water (Hem, 1970, p.93). Alkalinity ranged from 8 to 130 mg/L.

Specific conductance and dissolved-solids concentration, two related properties of water, ranged from 121 to 640 μmho/cm at 25°C and from 76 to 248 mg/L, respectively. Variations in specific conductance and dissolved-solids concentration were attributed by Ayers (1978) to differences in bedrock mineralogy within the drainage area and to the location of sampling sites relative to reservoirs. Dissolved-solids concentration upstream from reservoirs was greater than at sites downstream during medium and low flows but were similar during high flows.

Sulfate concentration of streams ranged from 13 to 73 mg/L. Sulfate was a dominant anion in only the Kraus Creek drainage. Its dominance there was attributed by Ayers (1978) to gypsum or sulfide minerals in the bedrock.

The concentration of dissolved iron in streams ranged from less than the detection limit of the method (10 μg/L) used to 610 μg/L and averaged less than the 300 μg/L limit recommended for drinking water by the U.S. Environmental Protection Agency (1976, p. 152). Total iron concentration was not measured in this study.

Dissolved manganese concentration ranged from 20 to 7,300 μg/L and at most sites exceeded the 50 μg/L concentration recommended by the U.S. Environmental Protection Agency (1976, p. 178) for drinking water. Ayers (1978) hypothesized that manganese concentrations were associated with organic acids in streams. Manganese concentration was higher and more variable downstream from reservoirs than upstream.

Suspended-sediment concentrations during the five surveys ranged from 1 to 148 mg/L. An analysis of 13 years of periodic, suspended-sediment measurements on the Middle Fork Anderson River at Bristow related suspended-sediment concentration to flow.

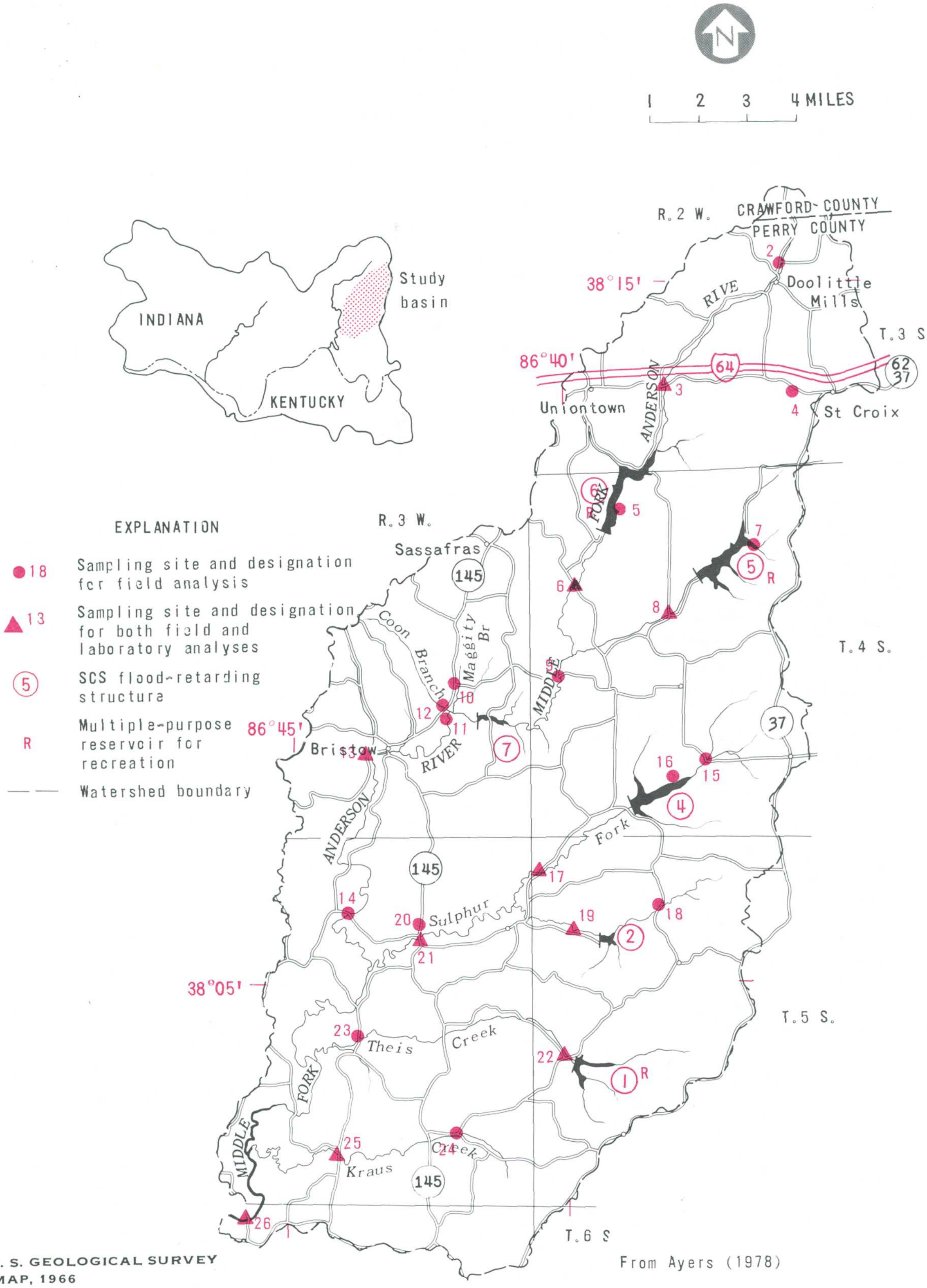


Figure 4.1.2.2.-- Data-collection sites in the Middle Fork Anderson River watershed.

4.0 WATER QUALITY (Continued)

4.1 SURFACE WATER (Continued)

4.1.2 SUMMARY OF WATERSHED ASSESSMENTS (Continued)

4.1.2.2 MIDDLE FORK ANDERSON RIVER IN CRAWFORD AND PERRY COUNTIES, INDIANA

WATER-QUALITY OF THE CYPRESS CREEK WATERSHED, WARRICK COUNTY, INDIANA

Several tributaries to Cypress Creek are affected by coal-mine drainage Acid mine drainage from these tributaries lowers pH and alkalinity and raises concentrations of dissolved solids and major cations of Cypress Creek. Effluent form the Boonville wastewater-treatment facility was probably responsible for adding nitrogen and phosphorus to the water and bottom sediments and PCB's (polychlorinated biphenyls) to the bottom sediments.

Five water-quality surveys of the Cypress Creek watershed were done by the Geological Survey from March to August 1979 (Bobo and Peters, 1980). The objectives of these surveys were to (1) define variation in water quality within the watershed, (2) identify possible water-quality problems, and (3) examine variations in periphyton and benthic-invertebrate communities within the watershed. A summary of the results of the study follows.

Cypress Creek drains a 65.9-square-mile area north of Boonville, Ind., and flows generally south to its confluence with the Ohio River. The locations of the sampling sites are shown on the adjoining map (fig. 4.1.2.3). The main stem of Cypress Creek is approximately 10 miles long and is in a predominantly agricultural area.

The water quality of Cypress Creek, north of Boonville, is affected by acid-mine drainage from several tributaries that drain into the creek during periods of runoff. Acid-mine drainage from these tributaries lower the pH and alkalinity concentrations and raise concentrations of dissolved solids and major cations in Cypress Creek. Downstream from Boonville, effluent from the Boonville wastewater-treatment facility added nutrients to the water and to the bottom sediments and PCB's to the bottom sediments.

The general water type of Cypress Creek during the study period was calcium and magnesium sulfate, which, according to Eikenberry (1978), is characteristic of streams draining past and present mining operations.

The pH of Cypress Creek ranged from 6.4 to 8.8. It was lower than this range in tributaries affected by past or present mining activities. The lowest pH during the study, 1.2, was measured in a tributary downstream from a tipple area (coal-washing area). Values of pH in Cypress Creek were generally lower during periods of high flow, when the stream received acid-mine drainage, than during low flow. The pH at the tributary sites did not seem to correlate with streamflow.

Alkalinity concentration within the watershed ranged from 39 to 340 mg/L. The lowest alkalinity concentration, determined in the headwaters, may have been due to the inflow of acid tributaries from a nearby tipple area. Alkalinity concentration in Cypress Creek steadily increased with distance downstream, an indication that the water in the creek was buffering the effects of acid-mine drainage.

Specific conductance and dissolved-solids concentration of Cypress Creek ranged from 470 to 2,200 μmho/cm at 25°C and from 626 to 1,790 mg/L, respectively. Ranges were higher for the tributary sites: specific conductance from 690 to 4,370 μmho/cm at 25°C and dissolved-solids concentration from 316 to 4,040 mg/L. The higher ranges were associated with tributaries draining mining areas. Both specific conductance and dissolved-solids concentration were lower during periods of high flow than of low flow, probably because of dilution.

Sulfate concentration, which ranged from 150 to 2,600 mg/L, was higher in tributaries draining areas with mining activities than in Cypress Creek.

Total aluminum concentration ranged from 120 to 850 μg/L in Cypress Creek and from 150 to 2,000 μg/L in the tributaries, which were directly affected by either past or present mining activities. Concentration of dissolved aluminum in the watershed ranged from 30 to 400 μg/L.

Total iron concentration ranged from 340 to 7,300 μg/L. Concentrations of suspended iron were greater than concentrations of dissolved iron for all sites studied.

Total manganese concentration of surface water within the study area ranged from 130 to 4,100 μg/L. The concentration of dissolved manganese was generally greater than that of suspended manganese.

Suspended-sediment concentration of Cypress Creek ranged from 13 to 362 mg/L in April and June 1979. Concentration of the tributary sites ranged from 15 to 78 mg/L in June 1979. Sieve analysis of the suspended sediment indicated that 96 percent of the total concentrations was silt and clay size and 4 percent was sand size. Erosion from adjacent fields and stream banks and the streambed material probably account for the high suspended-sediment concentrations during periods of high flows.

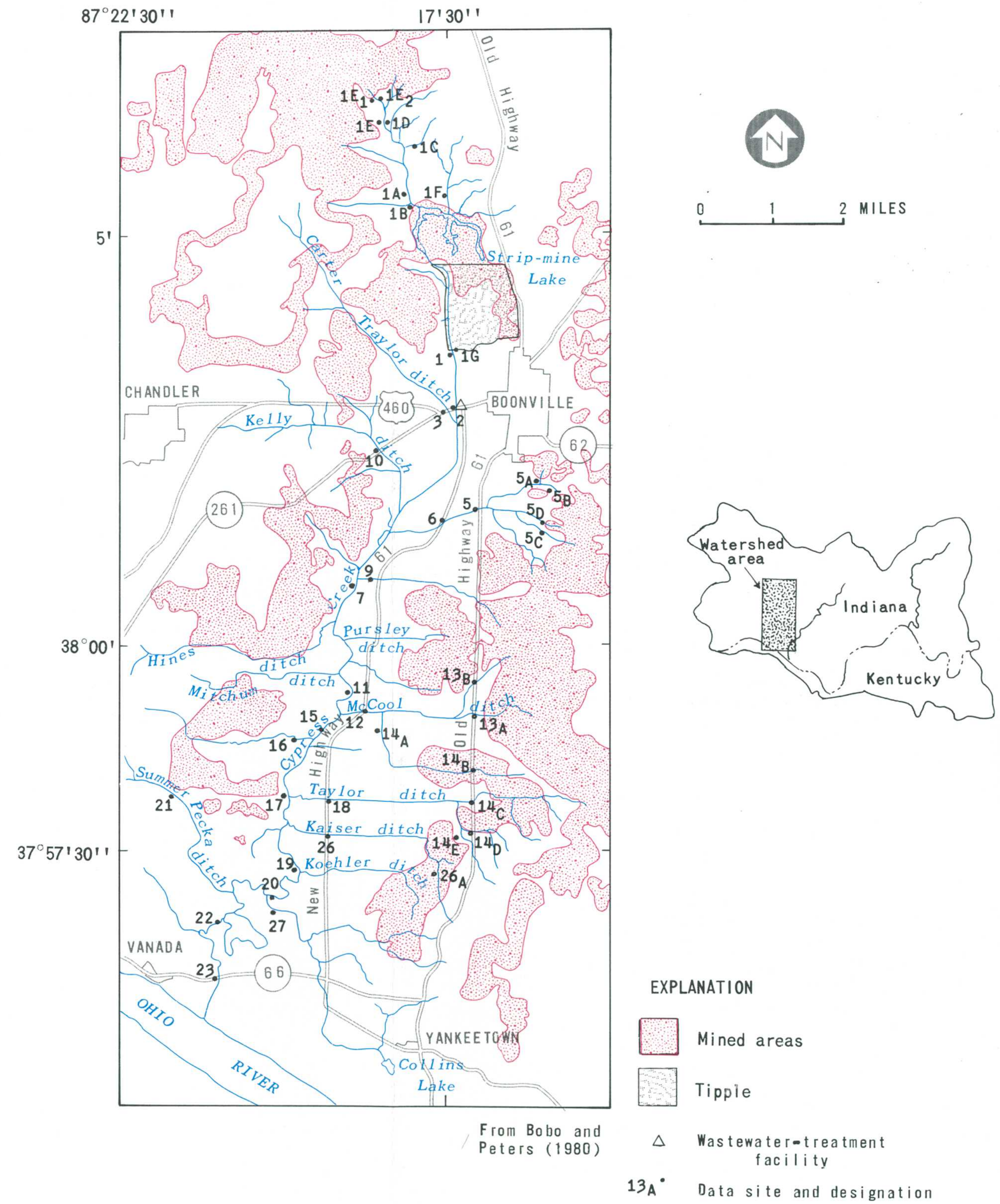


Figure 4.1.2.3.-- Cypress Creek watershed, Warrick County, Ind.

WATER-QUALITY OF EAST FORK LITTLE PIGEON CREEK NEAR CHRISNEY, SPENCER COUNTY, INDIANA

Water Quality in East Fork Little Pigeon Creek during 1979 was generally adversely affected by coal-mine drainage, effluent from the Chrisney wastewater-treatment facility, and back-water from Little Pigeon Creek.

A 3-month study of a potential coal-mining site near Chrisney, Ind., was done by the Geological Survey during 1979 (John S. Zogorski and others, written commun., January 1980). The objectives of this study were to (1) review the permit regulations of the Surface Mining Control and Reclamation Act and determine the kinds of information required by these regulations, (2) use the regulations as a guideline for preparing an example hydrologic assessment for a potential coal-mining site, and (3) determine where data are lacking or are inadequate for the completion of a hydrologic assessment. A summary of the results of the study follows.

Water-quality data were collected at 21 sampling sites in the 24-square-mile drainage basin Fork Little Pigeon Creek near Chrisney in Spencer County, Ind., of the East shown on the adjoining map (fig. 4.1.2.4).

Ambient water quality in East Fork Little Pigeon Creek, which varied substantially during sampling dates in June and July 1979, was influenced by three major factors: (1) inflow from the Kelco mining area; (2) effluent from the Chrisney wastewater-treatment facility, and (3) backwater from Little Pigeon Creek.

The pH of surface water within the study basin generally ranged from 6 to 9, typical of natural water (Hem, 1972, p. 93). Lower pH values were measured at two sites at Crooks Mine, an abandoned, unreclaimed surface mine on the study basin's drainage divide with East Fork Little Pigeon Creek. In comparison, pH of water discharging from the Kelco mining area, an active strip-mine area, ranged from 7.5 to 8.0.

The alkalinity at sites unaffected by acid-mine drainage ranged from 30 to 150 mg/L as $CaCO_3$. Water at the Crooks mining site was acidic and had no detectable alkalinity. In contrast, the alkalinity of water discharging from the Kelco mining area was about 400 mg/L during the July survey. Fluctuations in alkalinity upstream from the wastewater-treatment facility were attributed by John S. Zogorski (written commun., January 1980) to algal photosynthesis. The alkalinity of samples downstream from the wastewater-treatment facility ranged from 80 to 180 mg/L. The increase in alkalinity with distance downstream seemed to be due to backwater from Little Pigeon Creek rather than to effluent from the wastewater-treatment facility.

Only methyl-orange acidity of water samples was determined during the study, and only water samples from the Crooks mining site exhibited this acidity. The high acidity (2,400 mg/L) for this area is an indication of poor surface-water quality.

Dissolved-solids concentration and specific conductance at sampling sites on East Fork Little Pigeon Creek, ranged from 400 to 1,600 mg/L and from 600 to 2,000 μmho/cm at 25°C, respectively. The high specific conductance and dissolved-solids concentration were attributed to runoff from the Kelco mining area. Dissolved-solids concentration and specific conductance were lower downstream from the Kelco mining area as a result of dilution by effluent from the wastewater-treatment facility and backwater from Little Pigeon Creek.

Sulfate concentration of East Fork Little Pigeon Creek ranged from less than 200 mg/L in the headwaters unaffected by mining to 800 mg/L in reaches further downstream. Sulfate concentration of water discharging from the Kelco mining area and immediately downstream from the area were 1,000 and 1,200 mg/L, respectively. Weathering of pyritic materials and the gray shale overburden left exposed at the mining site are two probable causes for the high sulfate concentrations. Sulfate concentration of the creek downstream from the Kelco mining area decreased to 160 mg/L as a result of backwater from Little Pigeon Creek and possibly sulfate reduction due to biological processes or chemical precipitation.

The concentrations of both total iron and total manganese in East Fork Little Pigeon Creek downstream from the Kelco mining area to the wastewater-treatment facility ranged from 100 to 500 µg/L. Downstream from the wastewater-treatment facility, concentrations of total iron and total manganese gradually increased to 900 µg/L and 600 µg/L, respectively. The cause of the increase in concentrations of these metals downstream from the wastewater-treatment facility was undetermined.

The concentration of suspended solids in East Fork Little Pigeon Creek was 5 mg/L at all sites upstream from the wastewater-treatment facility. Suspended-solids concentration downstream from the wastewater-treatment facility, which ranged from 10 to 30 mg/L, was due to detritus, plankton, and other biomass rather than the effluent from the wastewater-treatment facility (John S. Zogorski and others, written commun., January 1980).

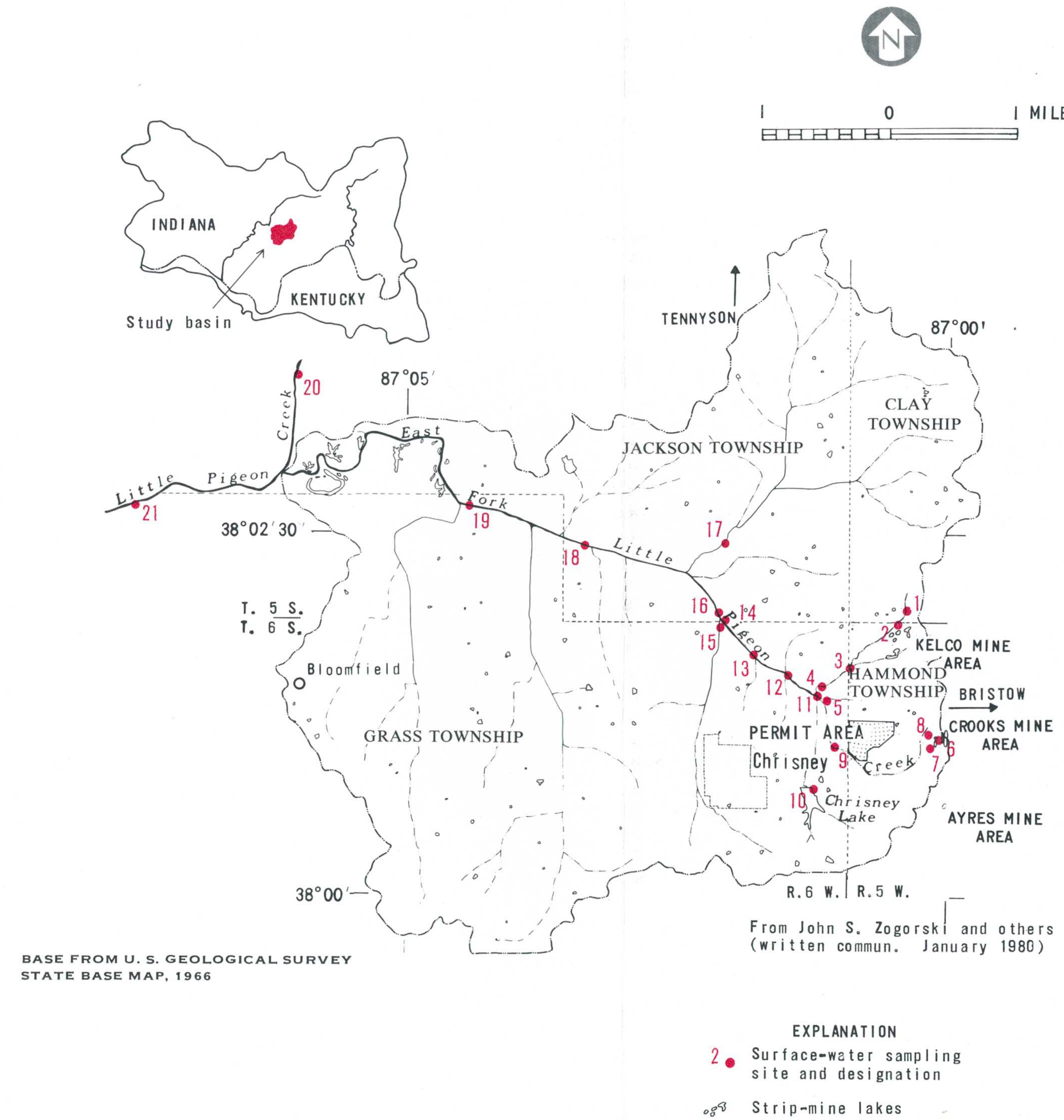


Figure 4.1.2.4.-- Surface-water sampling sites in the vicinity of Chrisney, Spencer County, Ind.

STATISTICAL ANALYSIS SYSTEM (SAS) USED IN ANALYSIS OF REGIONAL WATER-QUALITY TRENDS

Water-quality data collected by the U.S. Geological Survey, U.S. Forest Service, Ohio River Valley Water Sanitation Commission, and the Indiana State Board of Health were compiled from WATSTORE and STORET files and were analyzed by the univariate program in the Statistical Analysis System.[1]

Water-quality data on file in the WATSTORE and STORET computer data bases for 125 stations in or near Area 33 were retrieved for analysis by a retrieval system that uses latitude and longitude as the corners of a polygon. Some stations are just outside the study area, but their data were used in the statistical analysis. Water-quality data retrieved included total and dissolved iron, total and dissolved manganese, sulfate, alkalinity, pH, and specific conductance. The average value for each constituent at a sampling station (except pH) was determined. For stations where only one measurement was available, this measurement was assumed to represent the average value for that station, except for pH where the measurement was assumed to represent the median pH. These station averages and the median pH's were used for regional comparisons. The median of the station averages was used as a basin descriptor and is reported as median average. Average values were divided into six categories on the basis of a percentile distribution: values less than or equal to the 10th percentile, values between the 10th and the 25th percentiles, the 25th and the 50th percentiles, the 50th and the 75th percentiles, the 75th and 90th percentiles, and values equal to or greater than the 90th percentile. Percentile distribution was also used for pH, except that median values rather than averages were determined for all data collected at an individual station.

Stations used in the analysis are located on the adjoining map (fig. 4.1.3). Latitude and longitude of all stations having data stored in WATSTORE and STORET, the agency responsible for sample collection, and the number of observations for each water-quality constituent measured are listed in Appendix 1. The station identification number listed in the appendix and shown on the facing page is a chronological listing of all stations retrieved from WATSTORE and STORET files. This number may be different from the identification number used by other authors when describing the same point. The reader should be aware that the data in the appendix only applies to the corresponding number on the map in this section and should not be transferred to other sections of this report.

[1] Barr and others, 1979. (The use of the computer program name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.)

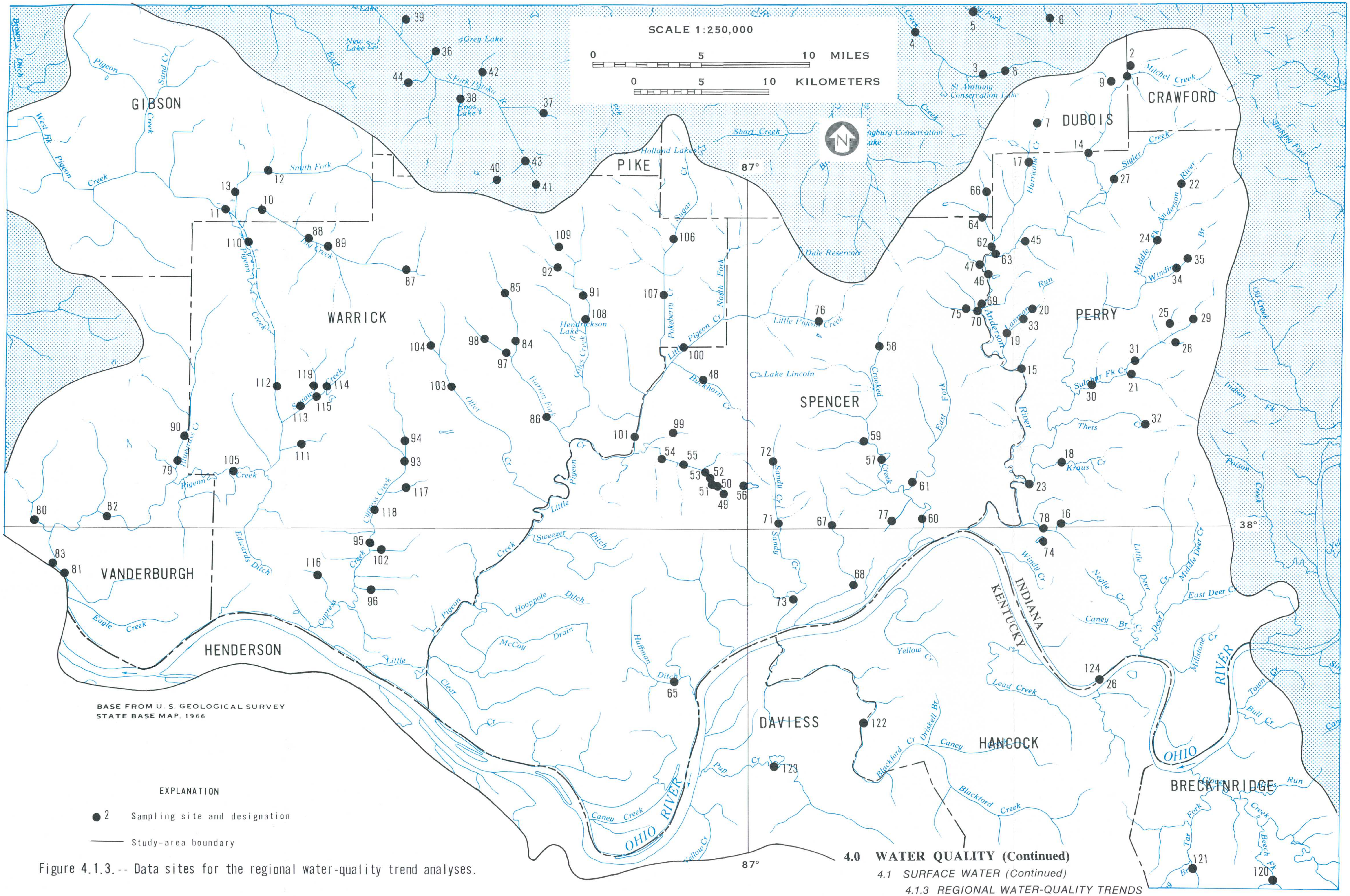
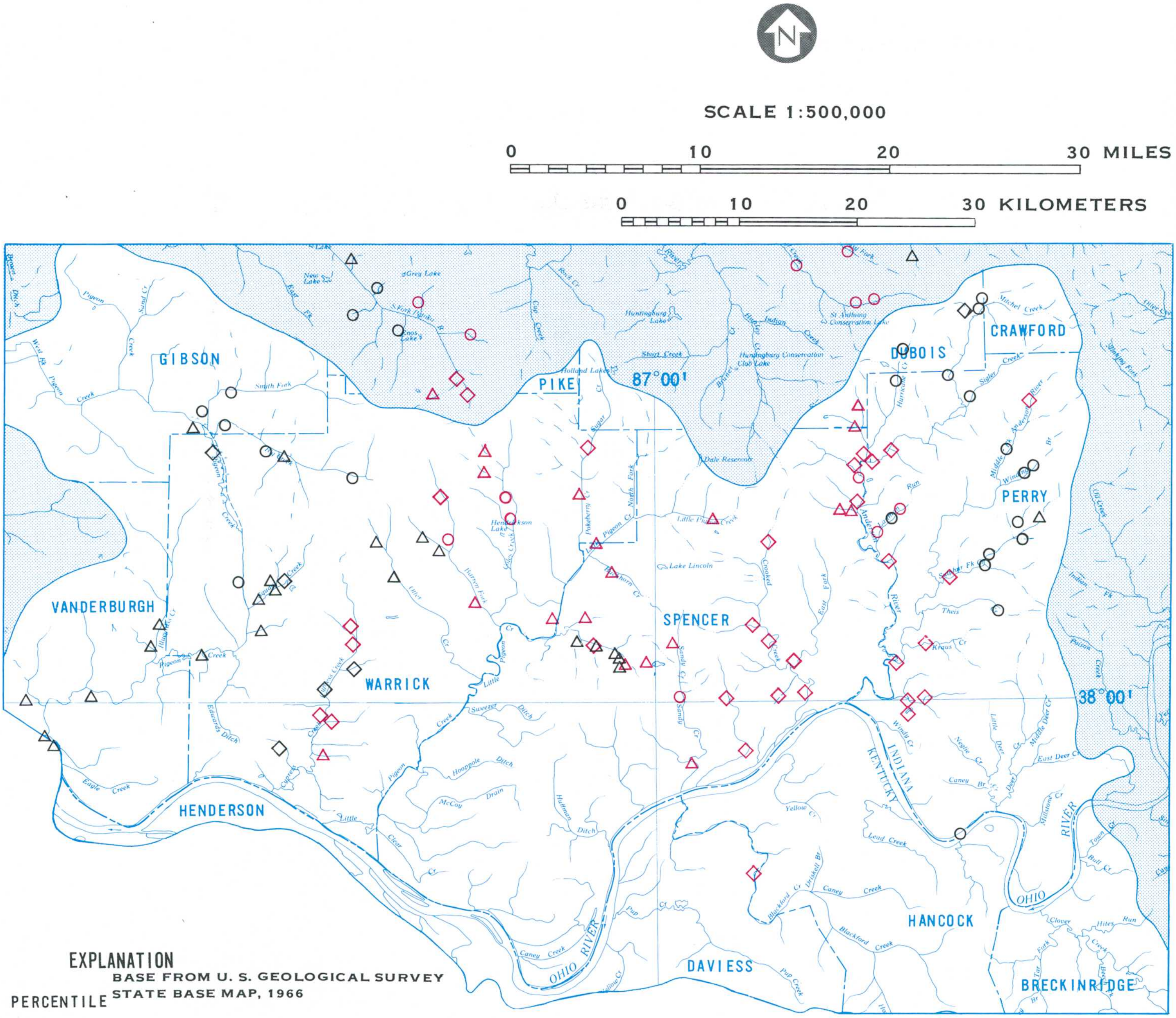


Figure 4.1.3.-- Data sites for the regional water-quality trend analyses.

REGIONAL WATER-QUALITY TRENDS IN pH

The median pH of the medians at 119 stations was 7.15, and the range in median pH was from 3.27 to 8.40. Values of pH were generally lower in the east half of Area 33 than in the west half. The amount and the extent of surface mining and the bedrock geology of the region seems to affect pH.

The pH of surface water was lower in the east half of Area 33 (Crawford Upland physiographic unit) than in the west half (Wabash Lowland physiographic unit), even though considerably more coal has been mined in the west half. The bedrock geology of the east half is primarily sandstone and shale, which are characteristically low in carbonate minerals. Consequently, there is little buffering of surface water in the Crawford Uplands. Conversely, there is more buffering of the water in the west half than in the east half because the bedrock geology in the west half has a higher concentration of carbonate minerals. Because of the greater surface-mining activity in the west half of the study area and the consequent exposure and oxidation of greater amounts of pyrite and marcasite there than in the east half, the pH of surface waters in the west should be greater than that in the east half. However, the dissolution chemistry of carbonate rocks also exposed during the mining process seems to more than compensate for these conditions. The median pH's at the 120 stations sampled in the study area were grouped into six ranges by percentile and are presented in the adjoining figure 4.1.3.1.



EXPLANATION

BASE FROM U. S. GEOLOGICAL SURVEY STATE BASE MAP, 1966

PERCENTILE	
○ ≤10	<6.1
△ 10-25	6.1-6.8
◇ 25-50	6.8-7.2
○ 50-75	7.2-7.5
△ 75-90	7.5-7.8
◇ ≥90	>7.8

Figure 4.1.3.1.-- Ranges of median pH values.

4.0 WATER QUALITY (Continued)

4.1 SURFACE WATER (Continued)

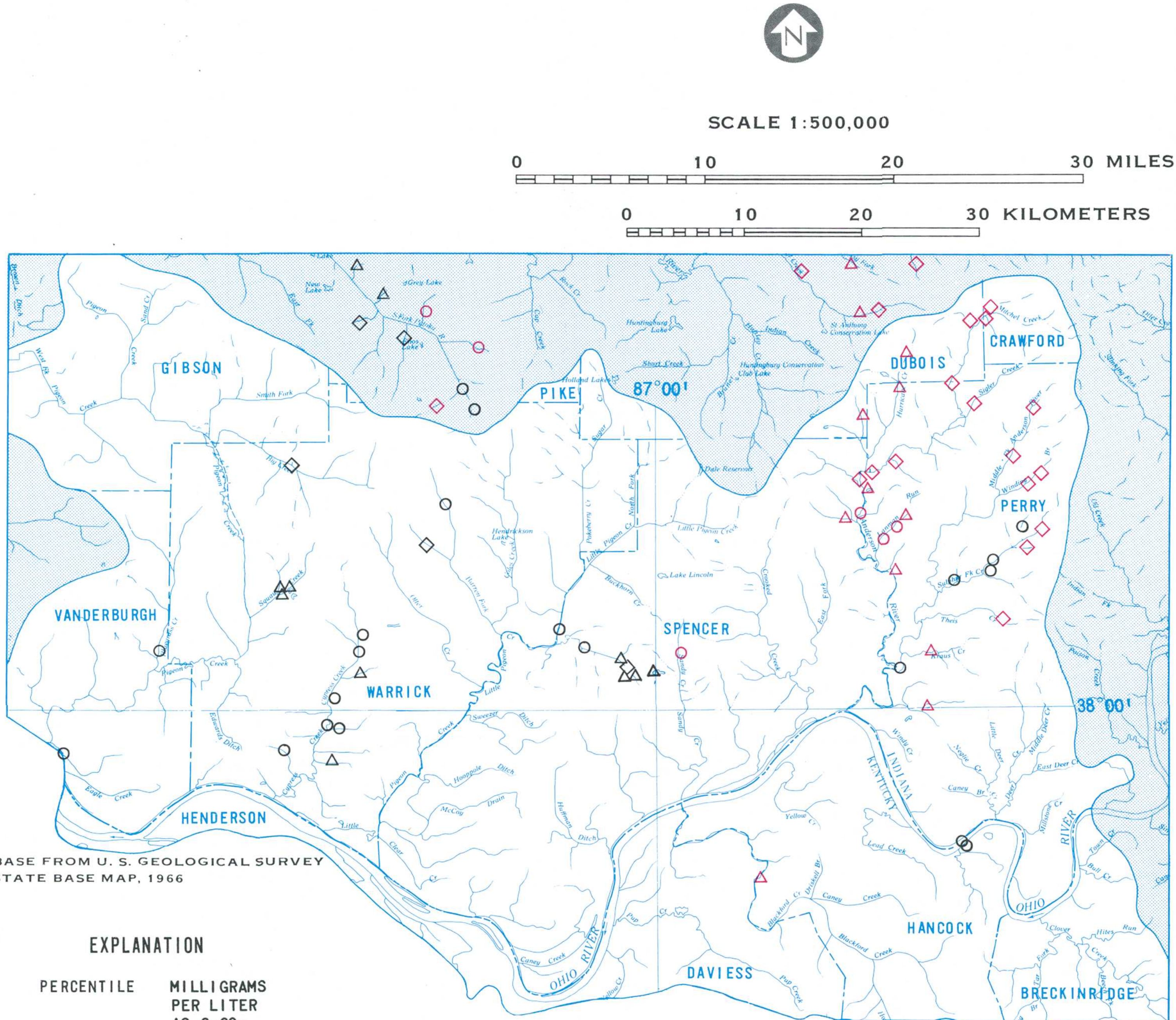
4.1.3 REGIONAL WATER-QUALITY TRENDS (Continued)

4.1.3.1 pH

REGIONAL WATER-QUALITY TRENDS IN ALKALINITY

The median of average alkalinity for samples from 73 stations was 50.6 mg/L, as calcium carbonate. The average concentration ranged from 0 to 380 mg/L.

Alkalinity of surface water in the east half of Area 33 is generally lower than the alkalinity of surface water in the west half. Like pH, the alkalinity is probably affected by the amount and the extent of surface mining as well as the bedrock geology of the region. The average alkalinity of water samples collected at each station in the study area was grouped into six ranges by percentile and are presented in the adjoining figure 4.1.3.2.



EXPLANATION

PERCENTILE	MILLIGRAMS PER LITER AS $CaCO_3$
○ <10	<11
△ 10-25	11-22
◇ 25-50	22-61
○ 50-75	61-140
△ 75-90	140-280
◇ >90	>280

Figure 4.1.3.2.-- Ranges of average alkalinity concentrations.

REGIONAL WATER-QUALITY TRENDS IN SPECIFIC CONDUCTANCE

The median of average specific conductance for samples from 120 stations within the study area was 358 μmho/cm at 25°C. Average specific conductance ranged from 80 to 1,600 μmho/cm at 25°C.

Average specific conductance was higher in the west half of Area 33 than in the east half. Both the amount and the extent of surface mining as well as the bedrock geology of the region seemed to affect specific conductance. Surface water in the west half of the study area is representative of the Wabash Lowland physiographic unit. Its dissolved-solids concentration may be higher than that of surface water in the east half because of contact with the bedrock, which has a higher concentration of carbonate minerals. Considerably more coal has been mined in the west half of the study area than in the east half. The increases in concentrations of most major dissolved constituents have been observed in drainage from both old and new mining areas. These increases account for at least some of the difference in specific conductance between the two halves. Without additional study, the relative contribution of dissolved ions from both bedrock and surface-mining activity cannot be determined. The average specific conductance of samples from each station in the study area was grouped into six ranges by percentile and are shown in the adjoining figure 4.1.3.3.

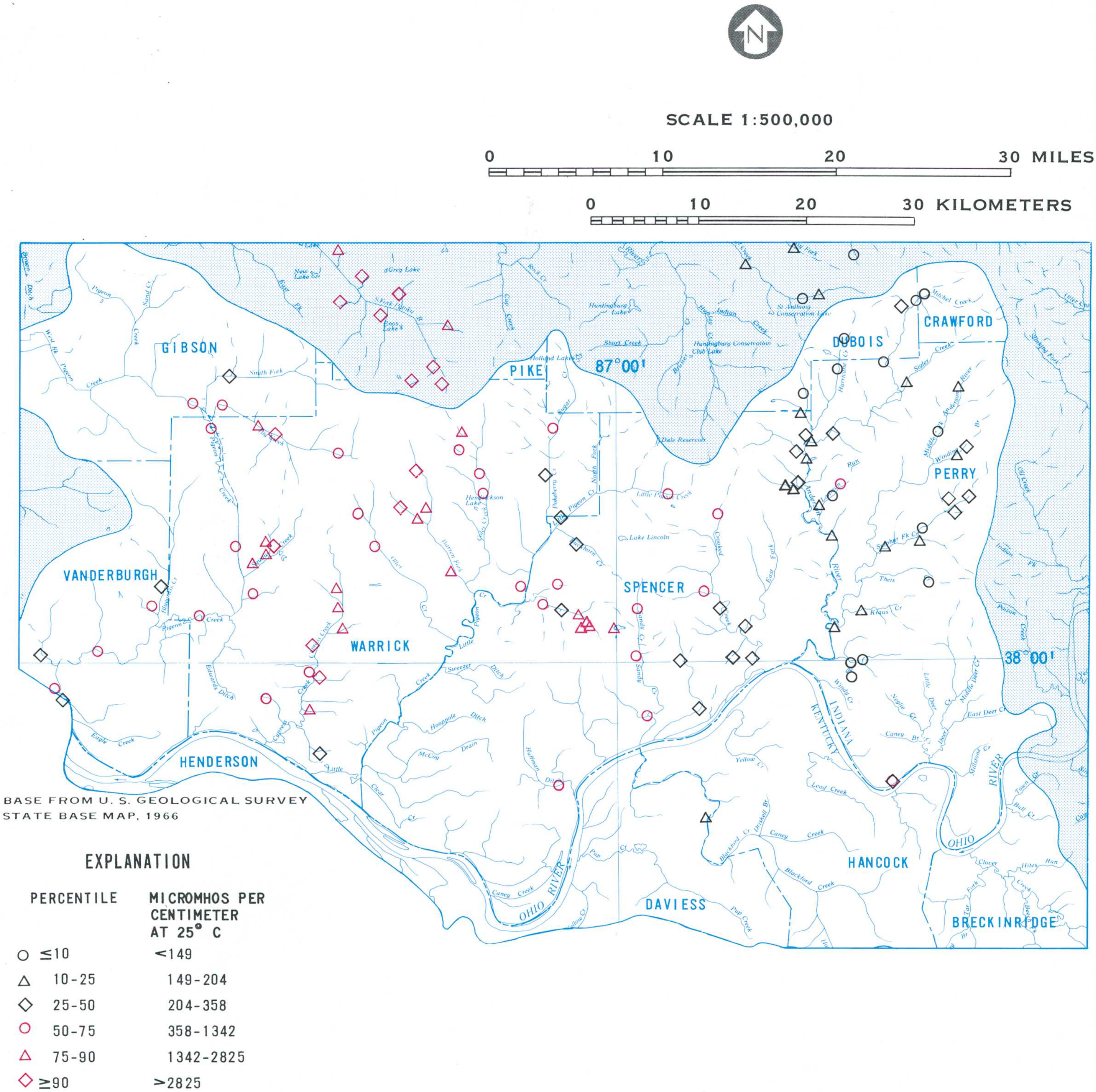


Figure 4.1.3.3.-- Ranges of average specific conductances.

REGIONAL WATER-QUALITY TRENDS IN SULFATE CONCENTRATION

The median of average sulfate concentration for samples from 59 stations within Area 33 was 150 mg/L. The average sulfate concentration ranged from 18 to 4,000 mg/L.

Average sulfate concentration of surface water was higher in the west half of Area 33 than in the east half. Considerably more coal has been mined in the west half of the study area than in the east half, which has resulted in exposure and oxidation of more pyrite and marcasite in the west half. In the oxidation, sulfate is produced (Hem, 1970, p.124 and 162). The average sulfate concentration of samples collected for each station sampled in the study area was grouped into six ranges by percentile and are shown in the adjoining figure 4.1.3.4.

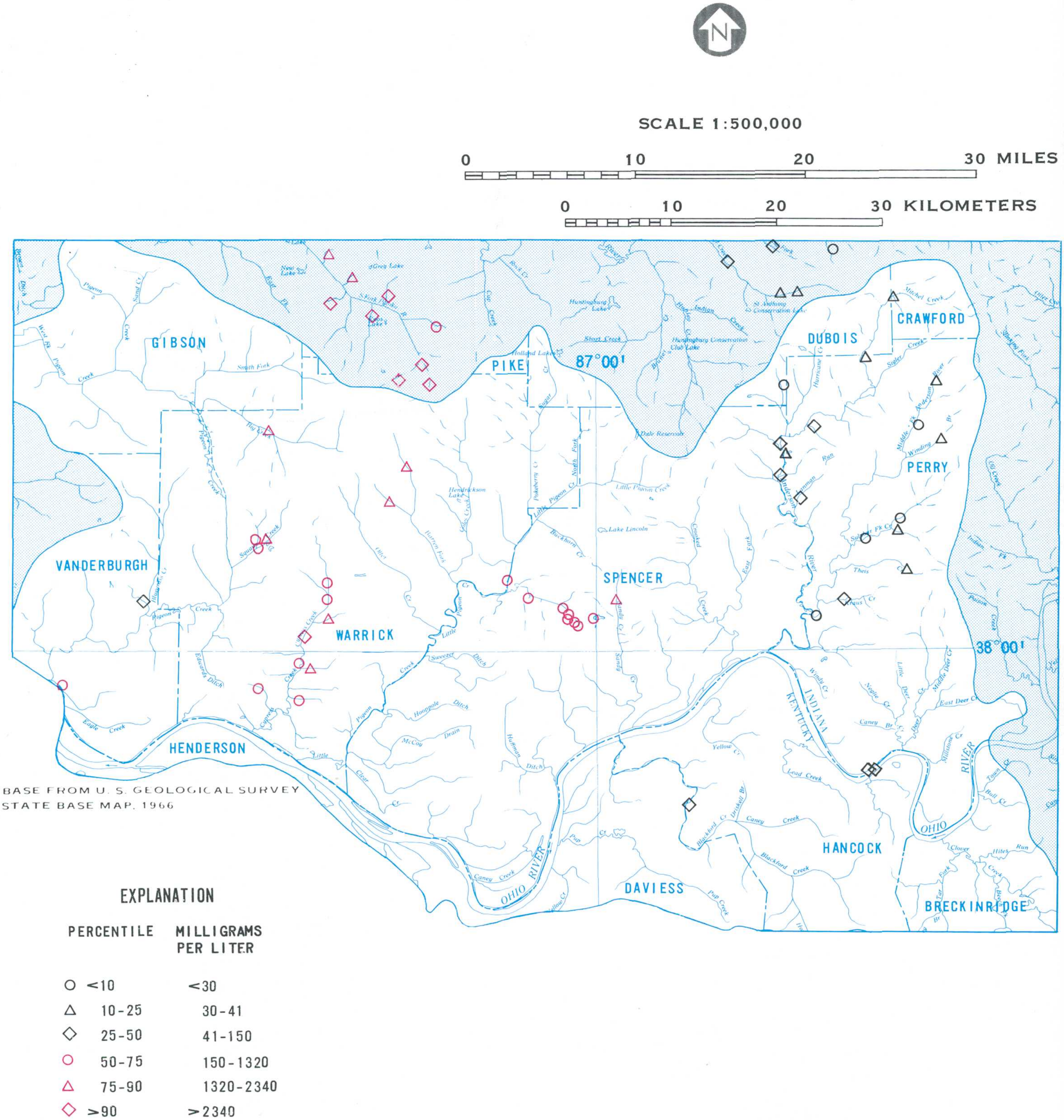


Figure 4.1.3.4.-- Ranges of average sulfate concentrations.

NO REGIONAL TRENDS IN TOTAL AND DISSOLVED IRON CONCENTRATIONS

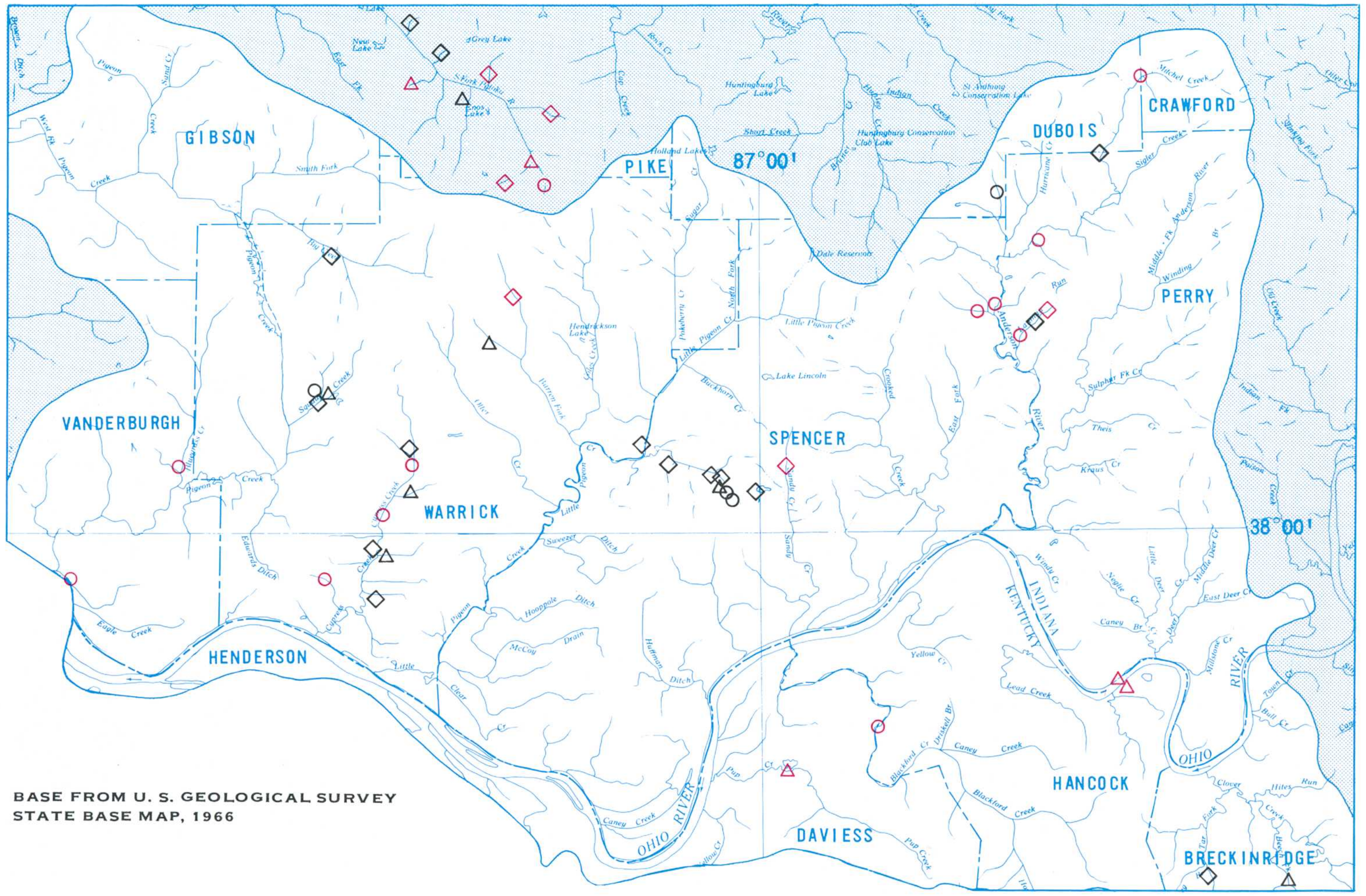
The median of average total iron concentration for samples from 4 stations within Area 33 was 14,500 μg/L. Average concentration ranged from 30 to 31,500 μg/L. The median of average dissolved iron concentration for samples from 60 stations was 60 μg/L. Average concentration ranged from 5 to 27,500 μg/L.

The data are variable and no regional trend was observed for either total or dissolved iron. The average total and dissolved iron concentrations of samples collected for each station sampled in Area 33 were grouped into six ranges by percentile and are shown in the adjoining figures 4.1.3.5a and 4.1.3.5b.

SCALE 1:500,000

0 10 20 30 MILES

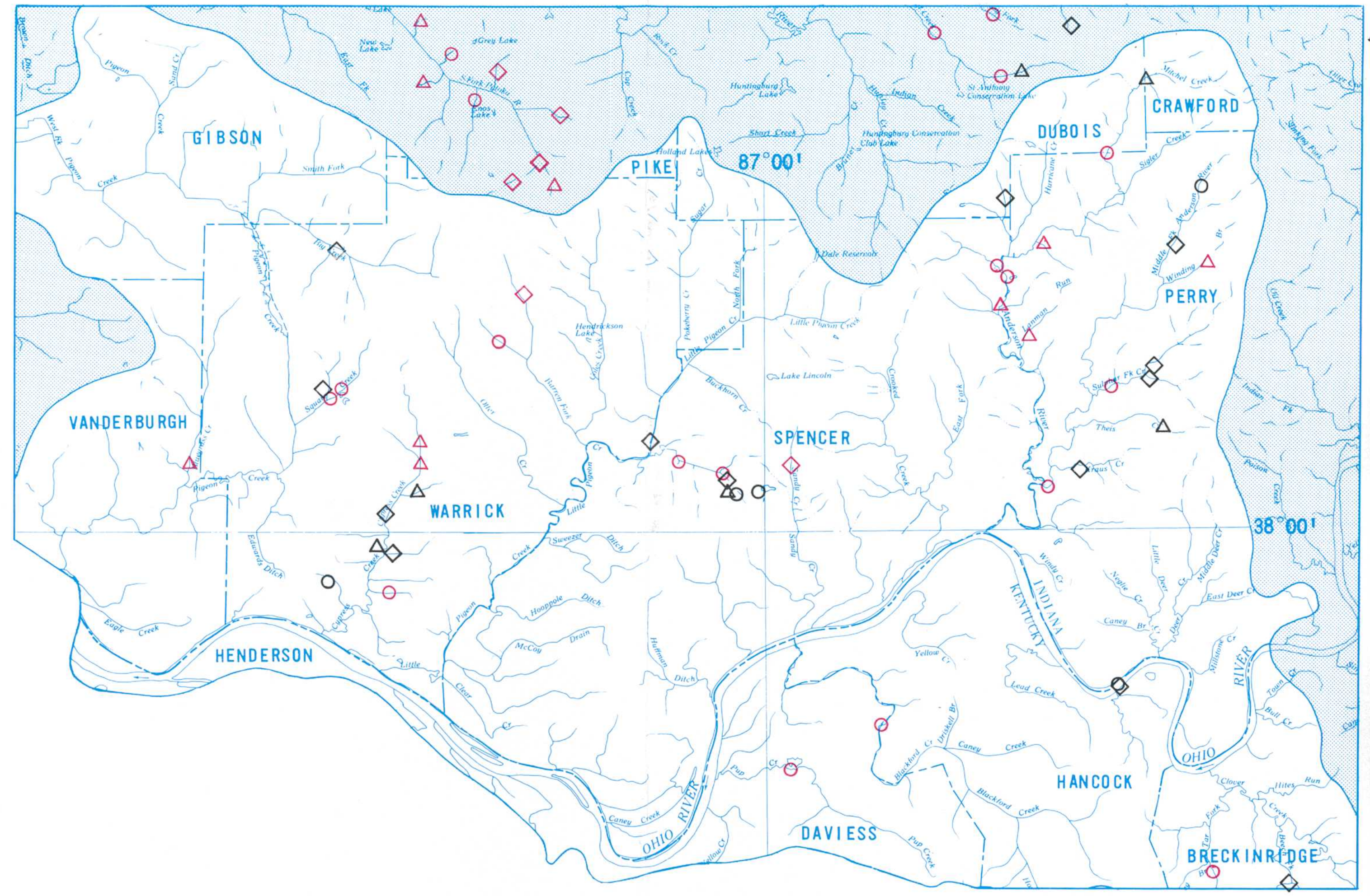
0 10 20 30 KILOMETERS



EXPLANATION

PERCENTILE	MICROGRAMS PER LITER
○ <10	<296
△ 10-25	296-550
◇ 25-50	550-1450
○ 50-75	1450-2715
△ 75-90	2715-6710
◇ >90	>6710

Figure 4.1.3.5a.--Ranges of average total-iron concentrations.



EXPLANATION

PERCENTILE	MICROGRAMS PER LITER
○ ≤10	<24
△ 10-25	24-40
◇ 25-50	40-60
○ 50-75	60-164
△ 75-90	164-916
◇ ≥90	>916

Figure 4.1.3.5b.--Ranges of average dissolved-iron concentrations.

REGIONAL WATER-QUALITY TRENDS IN TOTAL AND DISSOLVED MANGANESE CONCENTRATIONS

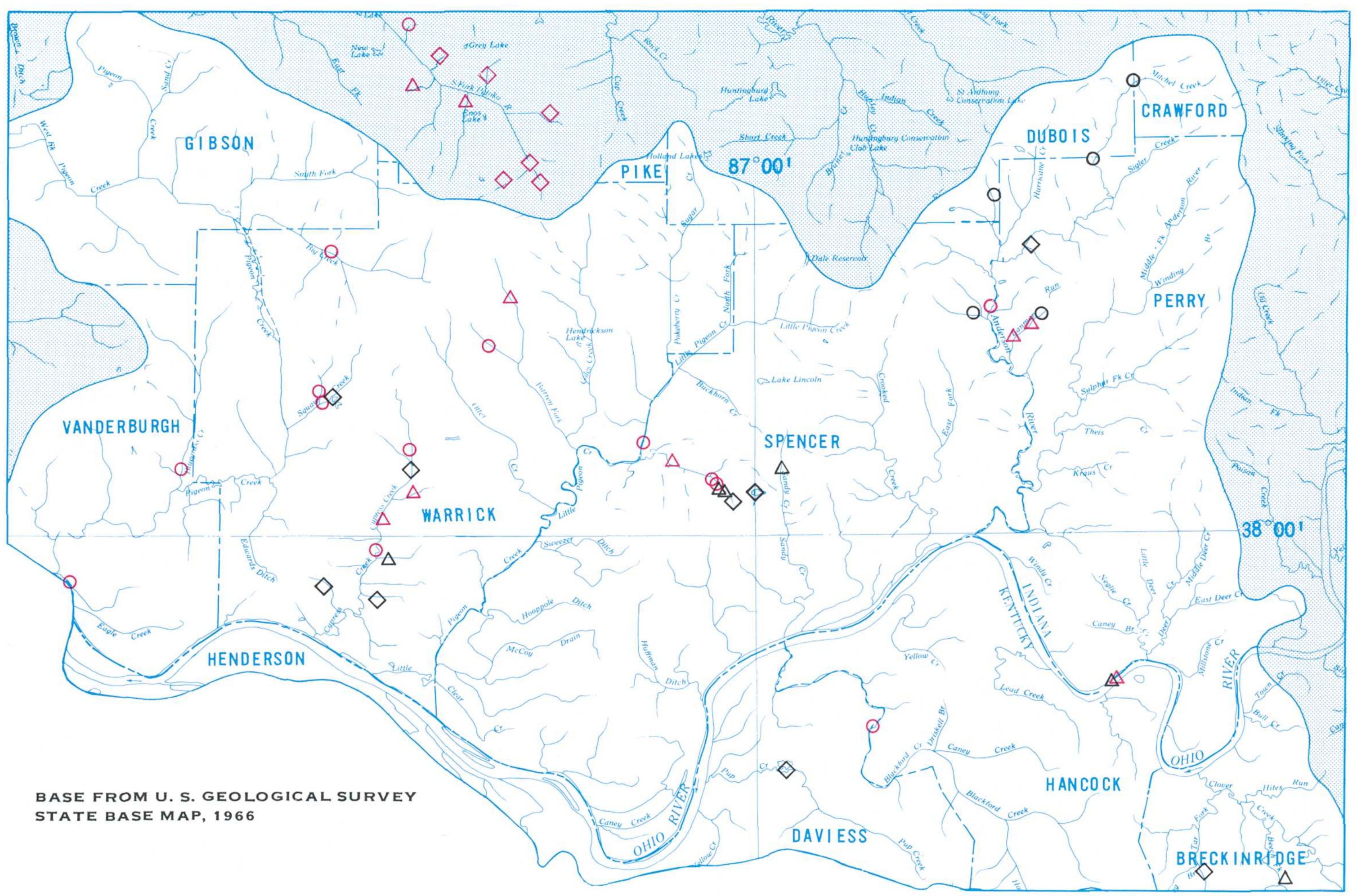
The median of average total manganese concentration for samples for 49 stations within Area 33 was 560 μg/L. Average concentration ranged form 0 to 33,000 μg/L. Most of the manganese in surface water was in the dissolved phase. The median of average dissolved manganese concentration for samples from 60 stations was 376 μg/L. Average concentration ranged from 17 to 33,500 μg/L.

Total and dissolved manganese concentrations of surface water in the west half of Area 33 are higher than in the east half. The amount and the extent of surface mining and the bedrock geology of the region seems to affect the manganese concentration in the streams. The average total and dissolved manganese concentrations of samples collected for each station sampled were grouped into six ranges by percentile and are shown in the adjoining figures 4.1.3.6a and 4.1.3.6b.

SCALE 1:500,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

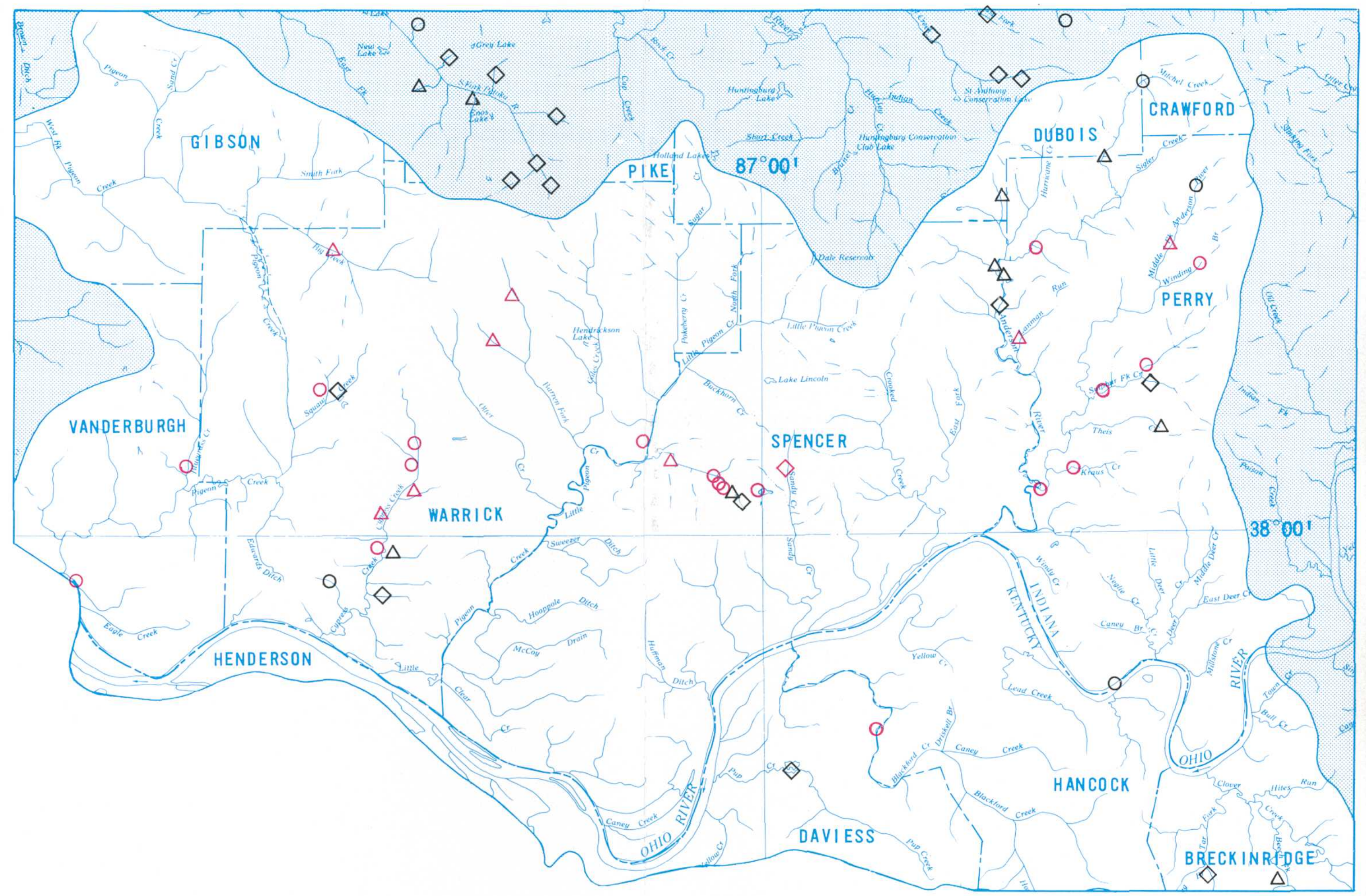


BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1966

EXPLANATION

Symbol	PERCENTILE	MICROGRAMS PER LITER
○	<10	<103
△	10-25	103-171
◇	25-50	171-560
○ (red)	50-75	560-1975
△ (red)	75-90	1975-6660
◇ (red)	>90	>6660

Figure 4.1.3.6a.-- Ranges of average total-manganese concentrations.



EXPLANATION

Symbol	PERCENTILE	MICROGRAMS PER LITER
○	≤10	<49
△	10-25	49-130
◇	25-50	130-376
○ (red)	50-75	376-1200
△ (red)	75-90	1200-5620
◇ (red)	≥90	>5620

Figure 4.1.3.6b.-- Ranges of average dissolved-manganese concentrations.

SUSPENDED-SEDIMENT DATA FOR MIDDLE FORK ANDERSON RIVER AT BRISTOW, INDIANA

Few suspended-sediment data are available within Area 33. The concentration of suspended sediment in 101 samples ranged from 1 to 578 mg/L for discharge that ranged from 0.1 to 1,600 ft^3/s in the Middle Fork Anderson River at Bristow.

The data presented here represent approximately 15 years of suspended-sediment data collected periodically from the Middle Fork Anderson River at Bristow (03303300). Location of the station is shown on the map below. The relationship between suspended-sediment concentration and discharge at the site is shown by the curve in the adjoining illustration (fig. 4.1.4). The curve is not a mathematical regression but was drawn to show the relation between suspended-sediment concentration and discharge. The variation about the line is probably due to factors such as seasonal, land use, precipitation intensity, and the time of sampling in relation to hydrologic events.

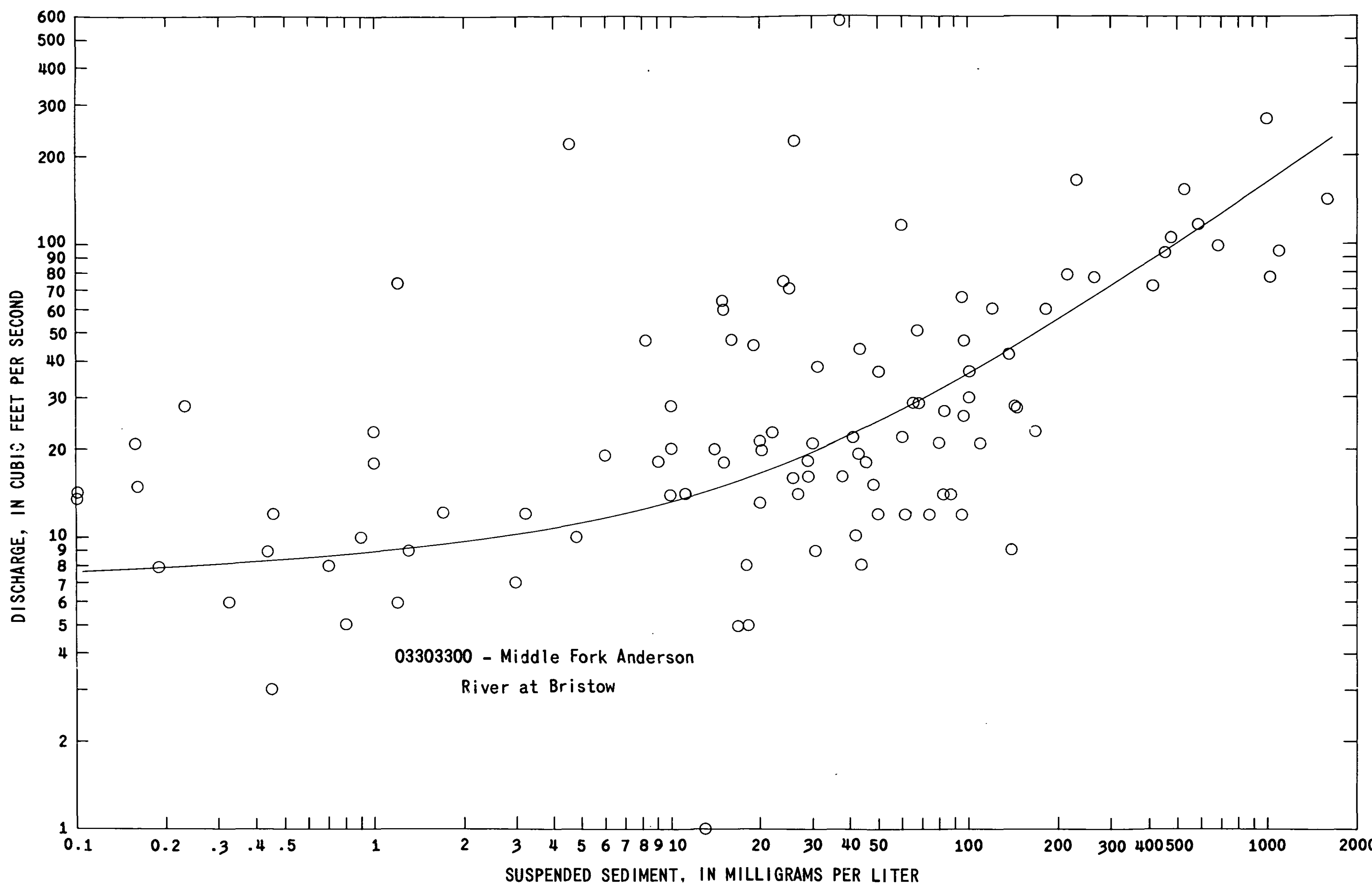


Figure 4.1 4.-- Relation of suspended-sediment concentrations to discharge, March 1964 to July 1979.

WATER-QUALITY VARIATION IS GREATEST IN THE BEDROCK AQUIFERS

Water in the Ohio River alluvial aquifer is a hard to very hard calcium bicarbonate type. In some localities, iron concentration of the water exceeds 300 μg/L. The quality of water in the Pennsylvanian rocks near the surface of the aquifer is similar, but in some localities the water changes with depth to a sodium bicarbonate type with a median dissolved-solids concentration of 514 mg/L.

The ground-water quality is affected by the calcareous materials of the aquifers. Calcium bicarbonate or calcium and magnesium bicarbonate are common water types in all aquifers in area 33. Water type varies because of human influences or, particularly in the bedrock system, with depth.

Water in the Ohio River alluvial aquifer is a hard to very hard calcium bicarbonate (200 to 400 mg/L hardness as calcium carbonate) type. Iron concentrations of this water are commonly as much as 10,000 μg/L (Gallaher and Price, 1966). Chloride concentration of the water is low relative to that of water in bedrock aquifers. A median chloride concentration of 11 mg/L was reported for the Indiana part of the alluvial aquifer by Pettijohn and Reussow (1969). Chemical quality of water in the aquifer has been affected by agricultural, municipal, and industrial development (Gallaher and Price, 1966).

According to Pettijohn and Reussow (1969), the ground water near the surface of the Pennsylvanian bedrock is usually calcium bicarbonate type and low in chloride. However, the water downdip is characteristically sodium bicarbonate type whose chloride concentration is higher and whose hardness is lower than those values for water in the Pennsylvanian bedrock. The median dissolved-solids concentration of water in the Pennsylvanian bedrock was 514 mg/L compared with a concentration of 368 mg/L for the alluvial aquifer according to Pettijohn and Reussow (1969). The variation in dissolved-solids concentration is controlled by the amount and the kind of soluble materials in the rock and may be influenced by man's activities.

The depth to freshwater (1,000 mg/L dissolved solids) varies areally. Pettijohn and Reussow (1969) reported that freshwater generally can be found at depths less than 200 feet below land surface.

Bedrock and alluvial ground waters mix, but the extent to which the bedrock water quality affects that in the alluvium is not known. Apparently the effect is minimal and is noticeable only locally (Gallaher and Price, 1966).

The adjoining map (fig. 4.2) shows the location of the formations mentioned in section 4.2. Also included is the extent of lake-sediment deposits. Data on the water quality of lake-sediment deposits is not known, but they are probably similar to those of the Ohio River alluvium.

Approximately 450 water wells have been sampled within the study area, and the data have been processed into the National Water Data Storage and Retrieval System. However, only about 40 wells from the glacial-outwash aquifers were identified. The data are summarized in the following table:

	Specific conductance (μmho/cm at 25°C)	pH	Sulfate (mg/L)
Average	539	6.7	32
Range	155-1,350	5.7-8.5	4.1-155

All data from the system are available for inspection at the Indianapolis office of the Geological Survey.

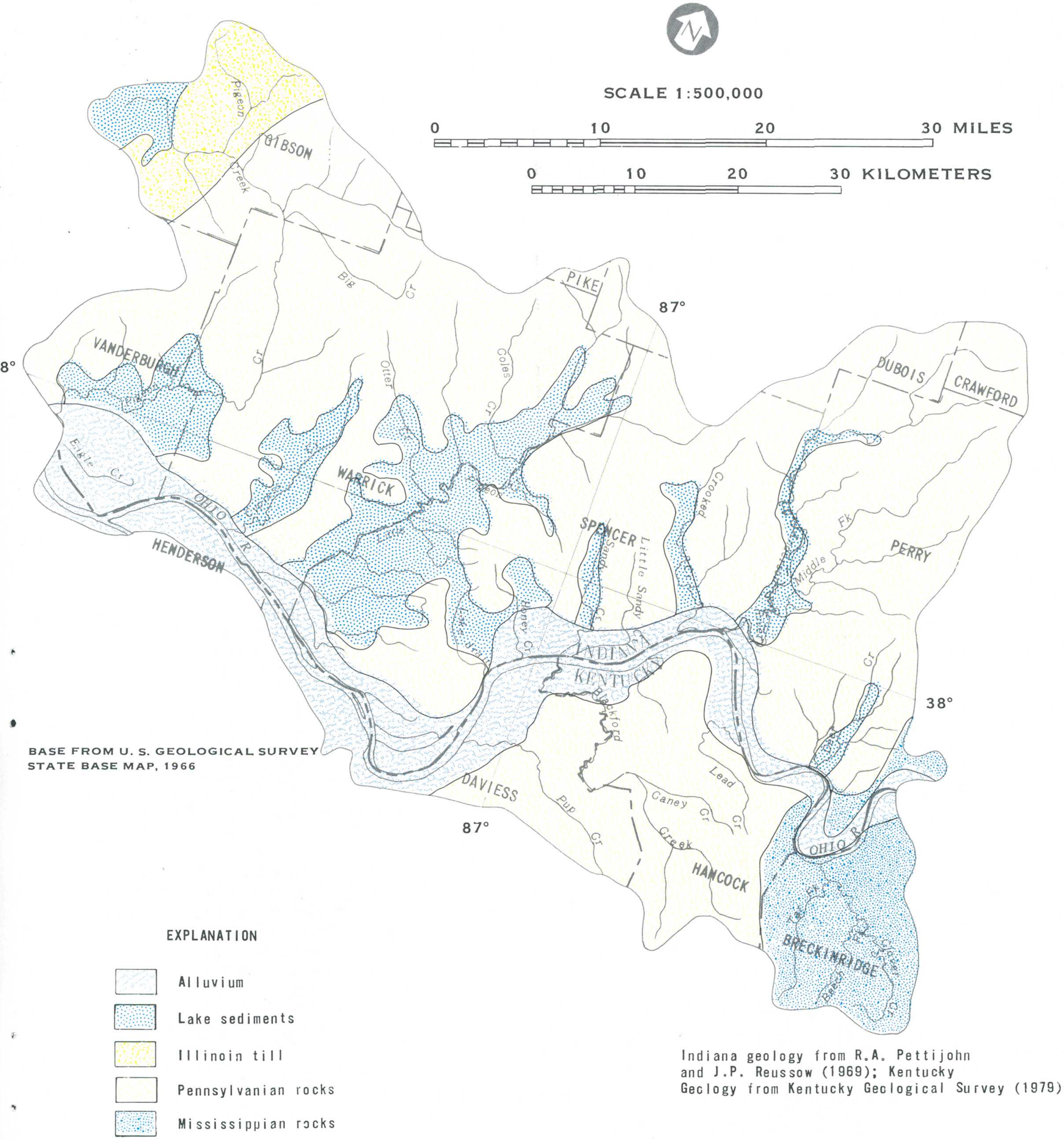


Figure 4.2. -- Extent of potential water-yielding formations.

NAWDEX, WATSTORE, AND OWDC HELP USERS OBTAIN WATER DATA

Water data in coal areas are collected by many organizations in response to a wide variety of needs.

Three facilities within the Geological Survey help to identify and improve access to the vast amount of water data:

(1) The National Water-Data Exchange (NAWDEX), which indexes the water data available from more than 400 organizations and serves as a central focal point for determining what water data are available.

(2) The National Water-Data Storage and Retrieval System (WATSTORE), which serves as the central repository of water data collected by the Geological Survey and which contains large volumes of data on the quantity and the quality of both surface water and ground water.

(3) The Office of Water-Data Coordination (OWDC), which coordinates Federal water-data acquisition activities and maintains a "Catalog of Information on Water Data." Special indexes to the catalog, identifying available water-data facilities in coal provinces of the United States, are being printed and made available to the public.

More detailed explanations of items 1, 2, and 3 are given in sections 5.2, 5.3, and 5.4.

NAWDEX SIMPLIFIES ACCESS TO WATER DATA

The National Water-Data Exchange (NAWDEX) is a nationwide facility managed by the U.S. Geological Survey to assist users of water data or water-related data in identifying, locating, and acquiring data.

NAWDEX is a national confederation of water-oriented organizations working together to make their data more readily accessible and to facilitate a more efficient exchange of water data.

Services are available through a Program Office at the Geological Survey National Center in Reston, Va., and a nationwide network of Assistance Centers in 45 states and Puerto Rico, which provide local and convenient access to NAWDEX facilities. A directory that provides names of organizations and persons to contact, as well as addresses, telephone numbers, and office hours for each of these organizations is available on request (Edwards, 1979).

NAWDEX can assist any organization or individual in identifying and locating water data. To accomplish this service, NAWDEX maintains a computerized Master Water-Data Index, which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. NAWDEX also maintains a Water-Data Sources Directory identifying organizations from which water data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search assistance services are provided free by NAWDEX to the greatest extent possible. Charges are assessed, however, for requests requiring computer cost, extensive personnel time, duplicating services, or other costs to NAWDEX providing services. Charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX on request and where costs are anticipated to be substantial.

For additional information concerning the NAWDEX program or its services contact:

Program Office
National Water-Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

Telephone: (703)860-6031
FTS 928-6031

Hours: 7:45 - 4:15 eastern time

or

NAWDEX ASSISTANCE CENTER
Indiana
U.S. Geological Survey
Water Resources Division
1819 North Meridian St.
Indianapolis, IN 46202

Telephone: (317) 269-7101
FTS 331-7101

Hours: 7:30 - 4:00 eastern time

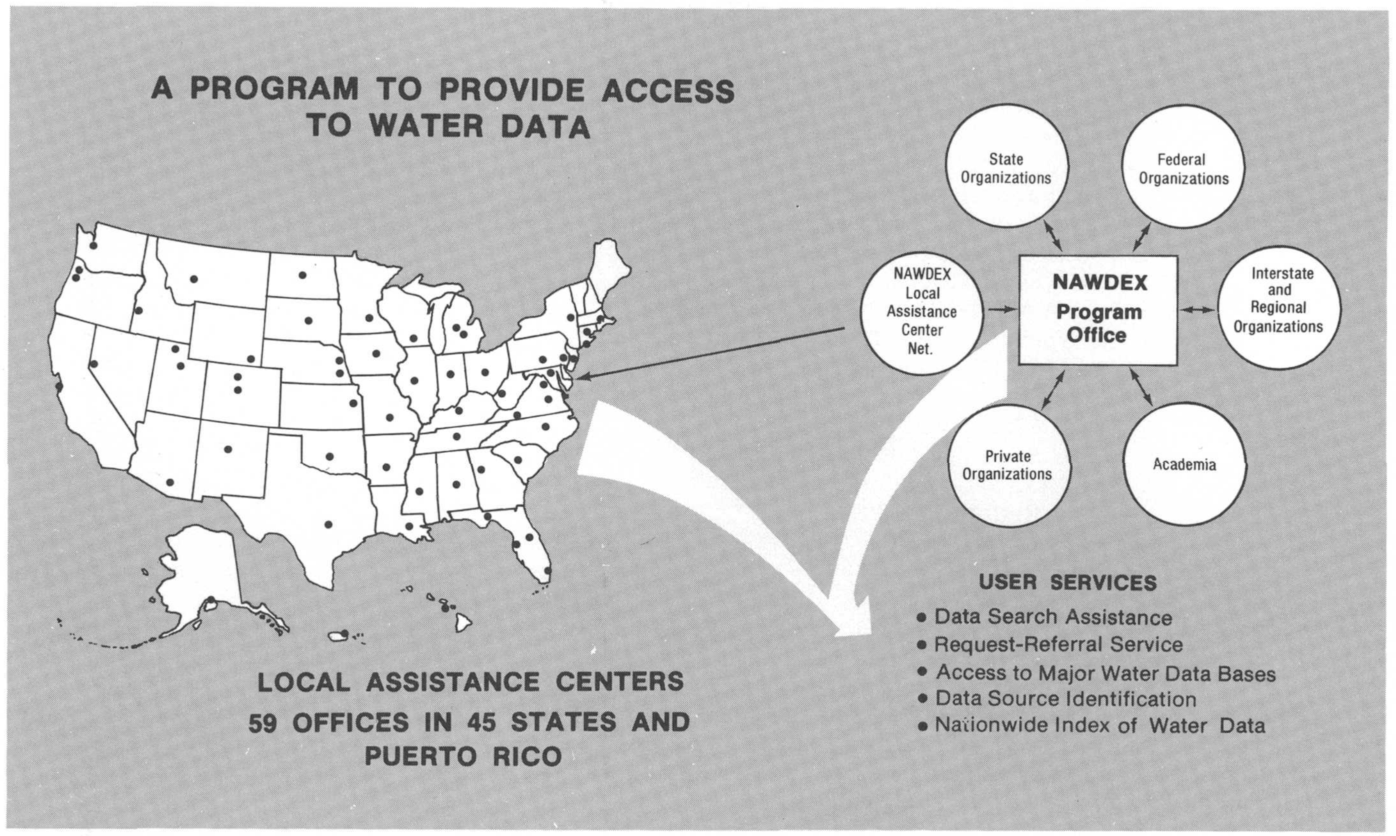


Figure 5.2-1 Access to water data

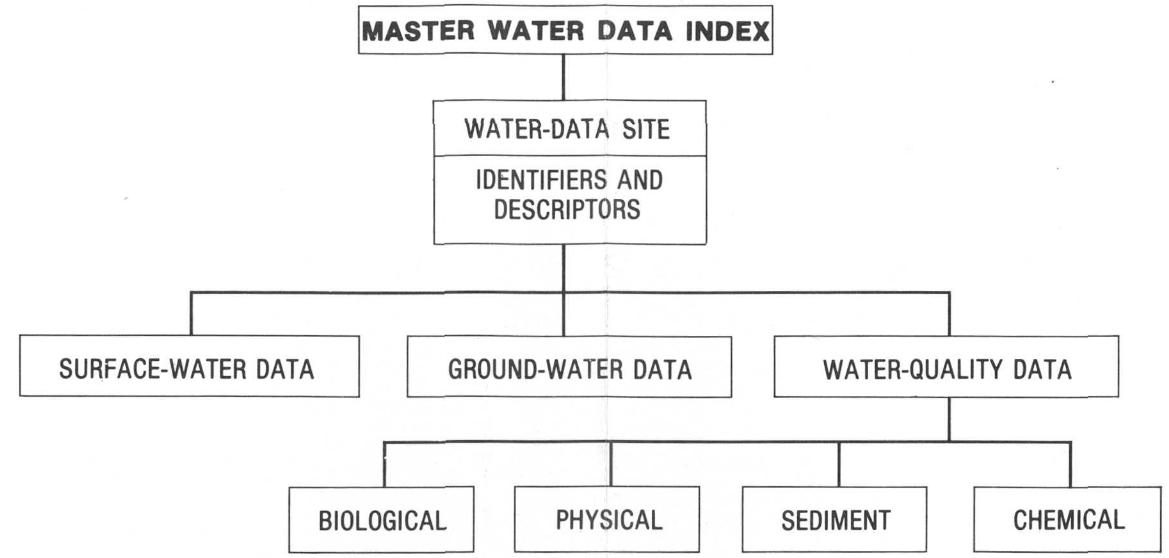


Figure 5.2-2 Master water-data index

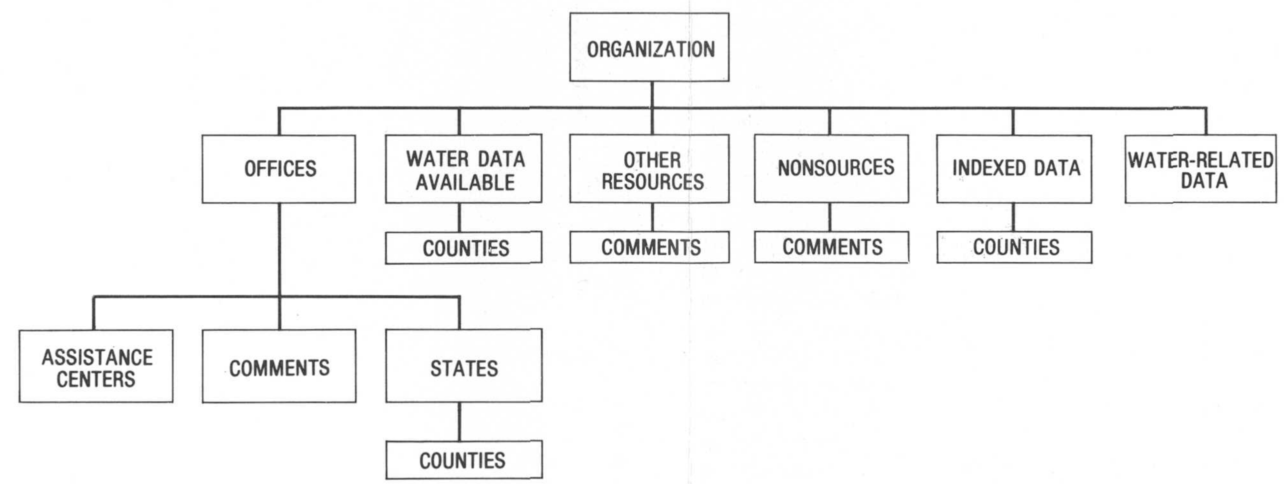


Figure 5.2-3 Water-data sources directory

WATSTORE AUTOMATED DATA SYSTEM

The National Water-Data Storage and Retrieval System (WATSTORE) of the Geological Survey provides computerized procedures and techniques for processing water data.

The National Water-Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the water-data system of the Geological Survey and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Geological Survey at its National Center in Reston, Va. Data may be obtained from WATSTORE through the 46 district offices of the Water Resources Division. General inquiries about WATSTORE may be directed to:

Chief Hydrologist
U.S. Geological Survey
437 National Center
Reston, VA 22092

or

U.S. Geological Survey
Water Resources Division
1819 North Meridian St.
Indianapolis, IN 46202

The Geological Survey currently (1981) collects data at approximately 16,000 stream-gaging stations, 1,000 lakes and reservoirs, 5,200 surface-water quality stations, 1,000 sediment stations, 30,000 observation wells, and 12,500 ground-water quality wells. Each year many water-data collection sites are added, and others are discontinued. Thus, large amounts of diversified data, both current and historical, are amassed by the data-collection activities of the Survey.

The WATSTORE system consists of several files in which data are grouped and are stored by common characteristics and data-collection frequencies. The system is designed to allow for the addition of data files as needed. Files are maintained for the storage of (1) surface-water, quality-of-water, and ground-water data measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained. A brief description of each file follows:

Station-Header File: All sites for which data are stored in the Daily-Values, Peak-Flow, Water-Quality, and Unit-Values files of WATSTORE are indexed in this file. It contains information pertinent to the identification, location, and physical description of nearly 220,000 sites.

Daily-Values File: All water-data parameters measured or observed, either on a daily or on a continuous basis, and numerically reduced to daily values are stored in this file. Instantaneous measurements at fixed-time intervals, daily mean values, and statistics such as daily maximum and minimum values also may be stored. The file currently contains over 200 million daily measurements, including data on streamflow, river stage, reservoir content, water temperature, specific conductance, sediment concentration, sediment discharge, and ground-water level.

Peak-Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) data at surface-water sites compose this file, which currently contains over 400,000 peak measurements.

Water-Quality File: More than 1.4 million analyses of water samples in this file describe the chemical, physical, biological, and radiochemical characteristics of both surface water and ground water. These analyses include data for 185 constituents and properties.

Unit-Values File: Water parameters measured more frequently than daily are stored in this file. Rainfall, stream-discharge, and water temperature data are examples of the types of data stored in the Unit-Values File.

Ground-Water Site-Inventory File: This file is maintained with WATSTORE independent of the preceding files, but it is cross referenced to the Water Quality and the Daily-Values Files. The file contains inventory data on wells, and springs. Examples of data are site location, site identification, geohydrologic characteristics, well-construction history, and field measurements of water temperature. The file is designed to accomodate 255 data elements and currently contains data for nearly 700,000 sites.

All data files of the WATSTORE system are maintained and managed on the central computer facilities of the Geological Survey at its National Center. However, data may be entered into or retrieved from WATSTORE at several locations that are part of a nationwide telecommunication network.

Remote Job-Entry Sites: Almost all district offices of the Water Resources Division are equipped with high-speed computer terminals for remote access to the WATSTORE system. These terminals allow each site to put data into or retrieve data from the system within times ranging from several minutes to overnight, depending on the priority of the request. The number of remote job-entry sites is increased as the need arises.

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stage, specific conductance, water temperature, turbidity, wind direction, and chloride concentration. Data are recorded on 16-channel paper tape and are transmitted over telephone lines to the receiver at Reston, Va. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data-collection platforms indicates their feasibility for collecting realtime hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200 data-relay stations are being operated currently (1981).

Central-Laboratory System: The two water-quality laboratories of the Water Resources Division, in Denver, Colo., and Doraville, Ga., analyze more than 150,000 water samples per year. These laboratories are equipped to determine concentrations of dissolved constituents ranging from chloride to complex organic compounds, such as pesticides, and to measure various properties of water. After verification by laboratory personnel, results of each analysis are transmitted by a computer terminal to the central computer facilities for storage in the Water-Quality File of WATSTORE.

Water data are used in many ways in the management, development, and monitoring of water resources. In addition to its data processing, storage, and retrieval capabilities, WATSTORE can provide a variety of useful products ranging from simple data tables to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requester.

Computer-Printed Tables: Users most often request data from WATSTORE in the form of tables printed by the computer. These tables may contain lists of data or condensed indexes that indicate the availability of data stored in the files. A variety of formats is available to display the many types of data.

Computer-Printed Graphs: Computer-printed graphs for the rapid analysis or display of data are another capability of WATSTORE. Computer programs are available to produce bar graphs (histograms), line graphs, frequency distribution curves, X-Y point plots, site-location map plots, and other similar items by means of line printers.

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package (SAS) to provide extensive analyses of data such as regression analysis, the analysis of variance, transformations, and correlations.

Digital Plotting: WATSTORE also makes use of software systems that prepare data for digital plotting on peripheral off-line plotters available at the central computer site. Hydrographs, frequency-distribution curves, X-Y point plots, contours, and three-dimensional illustrations can be plotted.

Data in Machine-Readable Form: Data stored in WATSTORE can be obtained in machine-readable form for use on other computers or for use as input to user-written computer programs. These data are available in the standard storage format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

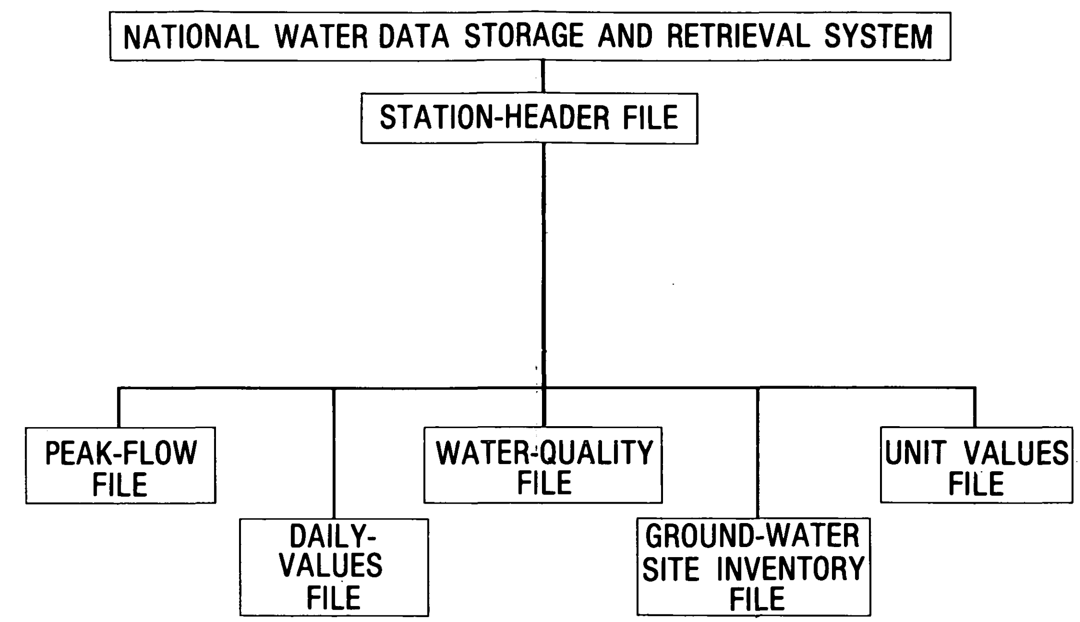


Figure 5.3-1 Index file stored data

WATER DATA INDEXED FOR COAL PROVINCES

A special index, "Index to Water-Data Activities in Coal Provinces of the United States," has been published by the Geological Survey Office of Water Data Coordination (OWDC).

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to provide information on the availability of water-resources data in the major coal provinces of the United States for people developing, managing, and regulating the coal resources of the Nation. It is derived from the "Catalog of Information on Water Data," a computerized information file about water-data acquisition in the United States, and some other countries. The index consists of five volumes: volume I, Eastern Coal province; volume II, Interior Coal province; volume III, Northern Great Plains and Rocky Mountain Coal provinces; volume IV, Gulf Coast Coal province; and volume V, Pacific Coast and Alaska Coal provinces. The volumes presented aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs.

Each volume of the special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal Investigations and Miscellaneous Activities. Information given for each activity in Parts A-C includes (1) identification and location of the station, (2) major types of data collected, (3) frequency of data collection, (4) form in which the data are stored, and (5) agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are shown in a table.

Assistance in obtaining additional information from the Catalog file or water data is available through the National Water-Data Exchange (NAWDEX).

Further information on the index volumes and their availability may be obtained from:

U.S. Geological Survey
Water Resources Division
1819 North Meridian St.
Indianapolis, IN 46202

Telephone: (317) 269-7101)
FTS 331-7101

or

Office of Surface Mining
U.S. Department of the Interior
46 East Ohio Street
Indianapolis, IN 46202

Telephone: (317) 269-2600
FTS 331-2636 or
FTS 331-2600

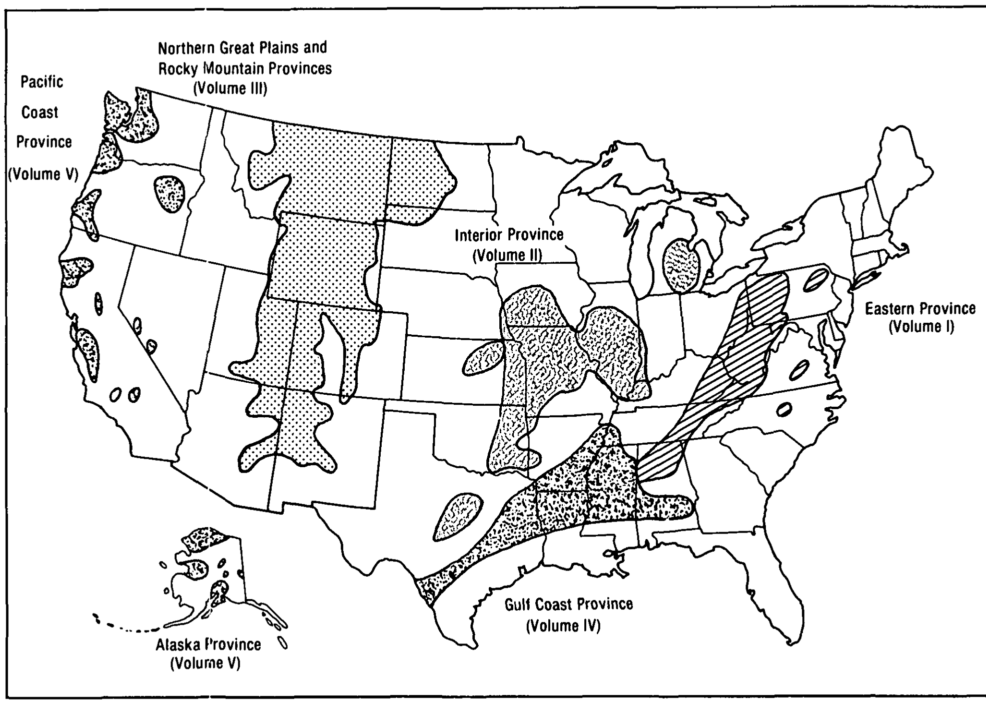


Figure 5.4-1 Index volumes and related provinces

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Appendix 1. -- Regional water-quality trends sites

Number of Observations for Water-Quality Parameters

ID	Station name	County	Agency	Lat	Long	Spec. Cond.	Sul-fate	pH	Alka-linity	Total Fe	Diss. Fe	Total Mn	Diss. Mn
1	Anderson R. nr Birdseye, Ind.	Crawford	USGS	381756	0864042	1	1	1	1	1	1	1	1
2	Trib. to Anderson R. nr Birdseye, Ind.	Crawford	USGS	381811	0864042	1	0	1	1	0	0	0	0
3[1]	Flat Cr at St Marks, Ind.	Dubois	USGS	381803	0864805	2	1	1	1	0	1	0	1
4[1]	Flat Cr nr St Anthony, Ind.	Dubois	USGS	381944	0865132	1	1	1	1	0	1	0	1
5[1]	Grassy Fk nr St Anthony, Ind.	Dubois	USGS	382034	0864844	1	1	1	1	0	1	0	1
6[1]	Hall Cr at Schnellville, Ind.	Dubois	USGS	382021	0864445	1	1	1	1	0	1	0	1
7	Hurricane Cr nr Birdseye, Ind.	Dubois	USGS	381602	0864517	1	0	1	1	0	0	0	0
8[1]	Richland Cr nr St Marks, Ind.	Dubois	USGS	381759	0864658	1	1	1	1	0	1	0	1
9	Trib. to Waddle Br nr Birdseye, Ind.	Dubois	USGS	381745	0864125	1	0	1	1	0	0	0	0
10	Big Cr nr Buckskin, Ind. (03322050)	Gibson	USGS	381241	0872436	1	0	1	0	0	0	0	0
11	Pigeon Cr nr Buckskin, Ind.	Gibson	USGS	381237	0872629	1	0	1	0	0	0	0	0
12	Smith Fk nr Buckskin, Ind.	Gibson	USGS	381411	0872425	1	0	1	0	0	0	0	0
13	Smith Fk nr Buckskin, Ind.	Gibson	USGS	381323	0872558	1	0	1	0	0	0	0	0
14	Anderson R. at Kitterman Corners, Ind.	Perry	USGS	381453	0864238	1	1	1	1	1	1	1	1
15	Anderson R. at Huffman, Ind.	Perry	USGS	380614	0864623	1	0	1	1	0	0	0	0
16	Brushy Hollow nr Tell City, Ind.	Perry	USGS	380005	0864413	1	0	1	1	0	0	0	0
17	Hurricane Cr nr Birdseye, Ind.	Perry	USGS	381437	0864544	1	0	1	1	0	0	0	0
18	Kraus Cr nr Bristow, Ind.	Perry	USGS	380232	0864413	5	5	5	5	0	5	0	5
19	Lanman Run nr St Meinrad, Ind.	Perry	USGS	380745	0864703	1	1	1	1	1	1	1	1
20	Lanman Run nr St Meinrad, Ind.	Perry	USGS	380828	0864551	1	0	1	1	1	0	1	0
21	Little Sulphur Cr nr Bristow, Ind.	Perry	USGS	380549	0864000	5	5	5	5	0	5	0	5
22	Middle Fk Anderson nr St Croix, Ind.	Perry	USGS	381331	0863815	4	4	4	4	0	4	0	4
23	Middle Fk Anderson R. nr Tell City, Ind.	Perry	USGS	380137	0864552	4	1	4	1	0	1	0	1
24	Middle Fk Anderson R. at Bristow, Ind. (03303300)	Perry	USGS	381123	0863924	5	5	5	5	0	5	0	5
25	N. Fk nr Bandon, Ind.	Perry	NFS	380801	0863850	28	0	5	28	0	0	0	0
26	Ohio R. at Cannelton, Ind.	Perry	ORSANCO	375358	0864220	83	76	83	1	35	0	28	0
27	Sigler Cr at Kitterman Corners, Ind.	Perry	USGS	381351	0864145	1	0	1	1	0	0	0	0
28	Snake Br nr Bandon, Ind.	Perry	NFS	380716	0863824	29	0	5	29	0	0	0	0
29	Sulphur Cr nr Bandon, Ind.	Perry	NFS	380810	0863732	30	0	5	30	0	0	0	0
30	Sulphur Fk Cr nr Bristow, Ind.	Perry	USGS	380539	0864245	5	1	5	1	0	1	0	1
31	Sulphur Fk Cr nr Bristow, Ind.	Perry	USGS	380634	0864032	2	1	2	1	0	2	0	2
32	Theis Cr nr Bristow, Ind.	Perry	USGS	380353	0864005	1	1	1	1	0	1	0	1
33	Trib. to Lanman Run nr St Meinrad, Ind.	Perry	USGS	380809	0864552	1	0	1	1	1	0	1	0
34	Winding Bridge nr Bristow, Ind.	Perry	NFS	381035	0863759	29	0	5	29	0	0	0	0
35	Winding Br nr Bristow, Ind.	Perry	USGS	381016	0863811	5	5	5	5	0	5	0	5
36[1]	Hat Cr nr Oakland, Ind.	Pike	USGS	381908	0871545	2	2	2	2	2	2	2	2
37[1]	Trib. to Houchin ditch nr Stendal, Ind.	Pike	USGS	381632	0871029	3	3	3	3	3	3	3	3
38[1]	Rough Cr nr Scottsburg, Ind.	Pike	USGS	381708	0871432	2	2	2	2	2	2	2	2
39[1]	Trib. to S. Fk Patoka R. nr Oakland City, Ind.	Pike	USGS	382028	0871722	2	2	2	2	2	2	2	2
40[1]	Trib. to S. Fk Patoka R. nr Old Friendship Church	Pike	USGS	381357	0871216	1	1	1	1	1	1	1	1
41[1]	Trib to S. Fk Patoka R. nr Scalesville, Ind.	Pike	USGS	381352	0871110	2	2	2	2	2	2	2	2
42[1]	Trib. to S. Fk Patoka R. nr Scottsburg, Ind.	Pike	USGS	381814	0871320	2	2	2	2	2	2	2	2

Number of Observations for Water-Quality Parameters--Continued

ID	Station name	County	Agency	Lat	Long	Spec. Cond.	Sul-fate	pH	Alka-linity	Total Fe	Diss. Fe	Total Mn	Diss. Mn
43[1]	Trib. to S. Fk Patoka R. nr Stendal, Ind.	Pike	USGS	381444	0871123	2	2	2	2	2	2	2	2
44[1]	Wheeler Cr nr Enos, Ind.	Pike	USGS	381740	0871715	2	2	2	3	2	2	2	2
45	Anderson R. nr Adyeville, Ind.	Spencer	USGS	381132	0864619	2	2	2	2	2	2	2	2
46	Anderson R. nr St Meinrad, Ind.	Spencer	USGS	381002	0864750	1	1	1	1	0	1	0	1
47	Blackhawk Cr at St Meinrad, Ind.	Spencer	USGS	381028	0864814	1	1	1	1	0	1	0	1
48	Buckhorn Cr nr Gentryville, Ind.	Spencer	USGS	380539	0870211	1	0	1	0	0	0	0	0
49	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380122	0870120	0	1	0	0	1	0	1	1
50	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380124	0870121	1	1	1	1	1	1	1	1
51	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380132	0870136	1	1	1	1	1	1	1	1
52	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380153	0870208	1	1	1	1	1	1	1	1
53	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380159	0870214	1	1	1	1	1	1	1	1
54	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380240	0870422	1	1	1	1	1	1	1	1
55	Chrisney ditch nr Chrisney, Ind.	Spencer	USGS	380225	0870325	1	0	1	0	0	0	0	0
56	Coal Lake nr Chrisney, Ind.	Spencer	USGS	380147	0870026	1	1	1	1	1	1	1	1
57	Crooked Cr at County Rd ½ mi E. of Clay Huff School	Spencer	USGS	380241	0865303	1	0	1	0	0	0	0	0
58	Crooked Cr nr Santa Claus, Ind. (03303400)	Spencer	USGS	380705	0865322	1	0	1	0	0	0	0	0
59	Crooked Cr nr Lamar, Ind.	Spencer	USGS	380332	0865417	1	0	1	0	0	0	0	0
60	Crooked Cr nr Maxville, Ind.	Spencer	USGS	380004	0865117	1	0	1	0	0	0	0	0
61	E. Fk Crooked Cr nr Evanston, Ind.	Spencer	USGS	380151	0865138	1	0	1	0	0	0	0	0
62	Ferdinand Run nr St. Meinrad, Ind.	Spencer	USGS	381106	0864750	1	0	1	0	0	0	0	0
63	Ferdinand Run nr St. Meinrad, Ind.	Spencer	USGS	381134	0864741	1	0	1	1	0	0	0	0
64	Friday Br nr Ferdinand, Ind.	Spencer	USGS	381222	0864804	1	0	1	0	0	0	0	0
65	Huffman ditch nr Rockport, Ind.	Spencer	USGS	373351	0870346	1	0	1	0	0	0	0	0
66	Trib. to Friday Br nr Ferdinand, Ind.	Spencer	USGS	381321	0864751	1	1	1	1	1	1	1	1
67	Little Sandy Cr nr Newtonville, Ind.	Spencer	USGS	380003	0865549	1	0	1	0	0	0	0	0
68	Little Sandy Cr nr Grandview, Ind.	Spencer	USGS	375752	0865448	1	0	1	0	0	0	0	0
69	Meinrad Hollow nr St. Meinrad, Ind.	Spencer	USGS	380859	0864828	1	1	1	1	1	1	1	1
70	Meinrad Hollow nr St. Meinrad, Ind.	Spencer	USGS	380848	0864836	1	0	1	0	0	0	0	0
71	Sandy Cr nr Newtonville, Ind.	Spencer	USGS	380006	0865827	1	0	1	0	0	0	0	0
72	Sandy Cr nr Chrisney, Ind.	Spencer	USGS	380246	0865842	1	1	1	1	1	1	1	1
73	Sandy Cr nr Grandview, Ind.	Spencer	USGS	375701	0865742	1	0	1	0	0	0	0	0
74	Sweezer Lake nr Richland City, Ind.	Spencer	USGS	375920	0864503	1	0	1	0	0	0	0	0
75	Swinging Cr nr St. Meinrad, Ind.	Spencer	USGS	380840	0864856	1	0	1	1	1	0	1	0
76	Trib. to Little Pigeon Cr	Spencer	USGS	380814	0865632	1	0	1	0	0	0	0	0
77	Trib. to Crooked Cr nr Maxville, Ind.	Spencer	USGS	380003	0865150	1	0	1	0	0	0	0	0
78	Trib. to Sweezer ditch	Spencer	USGS	375954	0864504	1	0	1	0	0	0	0	0
79	Bluegrass Cr nr Daylight, Ind.	Vanderburgh	USGS	380258	0872856	2	2	2	2	2	2	2	2
80	Locust Cr at Allen Lane nr St. Joseph Ave. Rd	Vanderburgh	USGS	380027	0873612	1	0	1	0	0	0	0	0
81	Ohio R. at Evansville, Ind.	Vanderburgh	USGS	375820	0873435	52	51	50	31	12	9	13	8
82	Pigeon Cr at Evansville, Ind. (03322100)	Vanderburgh	USGS	380014	0873219	1	0	1	0	0	0	0	0
83	Pigeon Cr nr Evansville, Ind	Vanderburgh	USGS	375840	0873513	1	0	1	0	0	0	0	0
84	Barren Fk nr Dickeyville, Ind.	Warrick	USGS	380735	0871142	1	0	1	0	0	0	0	0
85	Barren Fk nr Folsomville, Ind.	Warrick	USGS	380922	0871222	2	2	2	2	2	2	2	2

Number of Observations for Water-Quality Parameters--Continued

ID	Station name	County	Agency	Lat	Long	Spec. Cond.	Sul- fate	pH	Alka- linity	Total Fe	Diss. Fe	Total Mn	Diss. Mn
86	Barren Fk nr Jockey, Ind.	Warrick	USGS	380446	0871028	1	0	1	0	0	0	0	0
87	Big Cr nr Lynnville, Ind.	Warrick	USGS	381009	0871719	1	0	1	0	0	0	0	0
88	Big Cr at SR 68 ½ mi S of Gibson County Line	Warrick	USGS	381139	0872230	1	0	1	0	0	0	0	0
89	Big Cr nr Lynnville, Ind.	Warrick	USGS	381110	0872117	2	2	2	2	2	2	2	2
90	Bluegrass Cr nr Daylight, Ind.	Warrick	USGS	380352	0872818	1	0	1	0	0	0	0	0
91	Coles Cr nr Folsomville, Ind.	Warrick	USGS	380904	0870817	1	0	1	0	0	0	0	0
92	Coles Cr nr Jockey, Ind.	Warrick	USGS	381016	0870947	1	0	1	0	0	0	0	0
93	Cypress Cr at Highway 62	Warrick	USGS	380251	0871725	4	3	4	3	2	3	2	3
94	Cypress Cr nr Boonville, Ind.	Warrick	USGS	380330	0871725	6	4	6	4	3	4	3	4
95	Cypress Cr at 300 South Rd	Warrick	USGS	375925	0871900	4	3	4	3	2	3	2	3
96	Cypress Cr nr Dayville, Ind.	Warrick	USGS	375720	0871900	3	3	4	3	2	3	2	3
97	Ellison West ditch nr Boonville, Ind.	Warrick	USGS	380655	0871219	1	0	1	0	0	0	0	0
98	Ellison West ditch nr Folsomville, Ind.	Warrick	USGS	380736	0871332	2	2	2	2	2	2	2	2
99	Hoskinson drain nr Dayville, Ind.	Warrick	USGS	380357	0870931	1	0	1	0	0	0	0	0
100	Little Pigeon Cr nr Gentryville, Ind.	Warrick	USGS	380705	0870311	1	0	1	0	0	0	0	0
101	Little Pigeon Cr nr Tennyson, Ind. (03304000)	Warrick	USGS	380338	0870549	3	2	3	2	2	2	2	2
102	McCool ditch nr Dayville, Ind.	Warrick	USGS	375912	0871836	1	1	1	1	1	1	1	1
103	Otter Cr nr Boonville, Ind.	Warrick	USGS	380527	0871500	1	0	1	0	0	0	0	0
104	Otter Cr nr Greenbrier, Ind.	Warrick	USGS	380713	0871605	1	0	1	0	0	0	0	0
105	Pigeon Cr nr Baugh City, Ind.	Warrick	USGS	380211	0872611	1	0	1	0	0	0	0	0
106	Pokeberry Cr at SR 68	Warrick	USGS	381125	0870349	1	0	1	0	0	0	0	0
107	Pokeberry Cr nr Heilman, Ind.	Warrick	USGS	380928	0870419	1	0	1	0	0	0	0	0
108	Trib. to Coles Cr nr Folsomville, Ind.	Warrick	USGS	380819	0870819	1	0	1	0	0	0	0	0
109	Trib. to Coles Cr nr Jockey, Ind.	Warrick	USGS	381115	0870947	1	0	1	0	0	0	0	0
110	Trib. to Pigeon Cr at SR 68	Warrick	USGS	381138	0872546	1	0	1	0	0	0	0	0
111	Trib. to Pigeon Cr at 700 West Rd	Warrick	USGS	380314	0872237	1	0	1	0	0	0	0	0
112	Trib. to Pigeon Cr nr Millersburg, Ind.	Warrick	USGS	380550	0872340	1	0	1	0	0	0	0	0
113	Squaw Cr nr Millersburg, Ind.	Warrick	USGS	380438	0872236	1	0	1	0	0	0	0	0
114	Squaw Cr nr Boonville, Ind.	Warrick	USGS	380531	0872112	2	2	2	2	2	2	2	2
115	Squaw Cr at 625 West Rd	Warrick	ISBH	380512	0872148	1	1	0	1	1	1	1	0
116	Summer Pecka ditch nr Rustic Hills, Ind.	Warrick	USGS	375810	0872140	2	2	2	2	2	2	2	2
117	Trib. to Cypress Cr nr Boonville, Ind.	Warrick	USGS	380139	0871702	1	1	1	1	1	1	1	1
118	Trib. to Cypress Cr nr Boonville, Ind.	Warrick	USGS	380042	0871838	1	1	1	1	1	1	1	1
119	Trib. to Squaw Cr nr Boonville, Ind.	Warrick	USGS	380530	0872155	2	2	2	2	2	2	2	2
120	Beech Fk nr Cloverport, Ky.	Breckinridge	USGS	374549	0863348	0	0	0	0	1	1	1	1
121	Tar Fk nr Cloverport, Ky.	Breckinridge	USGS	374627	0863756	0	0	0	0	2	2	2	2
122	Blackford Cr nr Maceo, Ky.	Daviess	USGS	375219	0865401	2	2	2	2	2	2	2	2
123	Pup Cr nr Maceo, Ky.	Daviess	USGS	375030	0865845	0	0	0	0	2	2	2	2
124	Ohio R. at Cannelton Dam, Ky.	Hancock	USGS	375358	0864220	66	65	62	45	11	15	12	15

[1]Station location outside of study area but data were used in analyses.

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