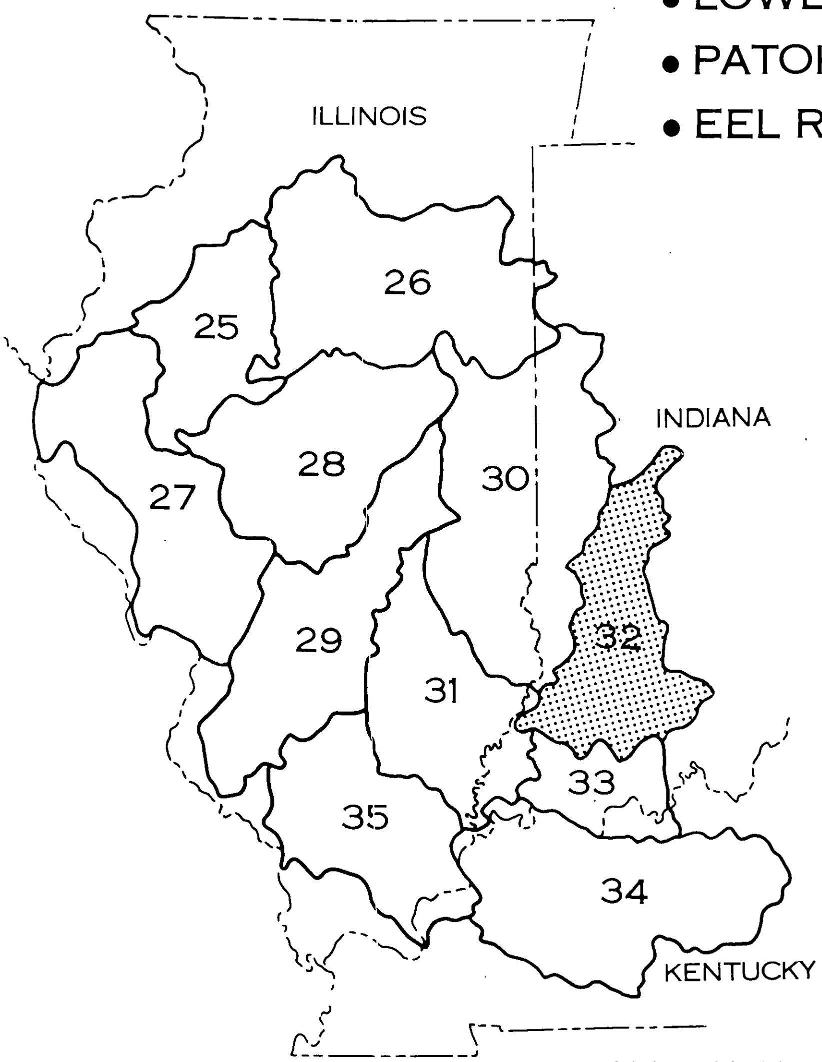
HYDROLOGY OF AREA 32, EASTERN REGION, INTERIOR COAL PROVINCE, INDIANA

- LOWER WHITE RIVER
- PATOKA RIVER
- EEL RIVER



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 81-498

HYDROLOGY OF AREA 32, EASTERN REGION, INTERIOR COAL PROVINCE, INDIANA

BY
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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)

$$°F = 1.8 \times °C + 32$$

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 32, at the eastern edge of the Interior Coal Province of the Eastern Coal Region, covers an area of about 10,000 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. The report format consists of brief texts and supporting illustrations or tables on a series of hydrologic topics that describe the hydrology of Area 32.

The topography of Area 32 is characterized by lowland plains (Tipton Till Plain, Mitchell Plain, and Wabash Lowland) separated by rugged upland areas (Norman Upland and Crawford Upland). Average elevation ranges from 400 feet in the southwest to 800 feet in the north.

There were at least three glacial advances (the Kansan, Illinoian, and Wisconsin) into what is now Indiana and neighboring States during the Pleistocene Epoch. About two-thirds of Area 32 was glaciated and is covered with glacial drift. The remaining area is covered by as much as 2 feet of Wisconsin loess (wind-blown material). The underlying bedrock is of Pennsylvanian and Mississippian age. Most of the coal in the study area has been mined from rocks of Pennsylvanian age. The major coal seam in Indiana, the Springfield coal member (Coal V), averages 4.4 feet in thickness. The coals in Area 32 are highly volatile bituminous types B or C and are generally high in sulfur. As of 1978, more than 1 billion tons of coal had been mined from counties within the study area. Reserves for this area have been estimated to total 12 billion tons. During 1978, 17.8 million tons of coal was mined from counties within the study area.

There are two major types of aquifers in Area 32. The bedrock aquifers of Pennsylvanian and Mississippian age generally yield less than 10 gallons per minute. Glacial sand and gravel aquifers are classified in two groups. The first group, the valley train and outwash aquifers, yields 1,000 gallons per minute or more and has a high development potential. The second group, sand and gravel lenses in till or lake sediments, yields from 50 to 500 gallons per minute but has small development potential. The source of ground water is precipitation percolating into the aquifers. The aquifers discharge ground water by seepage into streams, evapotranspiration, springs, and pumpage. Although flow in the bedrock and the glacial sand and gravel aquifers is locally toward a major stream, there is also a regional component of flow in the bedrock aquifer toward the southwest.

Median concentrations of dissolved solids, iron, and sulfate in glacial aquifers are 316, 0.5, and 22 milligrams per liter, respectively. Median concentrations of dissolved solids, iron, manganese, and sulfate in bedrock aquifers are 391, 0.5, 0.02, and 20 milligrams per liter, respectively. The dissolved-solids concentration of ground water generally increases with depth.

The major rivers draining the study area are the White, Eel, and Patoka Rivers. Records of discharge for streams and rivers in the study area indicate that the dominant factor affecting average annual flow is size of drainage area. Size of drainage area also affects low flow. Some streams with small drainage areas (less than 100 square miles) have 7-day, 10-year low flows of zero. Surficial aquifers have minimal discharge to these streams, and, therefore, the streams have little sustained streamflow. In large rivers like the White, the drainage area, as well as channel slope and stream length, are controlling factors of low flow and flood magnitude. In the smaller rivers and streams, precipitation index (rainfall minus snowfall and evapotranspiration) is the controlling factor of flood magnitude. Precipitation index in Area 32 is higher than that in much of the rest of the State, and, therefore, flood magnitude for streams and rivers in the study area is high compared to that in the rest of the State.

Considerably more coal has been mined in the south and west parts of Area 32, primarily in Pike, Knox, and Greene Counties, than in the remainder of the area. The exposure and the oxidation of pyrite and marcasite probably causes specific conductance and concentrations of sulfate, iron, and manganese to be higher, and pH and alkalinity to be lower, in the surface water in the west half of the study area than in the east half.

1.0 INTRODUCTION

1.1 Purpose of Report

REPORT SUMMARIZES AVAILABLE HYDROLOGIC AND WATER-QUALITY 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 505(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 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 the 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. 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 unit boundary crosses political and hydrologic boundaries and, therefore, creates problems in nomenclature and data presentation. Adjoining counties 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 unit boundary, data for the whole county are usually presented. Where a total figure is presented, such as total coal production for the study unit, that figure represents the total for all counties contacted by the study unit boundary and not just the total for the area within the unit boundaries. 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.

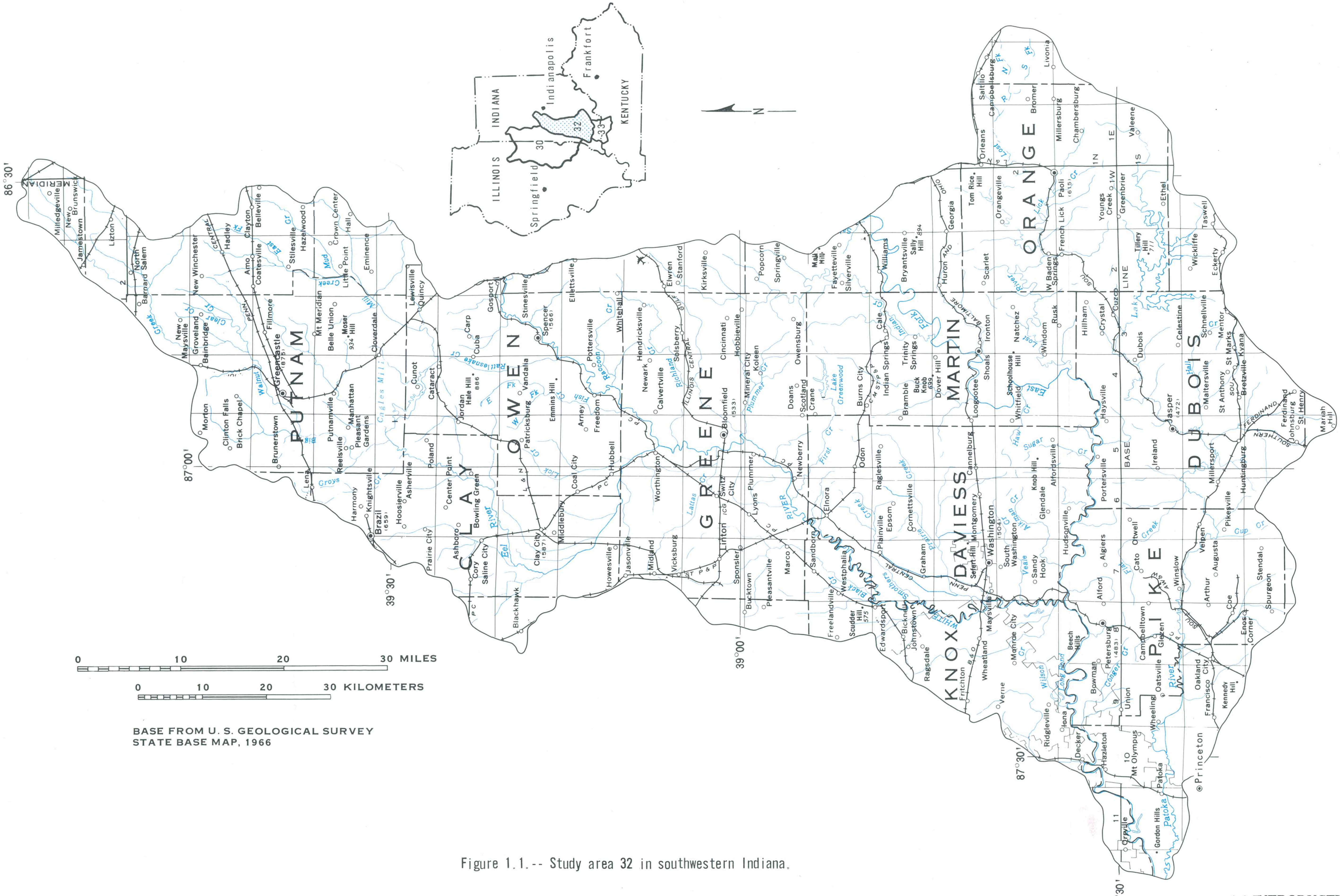


Figure 1.1.-- Study area 32 in southwestern Indiana.

TOPOGRAPHY CONSISTS OF LOWLANDS SEPARATED BY RUGGED UPLANDS

The topography has been formed by at least three glacial advances as well as by natural processes such as weathering, stream erosion, and mass movement. The area is characterized by lowland plains separated by rugged upland areas. Average elevation ranges from 400 feet in the southwest to 800 feet in the north.

The land slopes generally southwest, and its average elevation ranges from 800 feet (NGVD of 1929) in the north to less than 400 feet in the southwest. The north and much of the west parts of the study area were glaciated during the Illinoian Glaciation. The north part was glaciated again during the Wisconsin Glaciation. There are five physiographic units in the study area: (1) the Tipton Till Plain, (2) the Norman Upland, (3) the Mitchell Plain, (4) the Wabash Lowland, and (5) the Crawford Upland.

The Tipton Till Plain is a depositional plain of low relief, underlain by thick glacial till and modified only slightly by postglacial stream erosion. The plain is nearly flat to gently rolling and is crossed by several low and poorly developed end moraines. The flatness of the plain is broken by low eskers, esker troughs, and melt-water drainways that trend southwest.

The Norman Upland is a mature landform characterized by flat-topped narrow divides, steep slopes, and deep, V-shaped valleys. The upland is underlain by resistant siltstone and interbedded softer shale.

Some of the best developed karst topography in the world lies within the Mitchell Plain. Most of the solution features are developed on the St. Louis and Ste. Genevieve Limestones. The plain, an area of low relief, is covered with numerous sinkholes and other solution features such as dolines and swallow holes. The limestone bedrock contains a system of channels and caverns.

The Wabash Lowland, underlain by till, lacustrine, outwash, and alluvial sediments, is characterized by extensivly aggraded valleys. The lowland is a broad plain with low rolling hills. The glaciated north part of the lowland has less relief than the unglaciated south part.

The Crawford Upland is underlain by alternating layers of sandstone, shale, and limestone that have been eroded to produce a maturely dissected upland with diverse topographic features. The area has a well developed drainage pattern. Drainage divides are generally flat but narrow, and the valley walls are steep. The bottoms of the large valleys are moderately wide flood plains and are usually the only level land in the area. (See Schneider, 1966, p. 40-50).

The adjoining map (fig. 1.2) shows the extent of the physiographic regions and elevations of the area.

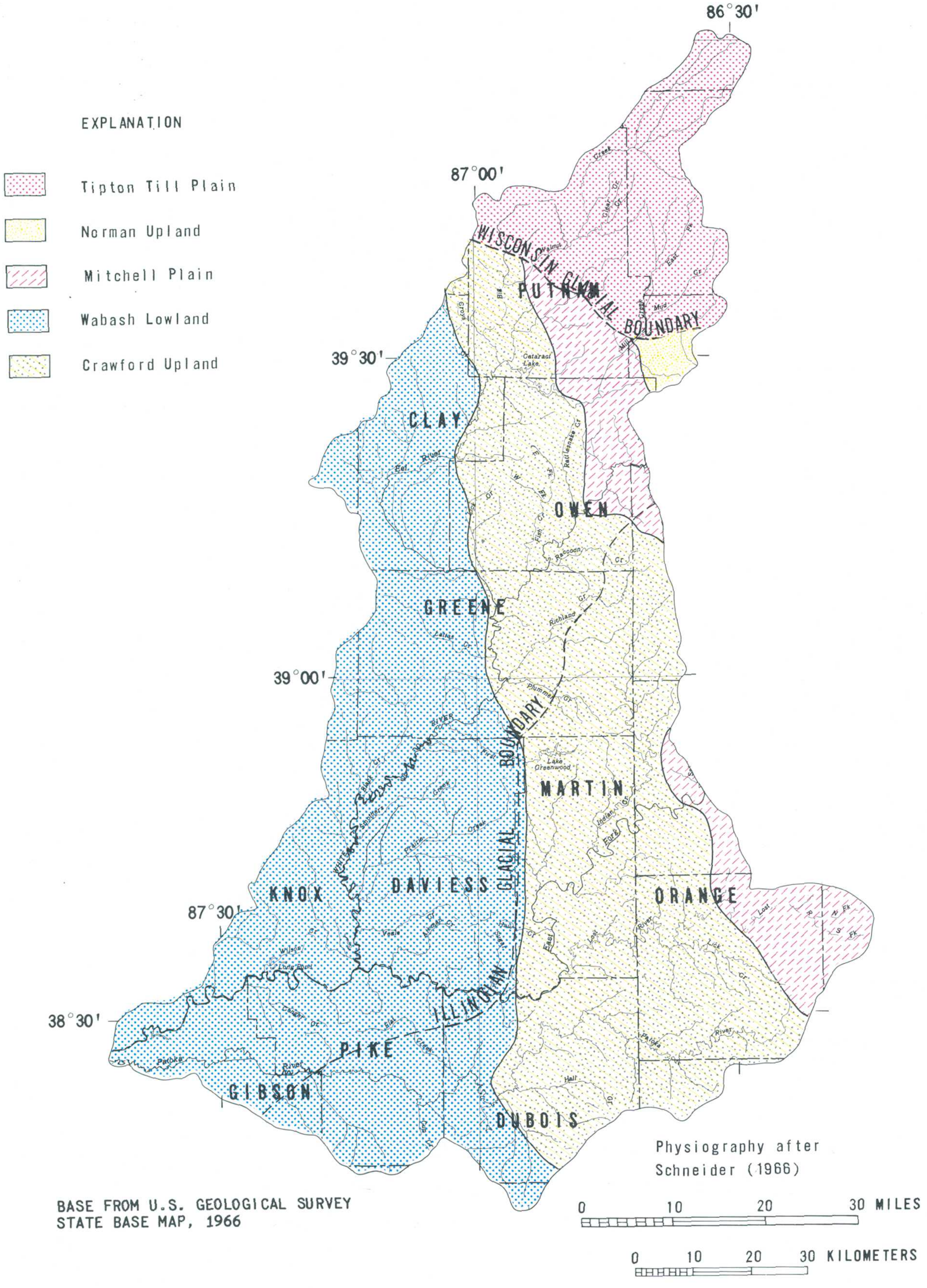


Figure 1.2.-- Glacial extent and physiographic regions.

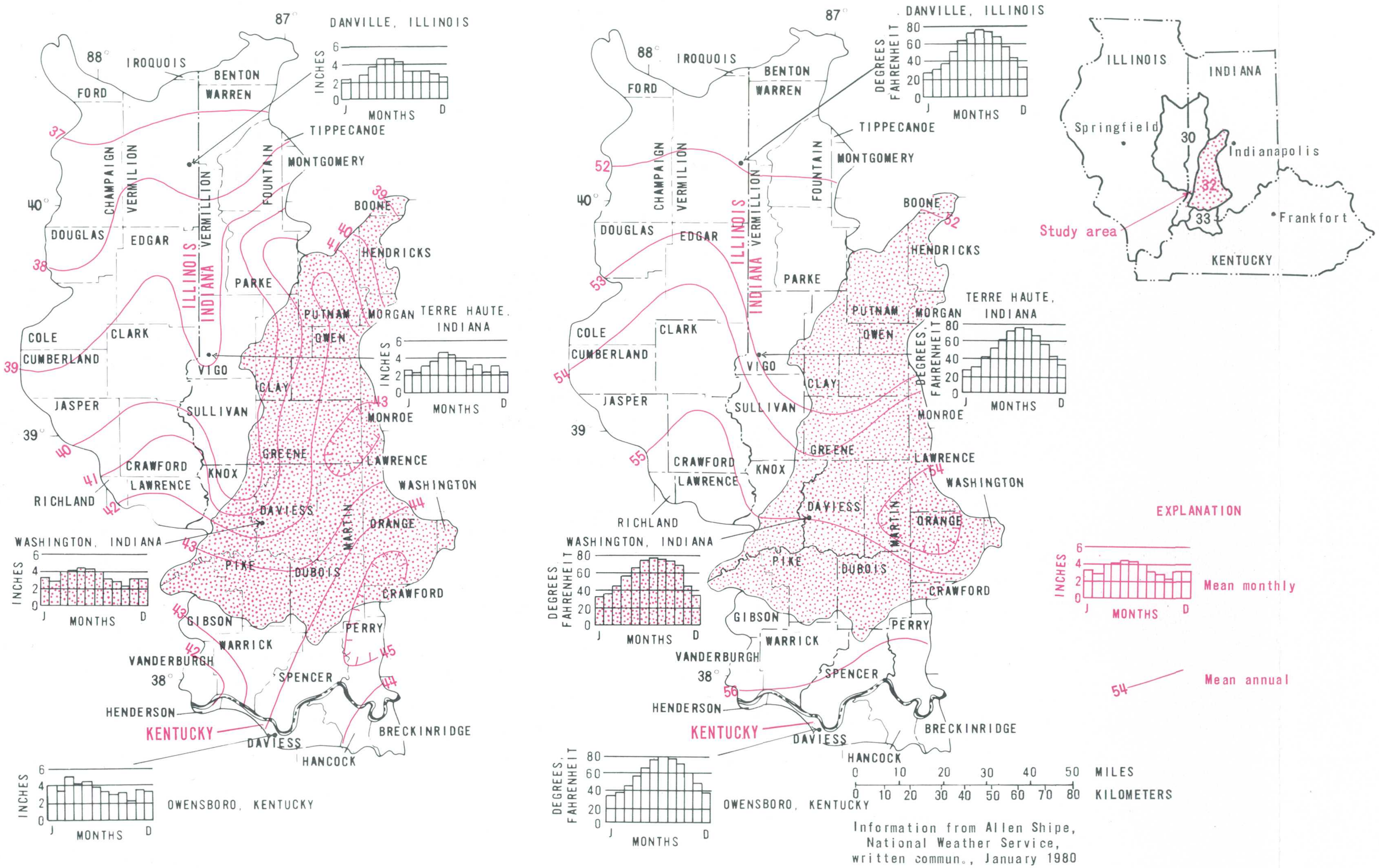
TEMPERATURE AND PRECIPITATION IN AREA 32 ARE REPRESENTATIVE OF MIDDLE-LATITUDE STATES

Annual temperature averages 55.0° F, and average monthly temperature ranges from 32.5° F in January to 77.0° F in July. Annual precipitation averages 39 inches in the north and 45 inches in the south. Maximum average monthly precipitation is 4.3 inches in the south and 4.6 inches in the north during spring. Average monthly minimum precipitation is 2.4 inches, usually in October.

Indiana has warm summers and cool winters because of its location in the middle latitudes (38° to nearly 42° north) in the interior of a large continent. Temperature can change significantly every few days, when surges of polar air or tropical air move into the State, but changes more frequently during the winter months than during the summer. A winter may be unusually cold or a summer may be cool if the influence of polar air is continuous. If tropical air dominates the weather, a winter may be mild and the summer may be 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. (See Schaal, 1959, and Schaal, 1966, p. 156 to 170.)

The climate of Area 32 differs from that of northern Indiana because of the difference in latitude. The average annual temperature for the period 1941 through 1970 is 55.0° F. The maximum monthly mean temperature at Washington, Daviess County, Ind., is 77.0° F during July, and the minimum mean monthly temperature is 32.5° F during January. Mean maximum and minimum temperatures to the north are 2° to 4° F lower, respectively. The date of the first freeze in autumn is usually between October 15 and 20. The date of the last freeze in the spring is usually in mid- to late April. Annual precipitation averages 39 inches in the north and 45 inches in the south. Average snowfall generally ranges from 10 inches in the north to 20 inches in the south. Maximum mean monthly precipitation (generally in late spring) ranges from 4.3 inches in the south to 4.6 inches in the north. Minimum mean monthly precipitation (usually in October) averages 2.4 inches. Rates of pan evaporation are not available for the study area. However, pan evaporation during July is 8 inches at Evansville, Ind., compared with 6 to 7 inches at Oaklandon, 12 miles northeast of Indianapolis. In October, pan evaporation is about 2.5 inches at Evansville and Oaklandon. Humidity ranges from 40 to 90 percent. (Information in this paragraph is from Allen Shipe, Indianapolis, National Weather Service, written commun., January, 1980.)

The adjoining maps (fig. 1.3.1) show mean annual precipitation and air-temperature curves for southwest 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 TEMPERATURE. 1941-70

MEAN ANNUAL PRECIPITATION AND SELECTED MEAN MONTHLY PRECIPITATION 1941-70

Figure 1.3.1.-- Mean precipitation and mean air temperature.

RAINFALL-FREQUENCY DATA ARE USED IN PROJECT DESIGN

The design of many hydrologic control projects requires precipitation data for various storm frequencies and durations.

Frequency analyses of rainfall data are used to compute hydrographs for the design of sewers, culverts, dams, reservoirs, and other hydrologic control projects. Designing hydrologic control projects for maximum runoff is seldom economical. Rather, projects are designed for 10-, 25-, 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, precipitation can be mapped for various frequencies and durations. A report by the Indiana Department of Natural Resources (1974) shows precipitation for frequencies of 1 to 100 years and durations of 1 to 24 hours. The adjacent maps (fig. 1.3.2) show amounts of precipitation for frequencies of 10-, 25-, and 100-years for a 24-hour duration. The near straight lines have been extended into northern Kentucky and eastern Illinois.

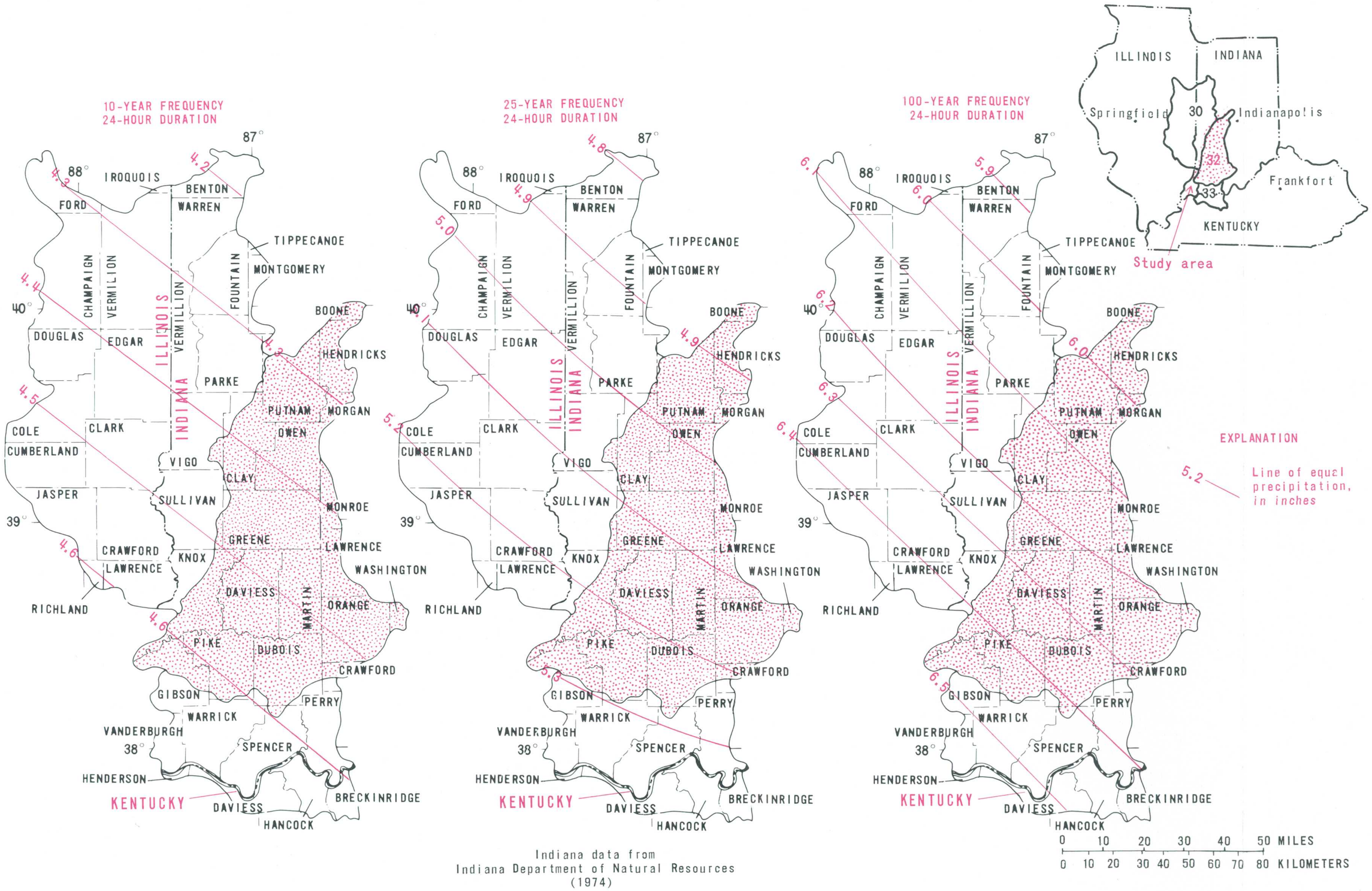


Figure 1.3.2.-- Precipitation magnitude and frequency for 24-hour duration.

FOUR MAJOR DRAINAGES IN AREA 32

Four major rivers drain Area 32: the (1) Eel, (2) East Fork White, (3) White, and (4) Patoka Rivers. All drainage flows into the Wabash River at the southwest corner of the study area.

Drainage area is useful in analyzing streamflow characteristics for design of hydrologic structures and for evaluating the availability of water. Drainage areas for most named rivers, streams, and ditches have been computed by Hoggatt (1975).

The stream network of Area 32 and the locations where drainage areas are reported are shown on the adjoining map (fig. 1.4). The major streams and computed drainage areas are listed in table 1.4.

Table 1.4.--Stream and drainage areas

Reference number (See fig. 1.4)	Site name	Drainage area (mi^2)[1]	
		Total area	Area of study
1	Big Walnut Creek at mouth	332	332
2	Mill Creek at mouth	387	387
3	Eel River at mouth	1,208	1,208
4	White River upstream from Eel River	3,184	[2]268
5	White River upstream from East Fork White River	5,372	[2]2,456
6	East Fork White River at mouth	5,745	[2]1,057
7	White River at mouth	11,349	[2]3,745
8	Patoka River at mouth	862	862

[1]Source: Hoggatt (1975).
[2]Includes only drainage area within Area 32.

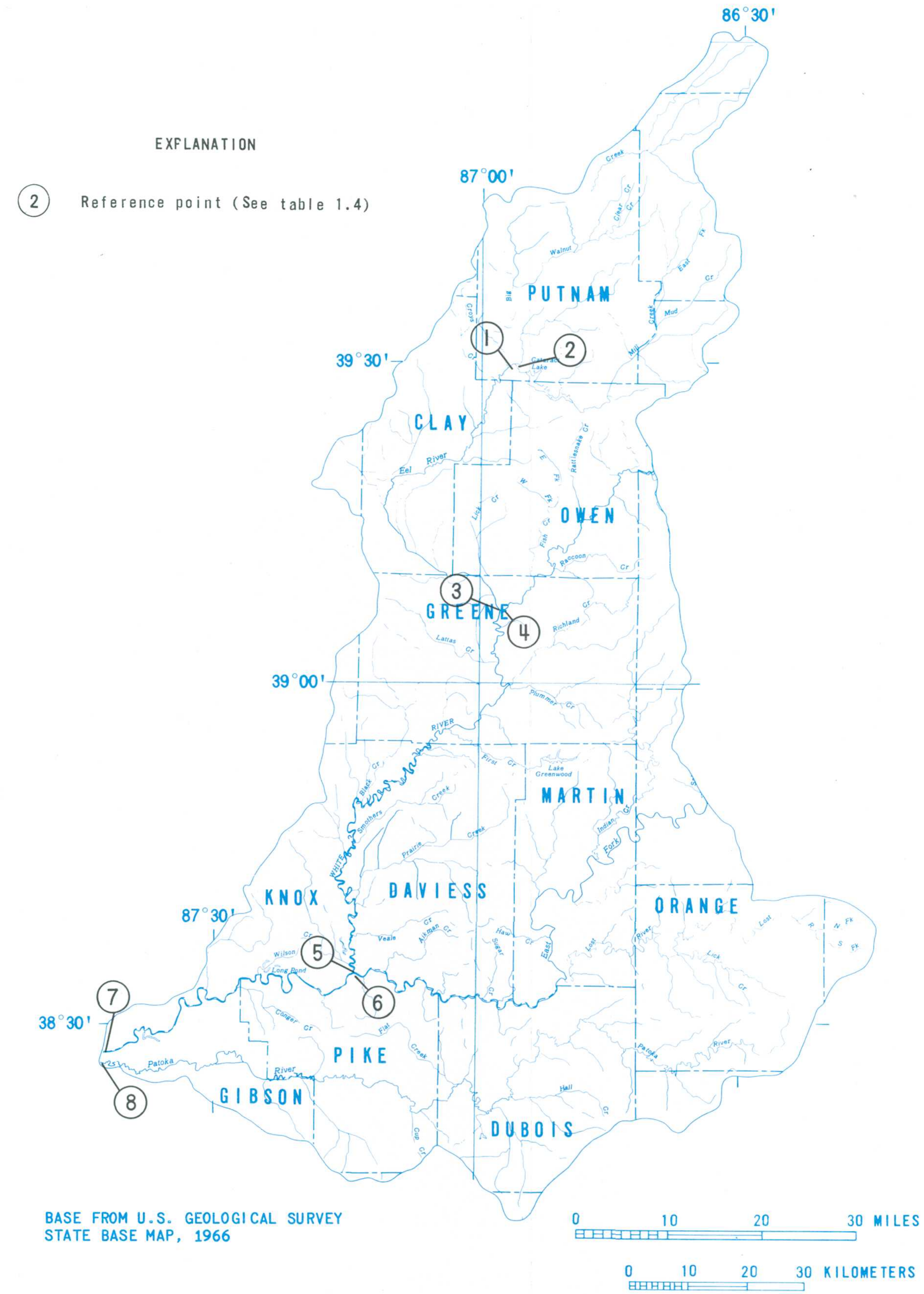


Figure 1.4.-- Stream network.

BEDROCK COMPOSED OF PENNSYLVANIAN AND MISSISSIPPIAN LIMESTONE, SANDSTONE, AND SHALE, INTERBEDDED WITH PENNSYLVANIAN COALS

Bedrock of Pennsylvanian and Mississippian age dips southwest into the Illinois Basin. Coal is mined mainly from eight of the Pennsylvanian coal units.

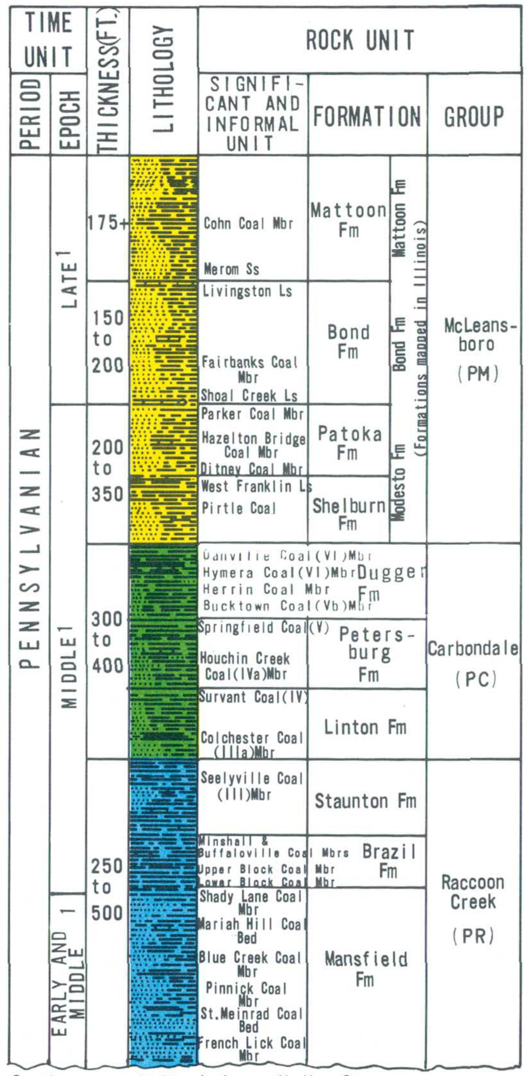
Southwestern Indiana is underlain by rocks of Pennsylvanian age that dip southwest at 25 to 30 feet per mile and of Mississippian age that dip 40 feet per mile into the Illinois Basin, as shown in the geologic section (fig. 1.5.1a) on the facing page. The formations strike generally northwest along the edge of the basin.

Pennsylvanian rocks underlying about two-thirds of Area 32 contain Indiana's coal resources. The stratigraphy of the Pennsylvanian formations and coal members is shown in the geologic column on the facing page (fig. 1.5.1b). Areal extent of the Pennsylvanian groups is shown on the geologic map (fig. 1.5.1c). The McLeansboro Group consists of shale, sandstone, and minor amounts of siltstone, limestone, clay, and coal (Shaver and others, 1970, p. 101). The Carbondale Group is a variable sequence of sandstone, shale, limestone, and coal. Most of the commercial coal beds in Indiana are in this group (Shaver and others, 1970, p. 32-33). Shale and sandstone dominate the lithology of the Raccoon Creek Group. Clay, coal, limestone, chert, and sedimentary iron deposits are also present in small amounts. Within Area 32, the Raccoon Creek Group lies unconformably on Mississippian rocks (Shaver and others, 1970, p. 136).

Eight of the Indiana coals are extensively mined. The Springfield Coal Member (V) provides about 49 percent of the total strip-mined coal. Much of this production is from Pike County. Most of the remaining Springfield coal is mined in Warrick County, outside Area 32 (Wangsness and others, in press). Hymera (VI) and Danville (VII) coals account for 23 percent of the total. Upper and Lower Block coals, mainly from Clay and Owen Counties, provide 11 percent. The remaining 17 percent of coal production is from Minshall, Seelyville (III), and Survant (IV) coals (Powell, 1972, p. 6).

Bedrock units of Mississippian age are shown in figures 1.5.1a, 1.5.1b, and 1.5.1c. The upper group, primarily sandstone containing some shale and limestone, crops out in stream valleys in a small southeast part of the study area. The Stephensport Group, which also crops out to the southeast, but over a larger area, consists of cliff-forming limestone, shale, and thin-bedded sandstone. The West Baden Group contains thin-bedded and crossbedded sandstone in shale and some limestone beds (Shaver and others, 1970, p. 173, 189). The Bethel Formation, the oldest formation of this group, contains some thin coal layers (Sunderman, 1968, p. 57). The Blue River Group is mostly carbonate rock containing gypsum, anhydrite, shale, and calcareous sandstone (Shaver and others, 1970, p. 18). Interbedded and interlensed limestones of various compositions make up the Sanders Group (Shaver and others, 1970, p. 160- 161). The Borden Group consists primarily of siltstone and shale but contains some discontinuous lenses and facies formed from interbedded limestones (Shaver and others, 1970, p. 21).

The Rockford Limestone, containing some shale, siltstone, and dolomite, is a transitional formation from the Valmeyeran to the Kinderhookian Series (Shaver and others, 1970, p. 141). The Mississippian and Devonian New Albany Shale in the lower part of the Kinderhookian Series crops out in the north tip of the study area. This dark organic shale contains minor amounts of dolomite and dolomitic quartz sandstone (Shaver and others, 1970, p. 115-116).



Geology modified from H.H. Gray and others(1970) and J.B. Patton(1956)

[1] Usage of U.S. Geological Survey, all other usage is of Indiana Geological Survey

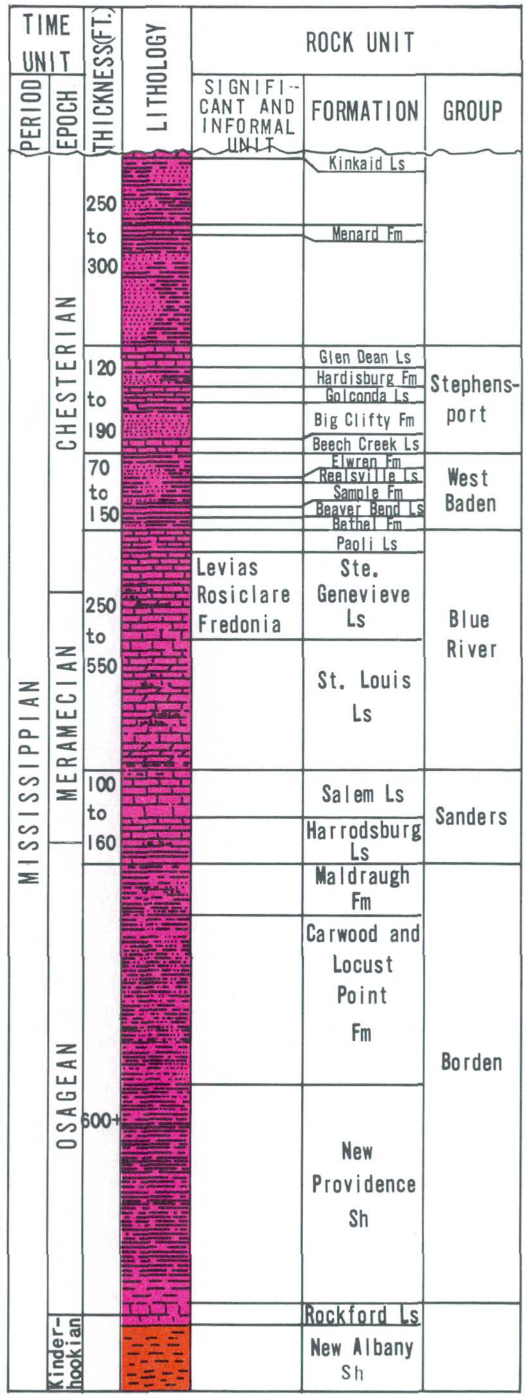
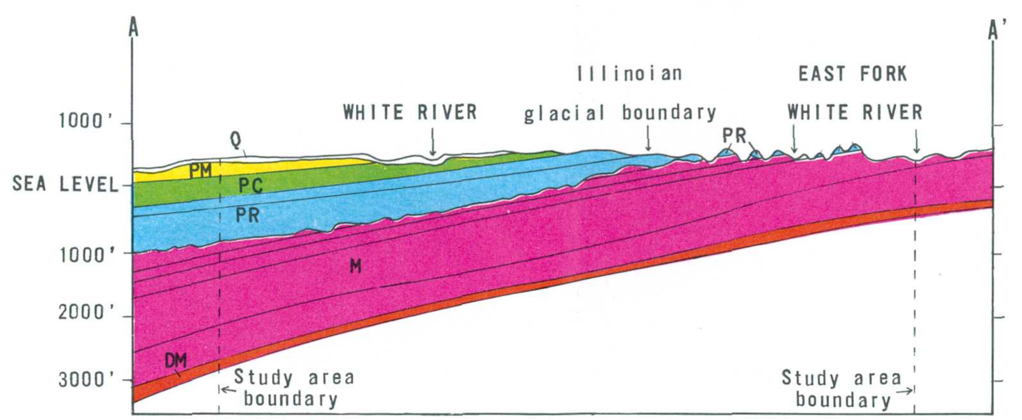


Figure 1.5.1b.-- Generalized geologic column.



Horizontal Scale - 1:1,000,000 Geology modified from J.B. Patton (1956)

Figure 1.5.1a.-- Geologic section.

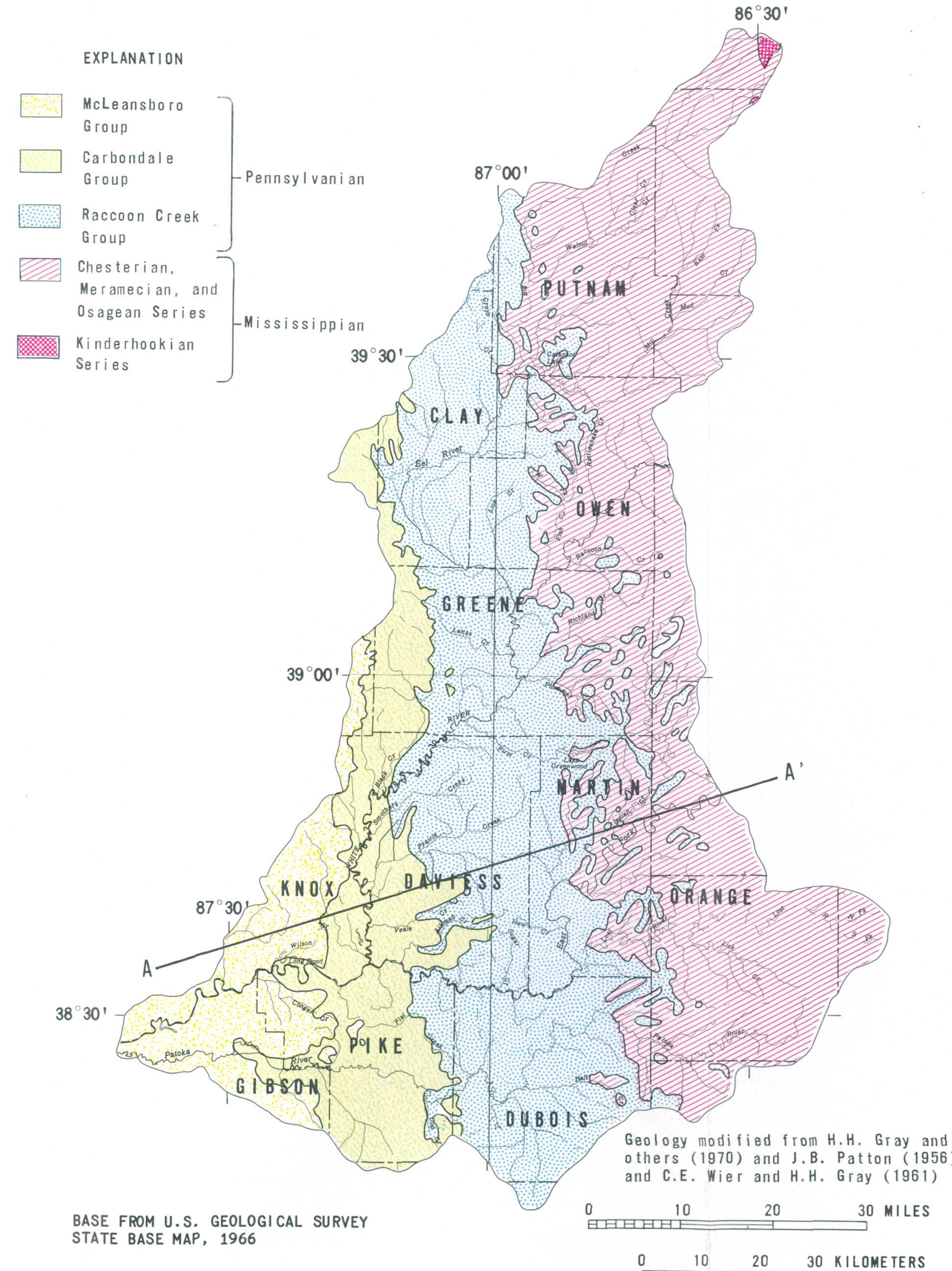


Figure 1.5.1c.-- Bedrock geology.

AT LEAST THREE GLACIAL ADVANCES EXTENDED INTO INDIANA DURING THE PLEISTOCENE EPOCH AND LEFT TWO SHEETS OF TILL

The Kansan, Illinoian, and Wisconsin glacial advances extended into Indiana during the Pleistocene Epoch. The more extensive Illinoian drift covers most of the Kansan drift, and Wisconsin drift covers only a small part of the study area. One-third of the area is unglaciated but is covered by as much as 2 feet of Wisconsin loess. The drift cover affects coal strip-mining operations.

At least three glacial advances extended into Indiana during the Pleistocene Epoch. Preglacial surface features were buried under drift left by the glaciers (Wayne, 1966). The Kansan, the first glacial advance into Indiana, was followed by the Illinoian and then the Wisconsin Glaciations. Each glacial advance was followed by a warm interglacial period of active plant growth, weathering, and erosion. The sequence is shown in the adjacent chart of Pleistocene glaciations and interglaciations (fig. 1.5.2a). The drift cover from each glaciation is shown on the glacial geology map (fig. 1.5.2b). About one-third of Area 32 is unglaciated.

Kansan drift is not easily recognized because of its position under more recent glacial advances. Only a few good exposures of Kansan drift have been found.

Advance of the Illinoian Glaciation deposited drift farther south than advances of other Pleistocene glaciers. Few moraines were deposited, but many post-glacial lakes and outwash plains were left. All the large valleys of southwestern Indiana were filled with Illinoian lake sediments (Wayne, 1966).

Wisconsin till covers only the north tip of the study area. However, during the Wisconsin Glaciation, winds deposited loess south of the Wisconsin glacial boundary to a maximum thickness of about 2 feet (Gray and Powell, 1965). The unglaciated part of the study area is covered with a layer of loess, and stream valleys are filled with glacial outwash and lake sediments as shown on the adjacent map (fig. 1.5.2b).

Thickness of drift varies throughout the study area. Thickness north of the Wisconsin boundary ranges from 100 to 200 feet. In the remaining area, covered by Illinoian drift, thickness ranges from 50 to 100 feet, sometimes thinning toward the Illinoian boundary to a range from 25 to 50 feet (Henry H. Gray, written commun., April, 1980). The unglaciated part is not covered with drift.

Strip mining is easier in glacial drift than in bedrock because the unconsolidated drift is easier to excavate than bedrock. Even with the additional overburden added by the drift, the leveled glacial surface provides a more uniform depth to coal. Drift cover can cause problems, however. Many sand and gravel lenses within the till contain large amounts of water. Drift slumps and does not provide a stable highwall. Estimates of coal reserves can be miscalculated where bedrock valleys that have cut through the coal are obscured by drift (Powell, 1972, p. 4).

GLACIATIONS AND INTERGLACIATIONS
HOLOCENE
WISCONSIN GLACIATION
SANGAMON INTERGLACIATION
ILLINOIAN GLACIATION
YARMOUTH INTERGLACIATION
KANSAN GLACIATION

Geology modified from
W.J. Wayne (1966, p.28)

Figure 1.5.2a.-- Pleistocene stages in Indiana.

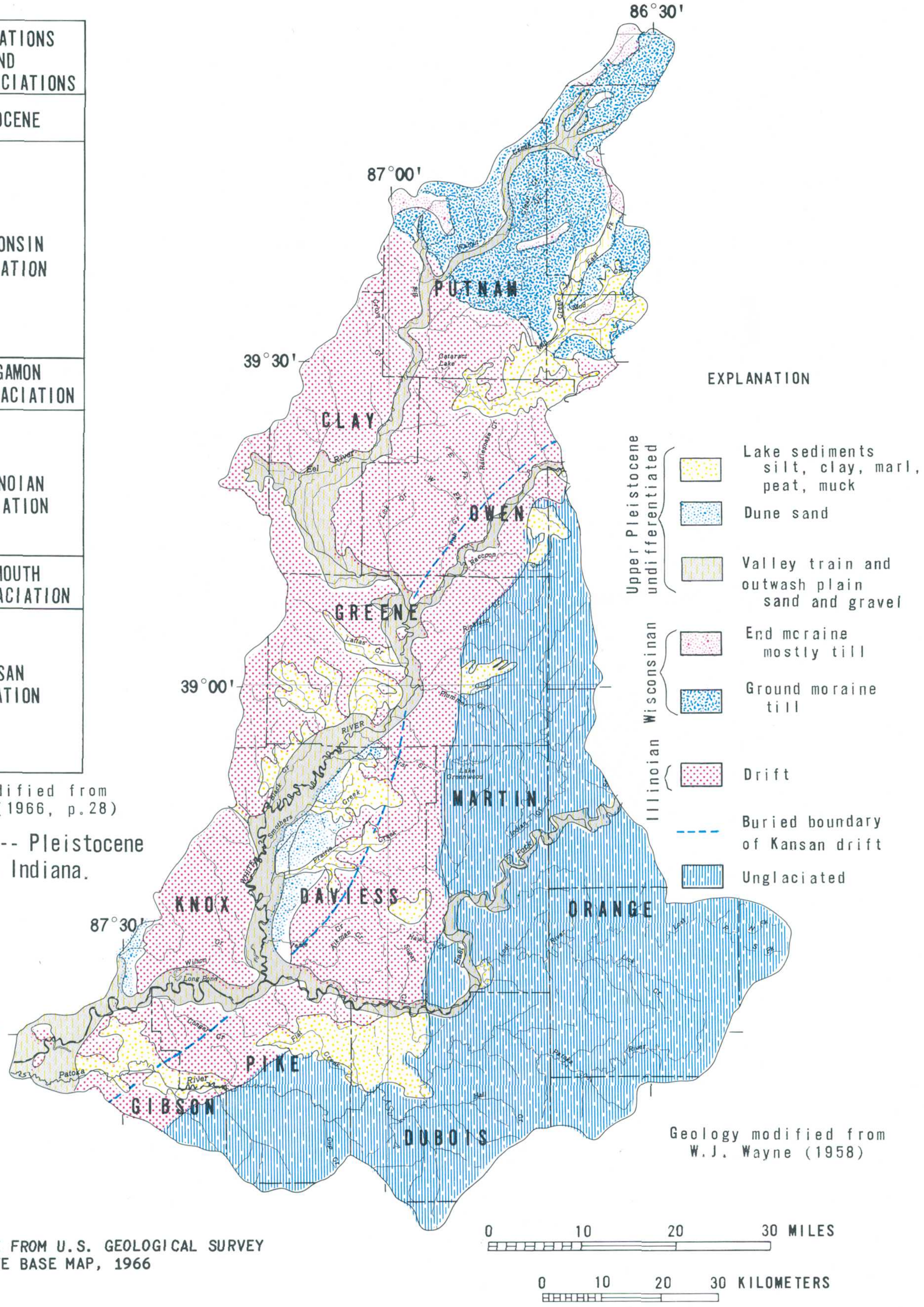
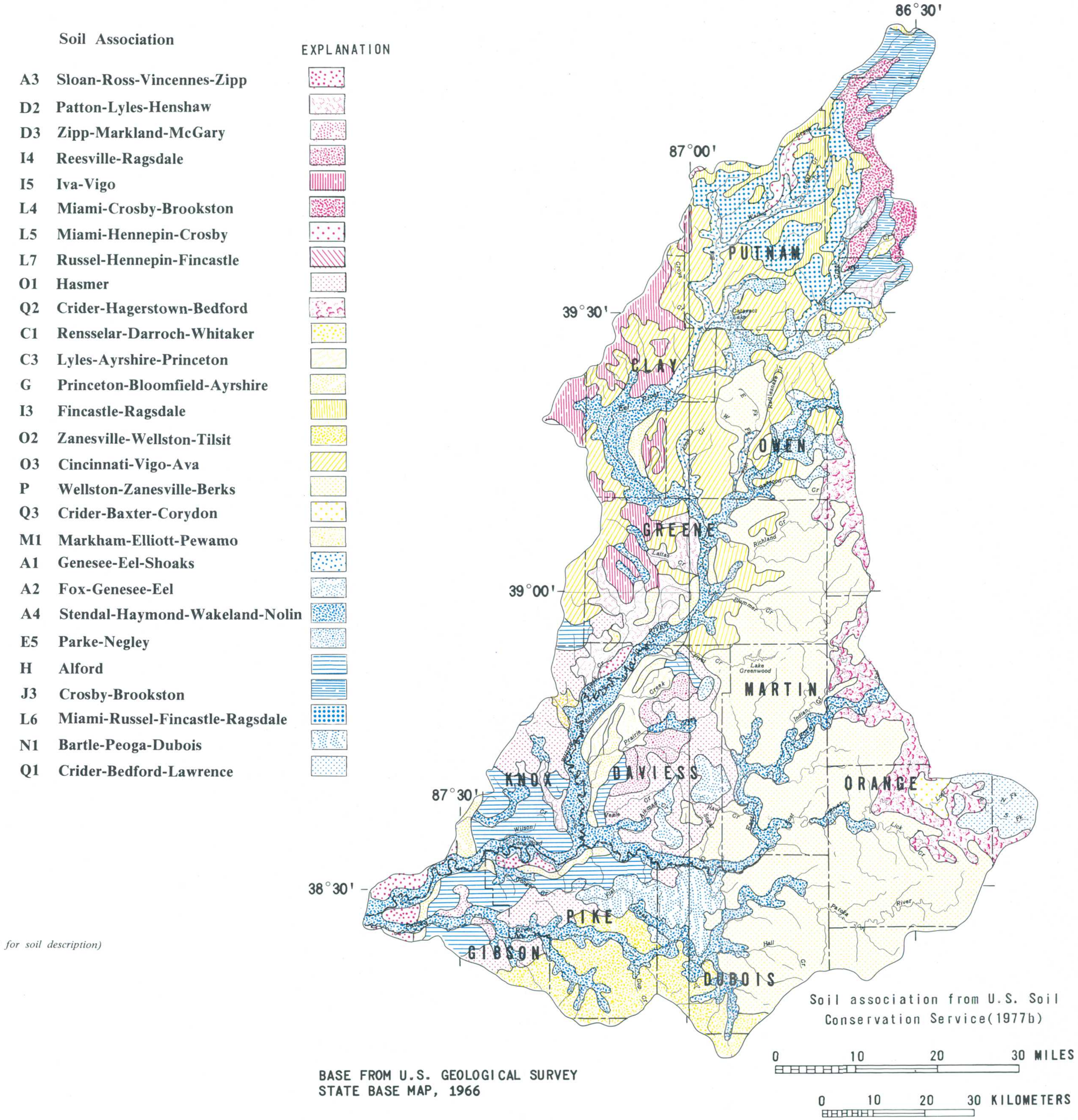


Figure 1.5.2b.-- Glacial geology.

SOIL TYPE AND LAND SLOPE VARY WIDELY

Area 32 contains 64 soil types. The surface horizons of many of the soils are light-colored silty loams or silty clay loams underlain by clay loams and silty clays. Poor to well-drained soils are found on slopes generally ranging from nearly level terraces and plains to slopes greater than 35 percent.

The soil associations within Area 32 are shown on the adjoining map (fig. 1.6), and descriptions of the associations are listed in Appendix 1. Information is from an Indiana soils association map published by the U.S. Soil Conservation Service (1977b). More detailed information is available in county soil surveys that are also published by the Soil Conservation Service. Some of these reports are referenced in section 6.2.



(See Appendix 1 for soil description)

Figure 1.6.-- Soil associations.

COAL PRODUCTION AND ESTIMATED RESERVES

Indiana coal production totaled nearly 24 million tons in 1978.[1] Seventy-four percent of this coal was mined in the counties represented in Area 32. As of 1978, more than 1 billion tons of coal had been mined from these same counties. Reserves are estimated to total more than 12 billion tons.

According to Carter and others (1974, p. III-6), commercial coal mines were opened 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, Indiana strip mines produced 9,682 tons of coal. As production demands increased, the mining industry turned to underground mines. By 1860, the industry was producing 100,000 tons of coal per year. By the late 1930's, the development of excavating equipment that could dig coal at a faster rate than the older equipment and the increased efficiency of explosives had caused a resurgence of surface mining. More than 50 percent of the coal produced came from surface mines. In 1978, about 98 percent of the coal produced came from surface mines. There were only four underground mines 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 Member). The coals in Indiana are generally high in sulfur and are highly volatile bituminous types B or C coals.

Estimates of coal reserves are subject to revision, owing to advances in mining technology. Carter and others (1974, p. III-11) and Wier (1973, p. 21) summarized the coal production figures through 1970. Data for 1971-78 are from annual reports of the Indiana Bureau of Mines and Mining (1972-79). 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, 1972; Powell, 1976) and of active mines (Powell, 1977) are also available. Coal-production figures and estimates of coal reserves by county for Area 32 from 1812 through 1978 are listed in table 1.7.

[1] Indiana Bureau of Mines and Mining, 1978.

Table 1.7.--Coal production and estimates of reserves

[Sources of data: Estimates of reserves, from Donald L. Eggart, Indiana Geological Survey, written commun., March 1980; Coal production, from Carter and others, 1974, III-II; Wier, 1973, p. 21; and Indiana Bureau of Mines and Mining, 1972-79]

Counties[2]	Coal production in Indiana 1812-1978 (tons)	Estimates of recoverable reserves[1]		
		Strippable reserves (thousand tons)	Underground reserves (thousand tons)	Total
Clay	100,960,095	307,872	252,366	560,238
Daviess	13,495,235	136,260	119,502	255,762
Dubois	992,304	3,963	3,978	7,941
Gibson	45,393,580	0	2,231,226	2,231,226
Greene	135,822,017	191,038	228,369	419,407
Knox	117,599,560	141,330	2,241,269	2,382,599
Martin	142,115	82,698	11	82,709
Owen	4,181,088	50,673	0	50,673
Pike	152,387,718	188,469	369,699	558,168
Sullivan	193,846,662	273,484	3,482,223	3,755,707
Vigo	247,820,597	253,780	1,448,432	1,702,212

[1]These figures 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 120 feet of overburden; with some equipment, as much as 150 feet of overburden can be removed. As technology and equipment are improved, thickness of overburden removed and, therefore, 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.

[2]Figures listed in the table 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 figures appear in other study area reports.

MOST OF LAND IS FARMED OR FORESTED

The greatest use of land within Area 32 is for agriculture (62 percent), followed by forested lands (29 percent). Land affected by mining activities amounts to less than 1 percent of the total land area. Sullivan County has the largest area affected by mining, 10,676 acres, about one-third of the area mined.

General land-use categories by area and percent of total area for the 18 counties discussed in this report are listed in 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--commercial forest and wooded farm lots.
Water--lakes, ponds, and rivers.
Wetland--marsh or bog areas.
Mined--surface area affected by strip or under ground mines.
Other--miscellaneous land uses not generally categorized.

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 of 1977. Areas of prime farmland are shown on the adjoining map (fig. 1.8).

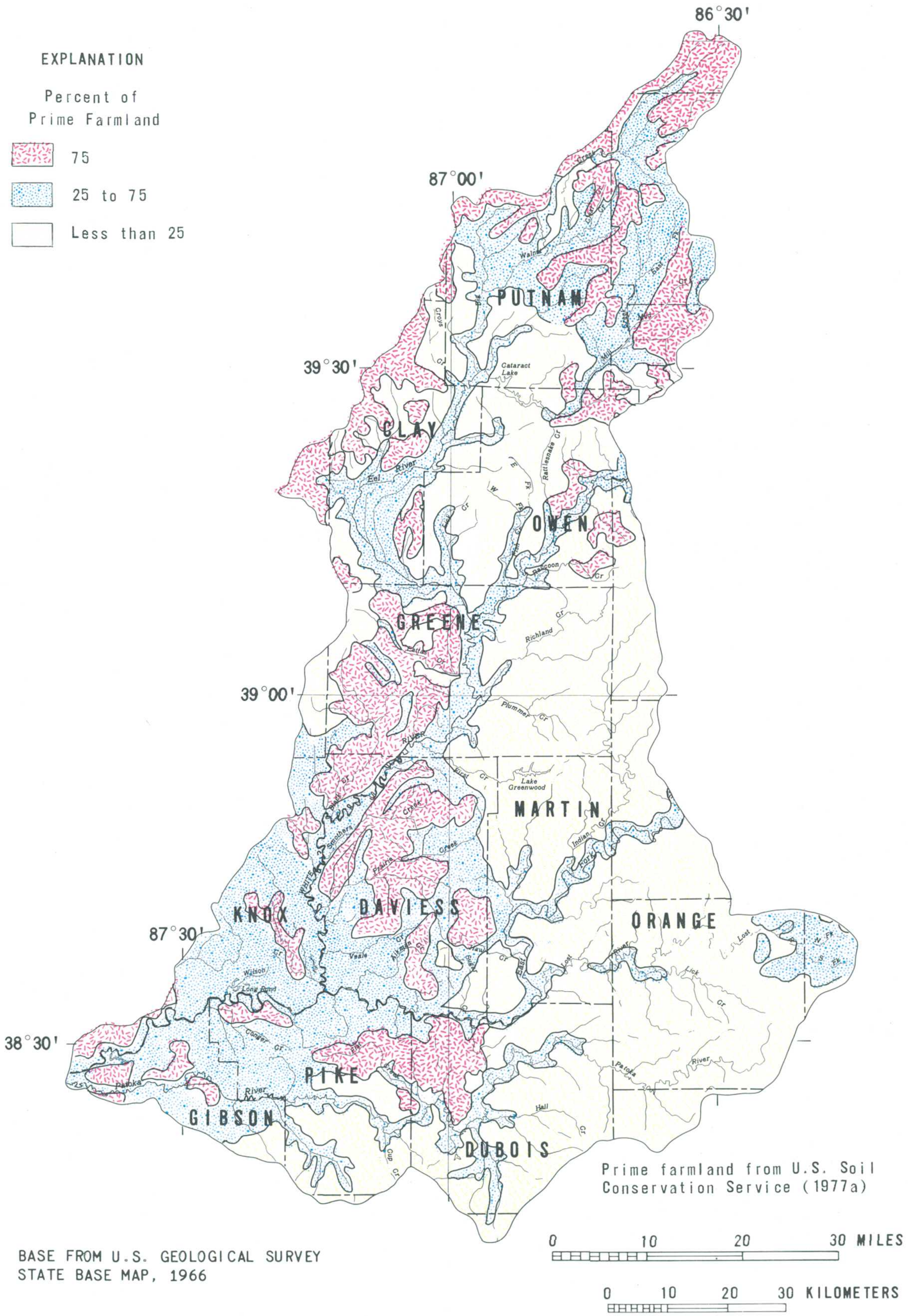


Figure 1.8.-- Prime farmland.

Table 1.8 Land use by county, southwestern Indiana

County	Agri-culture	Urban	Forested	Water	Wet-land	Mined	Other	Total (acres)
	(acres/percent)							
Clay[1]	146,346 / 62.8	9,621 / 4.1	72,218 / 31.1	769 / 0.3	0 / 0	4,007 / 1.7	0 / 0	232,961
Crawford[2]	76,744 / 38.4	10,783 / 5.4	108,813 / 54.5	2,357 / 1.2	9 / -	1,047 / 0.5	90 / --	199,743
Daviess[2]	214,100 / 77.8	20,466 / 7.4	29,851 / 10.8	2,694 / 1.1	55 / --	201 / 0.1	7,833 / 2.8	275,200
Dubois[2]	175,283 / 63.2	10,405 / 3.8	84,251 / 30.4	3,969 / 1.4	203 / 0.1	347 / 0.1	2,663 / 1	277,121
Gibson[2,3]	222,722 / 69.8	9,570 / 3.0	78,443 / 24.6	3,103 / 1	2,140 / 0.7	177 / ---	2,757 / 0.9	318,912
Greene[2]	217,150 / 61.8	14,586 / 4.2	106,900 / 30.4	1,791 / 0.5	0 / 0	248 / 0.1	10,685 / 3.0	351,360
Hendricks[4]	227,949 / 85.4	4,652 / 1.7	19,091 / 7.2	no information		0 / 0	15,188 / 5.7	266,880
Knox[2]	266,500 / 80.7	15,814 / 4.8	38,000 / 11.5	2,091 / 0.6	30 / --	311 / 0.1	7,494 / 2.3	330,240
Lawrence[2]	144,500 / 45.5	43,789 / 13.8	120,600 / 38	2,088 / 0.6	70 / --	730 / 0.2	5,983 / 1.9	317,760
Martin[2]	74,460 / 33.8	10,015 / 4.5	67,800 / 30.7	2,375 / 1.1	10 / --	700 / 0.3	65,440 / 29.6	220,800
Monroe[2]	113,901 / 44.1	23,654 / 9.2	99,536 / 38.6	14,200 / 5.5	1,725 / 0.7	552 / 0.2	4,350 / 1.7	257,918
Morgan[4]	165,817 / 63.9	2,694 / 1.0	80,301 / 30.9	no information		0 / 0	11,028 / 4.2	259,840
Owen[2]	117,312 / 48.1	5,010 / 2.1	116,580 / 47.8	1,970 / 0.8	985 / 0.4	2,073 / 0.8	140 / ---	244,070
Orange[2]	125,730 / 48.5	12,368 / 4.8	114,668 / 44.2	5,500 / 2.1	48 / --	148 / 0.1	673 / 0.3	259,135
Pike[2,3]	76,934 / 35.9	15,356 / 7.2	116,285 / 54.2	395 / 0.2	706 / 0.3	3,792 / 1.8	935 / 0.4	214,403
Putnam[1]	213,438 / 68.3	1,155 / 0.4	95,476 / 30.6	1,655 / 0.5	0 / 0	593 / 0.2	0 / 0	312,317
Sullivan[1]	245,144 / 83.8	4,389 / 1.5	29,367 / 10	2,924 / 0.1	0 / 0	10,676 / 3.6	0 / 0	292,500
Vigo[1]	191,816 / 72.2	22,601 / 8.5	42,151 / 15.9	3,055 / 1.2	0 / 0	5,976 / 2.2	0 / 0	265,599
Total	3,015,846 / 61.7	236,928 / 4.8	1,420,331 / 29.1	50,936 / 1	5,981 / ---	31,578 / 0.6	135,259 / 2.8	4,896,759

[1]Mark Blade, West Central Indiana Economic Development District, Inc., written commun., December 1979.

[2]Kris Kothe, Indiana State Planning Services Agency, written commun., December 1979.

[3]Marcia A. Werling, Southwest Indiana and Kentucky Regional Council of Governments, written commun., December 1979.

[4]Doug Winings, Indiana Heartland Coordinating Commission, written commun., March 1980.

DESCRIPTION OF U.S. GEOLOGICAL SURVEY GAGING STATIONS

Discharge data have been collected at 24 continuous-record stations, 16 low-flow stations, and 14 crest-stage partial-record stations.

Discharge data analyzed for this report have been collected at 24 continuous-record stations, 16 low-flow stations, 14 crest-stage partial-record stations, and at several miscellaneous measurement sites. Data from miscellaneous measurements are also available from the Geological Survey office in Indianapolis.

Length and type of records available at gaging stations vary. The gaging stations on the Patoka River near Princeton, Jasper, and Ellsworth have been controlled by the Patoka Reservoir since February 1978. The analyses for these stations were computed for the period of record ending with the 1977 water year, representing unregulated conditions. Lengths of record for the gaging stations on the White River upstream from Petersburg and Big Walnut Creek at Greencastle are insufficient for analysis.

The gaging stations on the Eel River at Bowling Green and Mill Creek near Manhattan recorded two periods of hydrologic record. Before July 1953, the flow was unregulated. From July 1953 to the present (1980), the flow was regulated by the Cagles Mill Lake Reservoir. Discharge data from the times that the stations were established through the 1952 water year and from the 1954 through 1979 water years were analyzed for this report.

Gaging stations within the study area are listed in table 2.1, and their locations are shown on the adjoining map (fig. 2.1).

Table 2.1.--Gaging stations

Station name	Station number	Drainage area (mi^2)	Period of record	Station type
South Fork Patoka River nr Spurgeon	03376350	42.8	1922 to present	Continuous
Hall Creek nr St. Anthony	03375800	21.8	1970 to present	Do.
Patoka River nr Princeton	03376500	822	1934 to present	Do.
Flat Creek nr Otwell	03376260	21.3	1964 to present	Do.
Patoka River at Jasper	03375500	262	1947 to present	Do.
Patoka River nr Ellsworth	03374500	171	1961 to present	Do.
Patoka Lake nr Cuzco	03374498	168	1978 to present	Do.
Patoka River nr Hardinsburg	03374455	12.8	1968 to present	Do.
White River at Petersburg	03374000	11,125	1927 to present	Do.
White River above Petersburg	03373980	11,123	1976 to present	Do.
Lost River nr West Baden Springs	03373700	287	1964 to present	Do.
East Fork White River at Shoals	03373500	4,927	1903 to 1906 1908 to 1916 1923 to present	Do.
White River at Newberry	03360500	4,688	1928 to present	Do.
Eel River at Bowling Green	03360000	830	1931 to present	Do.
Mill Greek nr Manhattan	03359000	294	1938 to present	Do.
Cagles Mill Lake nr Manhattan	03358900	293	1953 to present	Do.
Mill Creek nr Cataract	03358000	245	1949 to present	Do.
Big Walnut Creek nr Reelsville	03357500	326	1949 to present	Do.
Big Walnut Creek at Greencastle	03357420	216	1974 to present	Do.
Plum Creek nr Bainbridge	03357350	3.0	1969 to present	Do.

Table 2.1.--Gaging stations--Continued

Station name	Station number	Drainage area (mi^2)	Period of record	Station type
White River at Newberry	03360500	4,688	1928 to present	Continuous
Eel River at Bowling Green	03360000	830	1931 to present	Do.
Mill Greek nr Manhattan	03359000	294	1938 to present	Do.
Cagles Mill Lake nr Manhattan	03358900	293	1953 to present	Do.
Mill Creek nr Cataract	03358000	245	1949 to present	Do.
Big Walnut Creek nr Reelsville	03357500	326	1949 to present	Do.
Big Walnut Creek at Greencastle	03357420	216	1974 to present	Do.
Plum Creek nr Bainbridge	03357350	3.0	1969 to present	Do.
White River at Spencer	03357000	2,988	1925 to 1971	Do.
Deer Creek nr Putnamville	03359500	59	1954 to 1965	Do.
Patoka River nr Jasper	03376000	342	1945 to 1947	Low flow
Birch Creek nr Ashboro	03360050	40	1974 to 1978	Do.
Richland Creek nr Bloomfield	03360300	95	1960, 1965 to 1967	Do.
Plummer Creek nr Bloomfield	03360225	67	1968 to 1973	Do.
Prairie Creek nr Washington	03360800	120	1960, 1962 to 1965, 1967	Do.
Indiana Creek nr Trinity Springs	03373320	172	1961 to 1967	Do.
Lattas Creek at Switz City	03360200	33	1954, 1960 to 1965	Do.
Big Walnut Creek nr Barnard	03357300	119	1961 to 1965, 1967	Do.
Rattlesnake Creek nr Spencer	0337100	25	1960 to 1965, 1967	Do.
Black Creek nr Sandborn	03360700	109	1960 to 1963, 1965, 1967	Do.
Indian Creek nr Springville	03373200	61	1961 to 1973	Do.
Lick Creek nr Paoli	03373600	19	1962 to 1967	Do.
Mud Creek nr Little Point	03357700	35	1976 to 1978	Do.
Veales Creek nr Washington	03360860	29	1974 to 1978	Do.
Lost River nr Orleans	03373530	35	1976 to 1978	Do.
Upper River Deshee nr Monroe City	03374050	15	1976 to 1978	Do.
Patoka River at Winslow	03376300	603	1963 to 1974	Continuous
Clear Branch at Cory	03360100	.27	1973 to present	Crest stage
Veales Creek tributary at Washington	03360850	.27	1973 to present	Do.
Shiloh drain nr Jasper	03376230	.57	1973 to present	Do.
Patoka River tributary nr Patoka	03376600	.40	1973 to present	Do.
Doans Creek tributary nr Doans	03360400	.20	1973 to present	Do.
River Deshee tributary nr Frichton	03346650	.82	1973 to present	Do.
Miller ditch tributary nr Bicknell	03360750	.50	1973 to present	Do.
Spring Creek tributary nr Springville	03373240	.54	1972 to present	Do.
Slate Creek tributary nr Haysville	03373850	.14	1973 to present	Do.
French Lick Creek tributary nr French Lick	03373680	.29	1973 to present	Do.
Limestone Creek tributary nr Gosport	03356780	.72	1972 to present	Do.
Patoka River tributary nr Glezen	03376340	.84	1973 to present	Do.
Owl Creek tributary nr Bainbridge	03357430	.58	1973 to present	Do.
White River tributary nr Spencer	03357010	.32	1973 to 1978	Do.

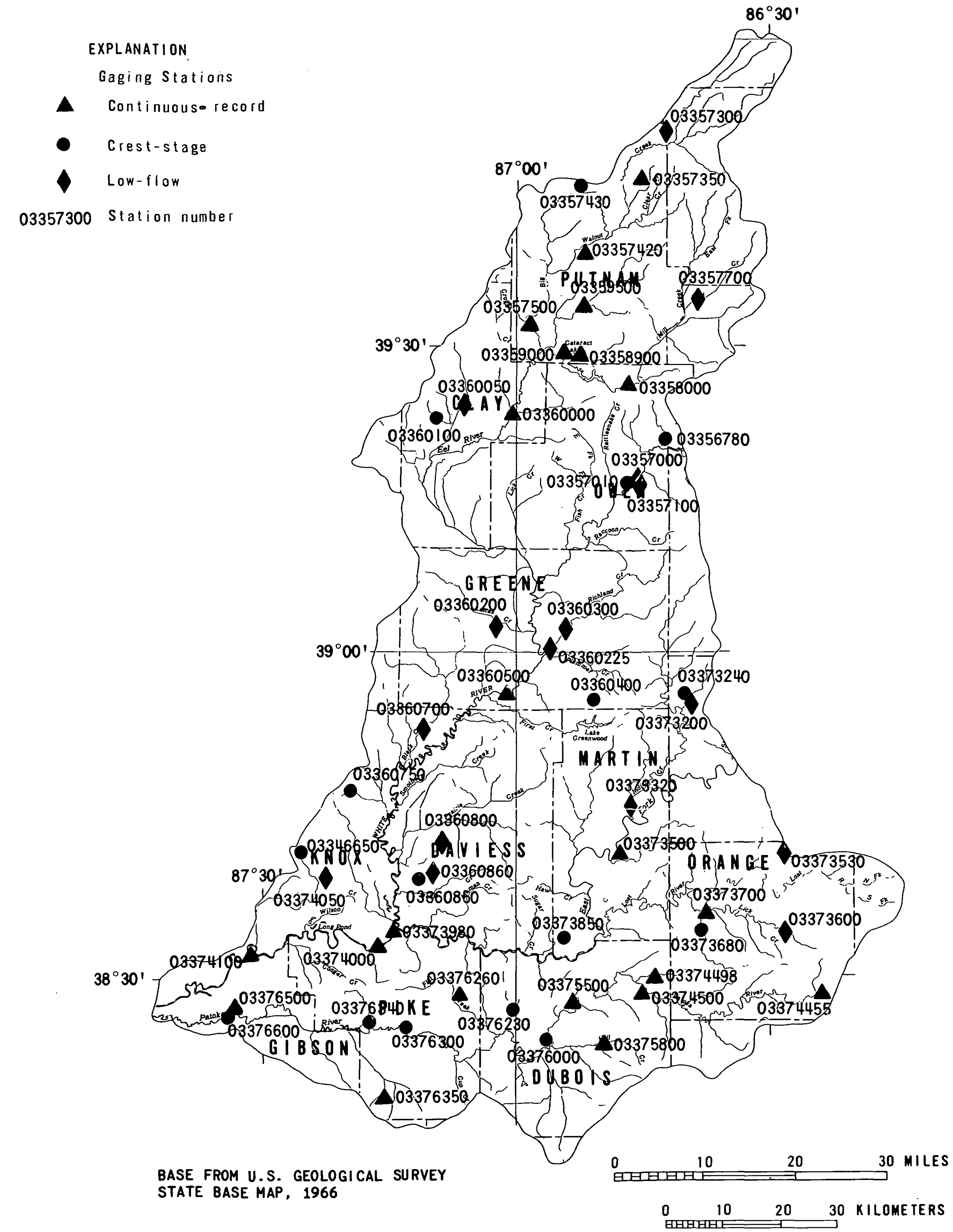


Figure 2.1.-- Gaging stations.

ESTIMATES OF 7-DAY, 10-YEAR LOW FLOW PRESENTED FOR 38 STATIONS

The 7-day, 10-year low flow is the lowest average rate of flow for 7 consecutive days to which streamflow can be expected to decline in 1 year out of 10.

Two types of analyses were used to obtain estimates of the 7-day, 10-year low flow at 38 stations. Where a 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 at partial-record sites was measured during periods of base flow, when flow is primarily from ground-water storage.

The Crawford Upland comprises the largest physiographic unit in the study area. The highly dissected unit represents a diverse area in terms of surface-water flow. The steep slope of the unit results in rapid runoff and little sustained flow. However, where erosion has been severe enough to penetrate into the karst limestone, numerous springs can occur (Schneider, 1966).

Most of the remainder of Area 32 is in the Wabash Lowlands. This lowland, underlain by siltstone and shale beds, is capped by a layer of glacial till in its north part (Schneider, 1966). The 7-day, 10-year low flow values for the lowland are minimal, owing to the absence of surficial aquifers. An exception is the outwash areas along major streams, which store water during high flow and rainstorms and release it to the streams during low-flow periods.

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

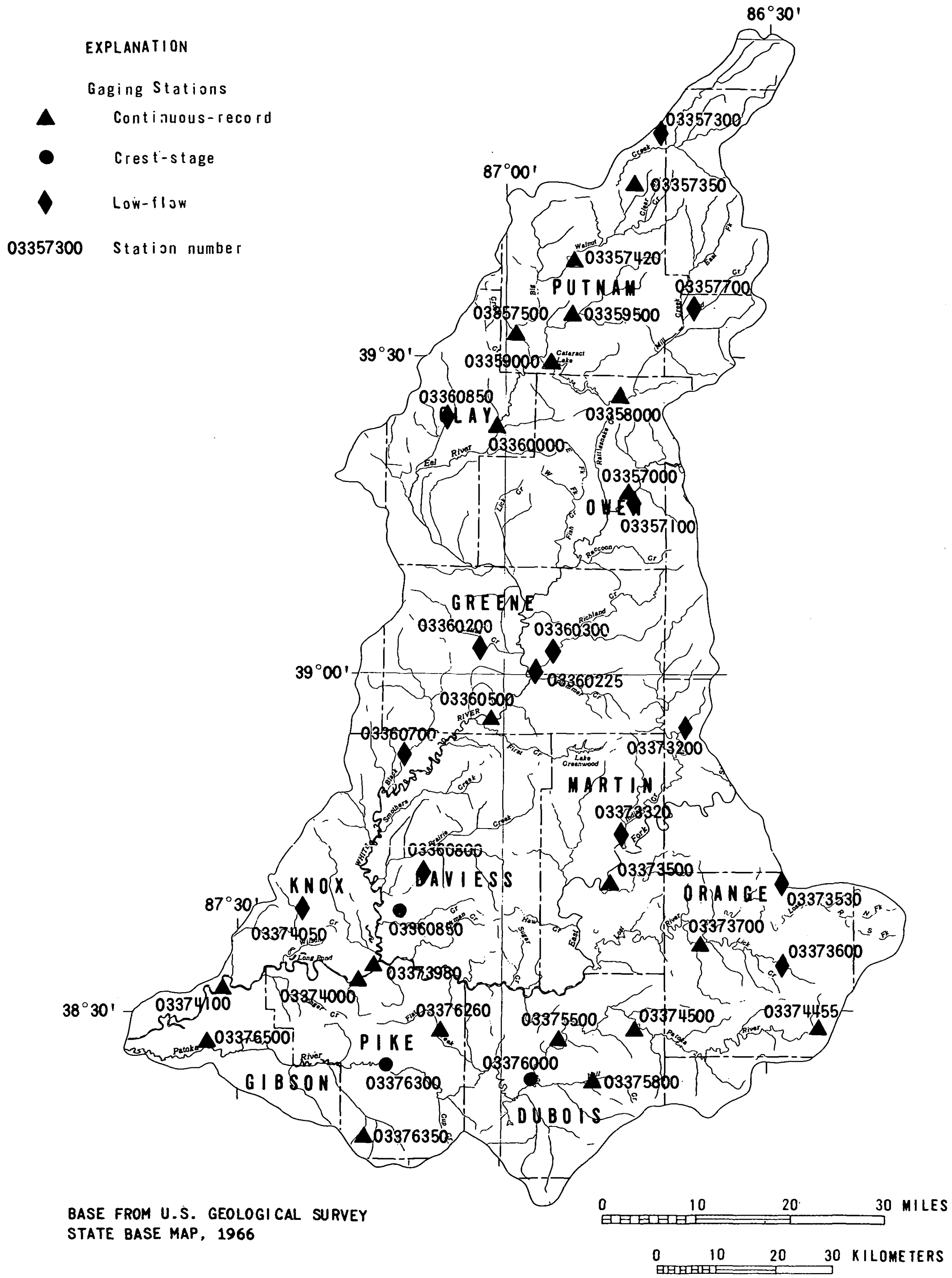


Figure 2.2.-- Data sites for 7-day, 10-year low-flow calculations.

Table 2.2.--Estimates of 7-day, 10-year low flow

Station name	Station number	Drainage area (mi^2)	Q7,10 (ft^3/s)
South Fork Patoka River nr Spurgeon	03376350	42.8	2.2
Hall Creek nr St. Anthony	03375800	21.8	0
Patoka River nr Princeton	03376500	822	1.4
Flat Creek nr Otwell	03376260	21.3	0
Patoka River at Jasper	03375500	262	0
Patoka River nr Ellsworth	03374500	171	.2
Patoka River nr Hardinsburg	03374455	12.8	0
White River at Hazleton	03374100	11,305	(1)
White River at Petersburg	03374000	11,125	790
White River above Petersburg	03373980	11,123	(1)
Lost River nr West Baden Springs	03373700	287	10.4
East Fork White River at Shoals	03373500	4,927	275
White River at Newberry	03360500	4,688	319
Eel River at Bowling Green	03360000	830	[2]17.6/19.5
Mill Creek nr Manhattan	03359000	294	[2]1.0/2.4
Mill Creek nr Cataract	03358000	245	1.4
Big Walnut Creek nr Reelsville	03357500	326	5.7
Big Walnut Creek at Greencastle	03357420	216	(1)
Plum Creek nr Bainbridge	03357350	3.0	0
White River at Spencer	03357000	2,988	226
Deer Creek nr Putnamville	03359500	59	.1
Patoka River nr Jasper	03376000	342	(1)
Patoka River at Winslow	03376300	603	1.1
Birch Creek nr Ashboro	03360050	40	1.1
Richland Creek nr Bloomfield	03360300	95	.5
Plummer Creek nr Bloomfield	03360225	67	0
Prairie Creek nr Washington	03360800	120	.1
Indiana Creek nr Trinity Springs	03373320	172	.1
Lattas Creek at Switz City	03360200	33	0
Big Walnut Creek nr Barnard	03357300	119	1.6
Rattlesnake Creek nr Spencer	03357100	25	.2
Black Creek nr Sandborn	03360700	109	2.5
Indian Creek nr Springville	03373200	61	0
Lick Creek nr Paoli	03373600	19	.1
Mud Creek nr Little Point	03357700	35	(1)
Veales Creek nr Washington	03360850	29	(1)
Lost River nr Orleans	03373530	35	(1)
Upper River Deshee nr Monroe City	03374050	15	(1)

[1]Insufficient data.
[2]Unregulated flow/regulated flow.

FLOOD FREQUENCIES ESTIMATED FOR SELECTED GAGING STATIONS

The 10-, 25-, 50-, and 100-year floods are floods of magnitudes 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 discharge for the 10-, 25-, 50-, and 100-year flood frequencies are presented for selected gaging stations. The recurrence interval 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. Estimates of flood peaks are listed in table 2.3. The relation between discharge and drainage area for three major rivers within Area 32 is shown in the adjoining curves (fig. 2.3a), and locations of the gaging stations used to compute flood peaks are shown in figure 2.3b.

Discharge records of less than 5 years are insufficient to compute flood peaks. Where discharge records for 5 to 10 years 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-years were computed.

Davis (1974) and Gold (1980) prepared manuals that provide methods for estimating the magnitude and the frequency of floods on unregulated and unurbanized Indiana streams. Additional methods are provided by the U.S. Soil Conservation Service (1975) for areas less than 2,000 acres. Davis (1974) and Gold (1980) found that precipitation index (precipitation minus snowfall and evapotranspiration) is the controlling factor on flood magnitude for most streams in the study area. Davis (1974) concluded that, for the Wabash and White Rivers, drainage area, channel slope, and stream length are the dominant factors and that precipitation index is insignificant. Precipitation index ranges from 10 in the north end of the study to 16 in the south (Davis, 1974) and from 5 to 18 in the rest of Indiana. Thus, flood magnitude for streams in the study area is moderately high compared to that for the rest of the streams in the State.

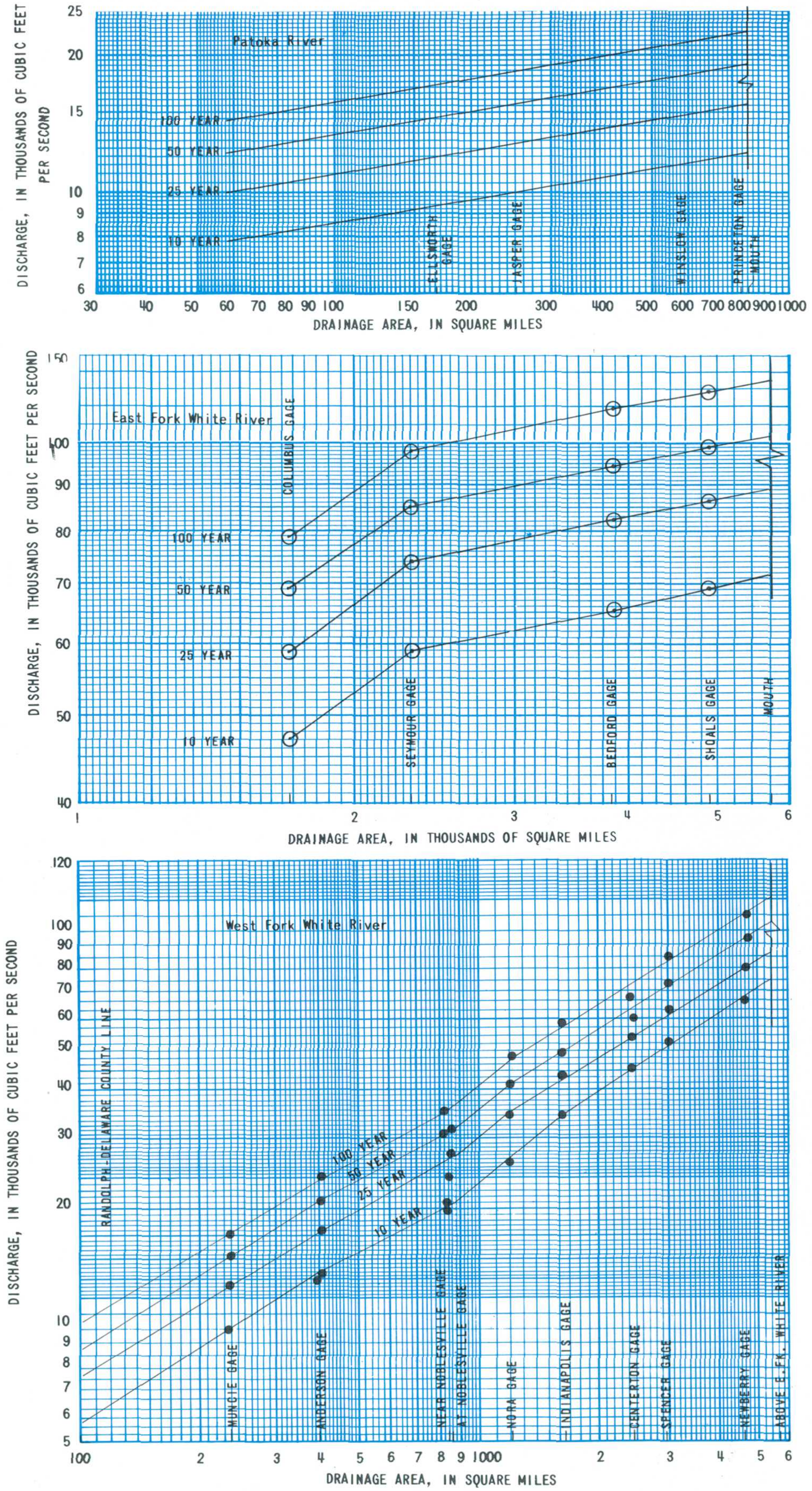


Figure 2.3a.-- Relation of drainage area to discharge.

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

Station name	Station number	Drainage area (mi²)	Years of record	Flood peaks (ft³/s) 10 years	25 years	50 years	100 years
Flat Creek nr Otwell	03376260	21.3	15	1,390	1,480	1,540	1,590
Lost River nr West Baden Springs	03373700	287	15	6,980	8,160	8,980	9,760
Plum Creek nr Bainbridge	03357350	3.0	10	634	757	844	925
Deer Creek nr Putnamville	03359500	59	11	9,560	11,300	12,500	13,600
Mill Creek nr Cataract	03358000	245	30	9,680	11,700	13,100	14,500
Mill Creek nr Manhattan	03359000	294	15	6,650	7,480	8,040	8,550
Mill Creek nr Manhattan[1]	03359000	294	26	3,320	3,600	3,780	3,940
Eel River at Bowling Green	03360000	830	22	24,900	31,900	37,800	44,400
Eel River at Bowling Green[1]	03360000	830	26	23,600	29,800	34,400	38,800
Big Walnut Creek nr Reelsville	03357500	326	30	18,200	22,600	25,700	28,600
Hall Creek nr St. Anthony	03375800	21.8	9	3,890	(2)	(2)	(2)
Patoka River nr Hardinsburg	03374455	12.8	11	2,110	2,800	3,500	4,440
White River at Petersburg	03374000	11,125	52	125,000	148,000	163,000	176,000
South Fork Patoka River nr Spurgeon	03376350	42.8	15	3,480	3,940	4,260	4,550
Big Walnut Creek at Greencastle	03357420	216	5	9,520	(2)	(2)	(2)
Clear Branch at Cory	03360100	.27	6	102	(2)	(2)	(2)
Veales Creek tributary at Washington	03360850	.27	6	215	(2)	(2)	(2)
Shiloh drain nr Jasper	03376230	.57	6	288	(2)	(2)	(2)
Patoka River Patoka River tributary nr Patoka	03376600	.40	6	186	(2)	(2)	(2)
Doans Creek tributary nr Doans	03360400	.20	6	120	(2)	(2)	(2)
River Deshee tributary nr Frichton	03346650	.82	6	182	(2)	(2)	(2)
Miller ditch tributary nr Bicknell	03360750	.50	6	125	(2)	(2)	(2)
Spring Creek tributary nr Springville	03373240	.54	7	260	(2)	(2)	(2)
Slate Creek tributary nr Haysville	03373850	.14	6	129	(2)	(2)	(2)
French Lick Creek nr French Lick	03373680	.29	6	205	(2)	(2)	(2)
Limestone Creek tributary nr Gosport	03356780	.72	7	221	(2)	(2)	(2)
Patoka River tributary nr Glezen	03376340	.84	6	259	(2)	(2)	(2)
Owl Creek tributary nr Bainbridge	03357430	.58	6	366	(2)	(2)	(2)
Patoka River nr Princeton	03376500	822	45	See curve on adjacent figure			
Patoka River at Jasper	03375500	262	32	Do.			
Patoka River at Ellsworth	03374500	171	18	Do.			
East Fork White River at Shoals	03373500	4,927	67	Do.			
White River at Newberry	03360500	4,688	51	Do.			
White River at Spencer	03357000	2,988	46	Do.			
Patoka River at Winslow	03376300	603	11	Do.			

[1]Record reflects regulated condition.
[2]Insufficient record.

Data from Indiana Department of Natural Resources (1979)

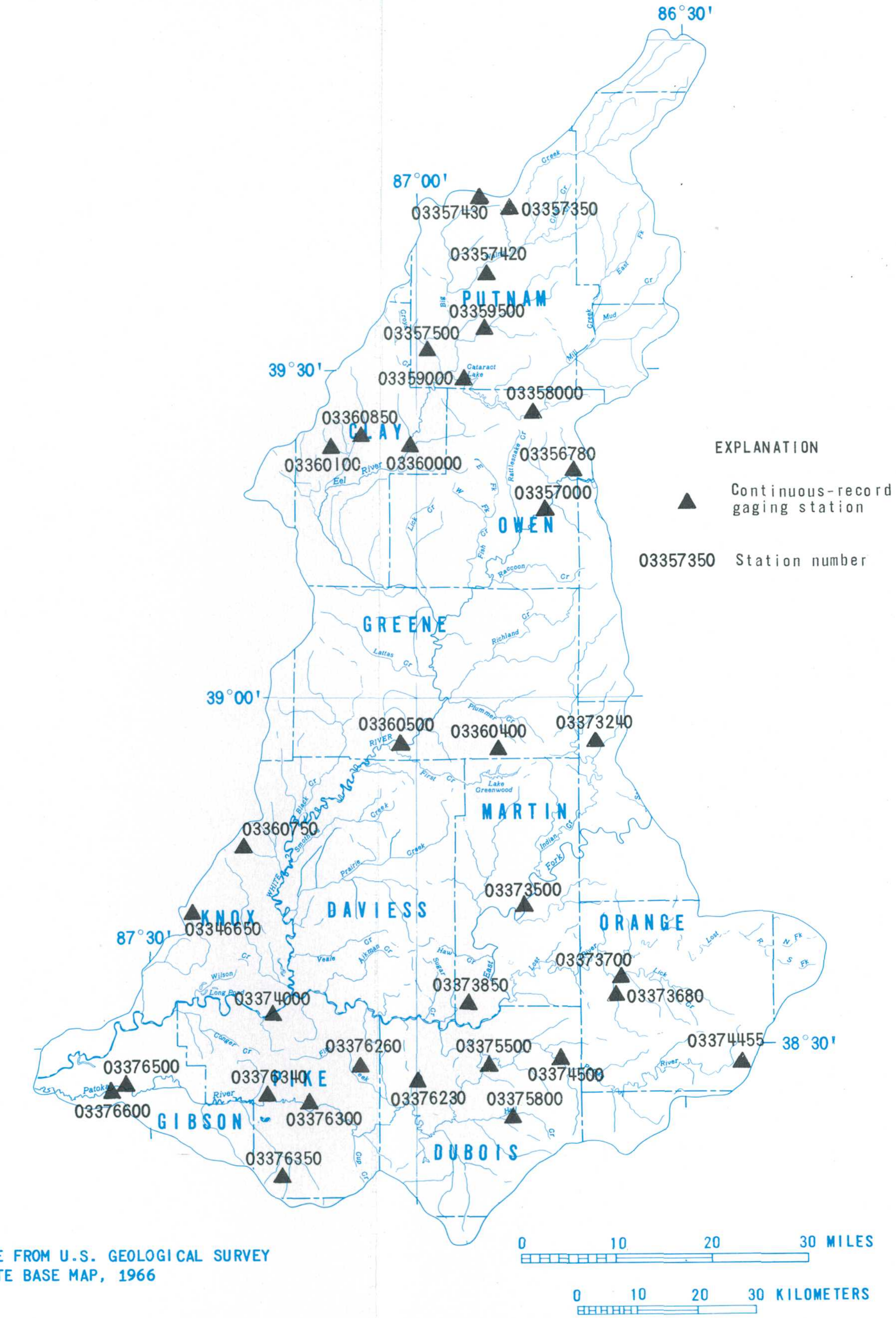


Figure 2.3b.-- Data sites for flood-frequency calculations.

DURATION CURVES FOR SELECTED GAGING STATIONS

Flow-duration curves show the percent of time that specified discharges were equaled or exceeded during a given period of record. Curves developed for the White River at Newberry, Flat Creek near Cataract, and Eel River at Bowling Green indicate a wide variation of sustained flow in the area.

Duration curves for four gaging stations are presented in figure 2.4a. The 95-, 90-, 75-, 70-, 50-, 25-, and 10-percent flow durations for 15 additional stations are listed in table 2.4. Locations of the stations are shown on the adjoining map (fig. 2.4b). Two sets of data were developed for the Eel River at Bowling Green and Mill Creek near Manhattan, one for the period of record through 1952, before the constructon of Cagles Mill Lake, and the second, for 1955 through 1979, after the reservoir was put into operation.

A Geological Survey computer program (Hutchison, 1975) was used to compute flow duration by a magnitude-frequency analysis of daily discharge values. The computed values, listed in the following table, were used to construct the duration curves in the adjoining figure 2.4a.

A wide variation in streamflow is indicated by the duration curves for streams in the study area. Broad rivers with low slopes have a sustained flow, but streams with steep slopes, and low recharge due to the lack of surficial aquifers, sustain little flow. (See the steep slope at the lower end of the duration curve in figure 2.4a.)

Table 2.4.--Flow duration at selected gaging stations

Station name	Station number	Period of record used	Percent of time discharge in cubic feet per second exceeded 95	90	75	70	50	25	10
South Fork Patoka River near Spurgeon	03376350	1966 to 1979	4.8	6.1	10	12	23	52	120
Hall Creek near St. Anthony	03375800	1972 to 1979	.1	.3	1.7	2.5	8.0	25	72
Patoka River near Princeton	03376500	1936 to 1977	10	17	54	72	270	1,500	2,800
Flat Creek near Otwell	03376260	1966 to 1979	See curve in figure 2.4a.						
Patoka River at Jasper	03375500	1949 to 1977	1.0	3.1	14	21	74	360	1,200
Patoka River near Ellsworth	03374500	1963 to 1977	.9	2.0	9.7	14	51	200	660
Patoka River near Hardinsburg	03374455	1970 to 1978	.3	.5	1.4	1.9	6.2	22	56
White River at Petersburg	03374000	1929 to 1979	1,100	1,400	2,500	2,900	5,700	14,000	30,000
Lost River near West Baden Springs	03373700	1966 to 1979	19	24	49	62	160	430	960
East Fork White River at Shoals	03373500	1905 to 1979[1]	380	490	890	1,100	2,400	6,500	14,000
White River at Newberry	03360500	1930 to 1979	See curve in figure 2.4a.						
Eel River at Bowling Green	03360000	1932 to 1952[1] 1955 to 1979[2]	Do. Do.						
Mill Creek near Manhattan	03359000	1941 to 1952 1955 to 1978[2]	5.6 2.7	8.8 4.2	23 20	30 30	79 89	250 210	760 980
Mill Creek near Cataract	03358000	1951 to 1979	See curve in figure 2.4a.						
Big Walnut Creek near Reelsville	03357500	1951 to 1979	14	21	50	62	140	340	760
Plum Creek near Bainbridge	03357350	1971 to 1979	.01	.02	.1	.2	1	3.4	8.1
Big Walnut Creek near Reelsville	03357500	1951 to 1979	14	21	50	62	140	340	760
Plum Creek near Bainbridge	03357350	1971 to 1979	.01	.02	.1	.2	1	3.4	8.1
White River at Spencer	03357000	1927 to 1971	330	400	630	730	1,400	3,200	6,900
Deer Creek near Putnamville	03359500	1956 to 1972	.6	1.2	4.4	6.1	18	48	110
Patoka River at Winslow	03376300	1965 to 1974	4.1	8.3	33	47	200	1,000	1,900

[1]No records for periods from 1906 to 1908 and 1916 to 1923.
[2]Record reflects regulated condition.

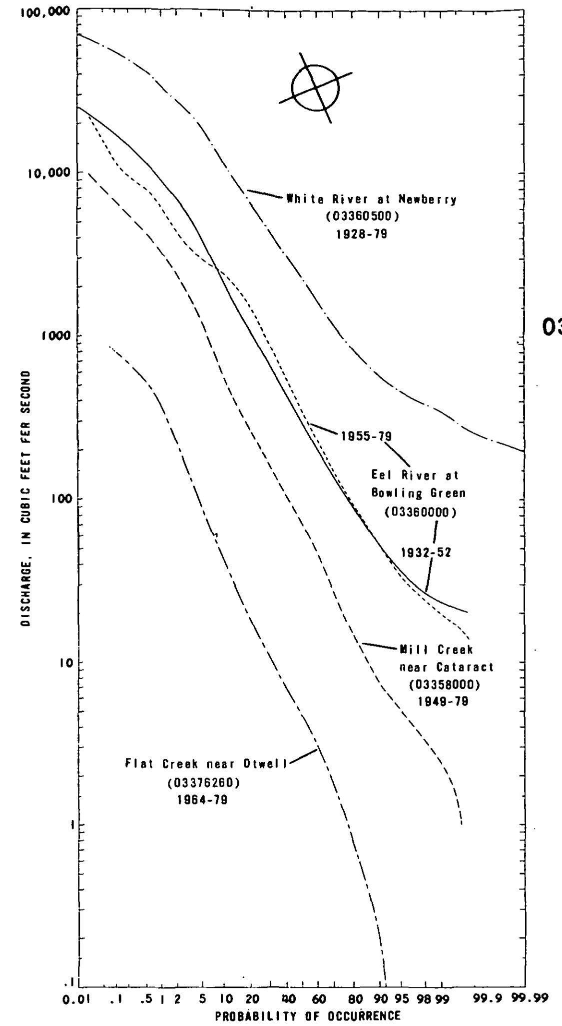


Figure 2.4a.-- Duration curves for selected sites.

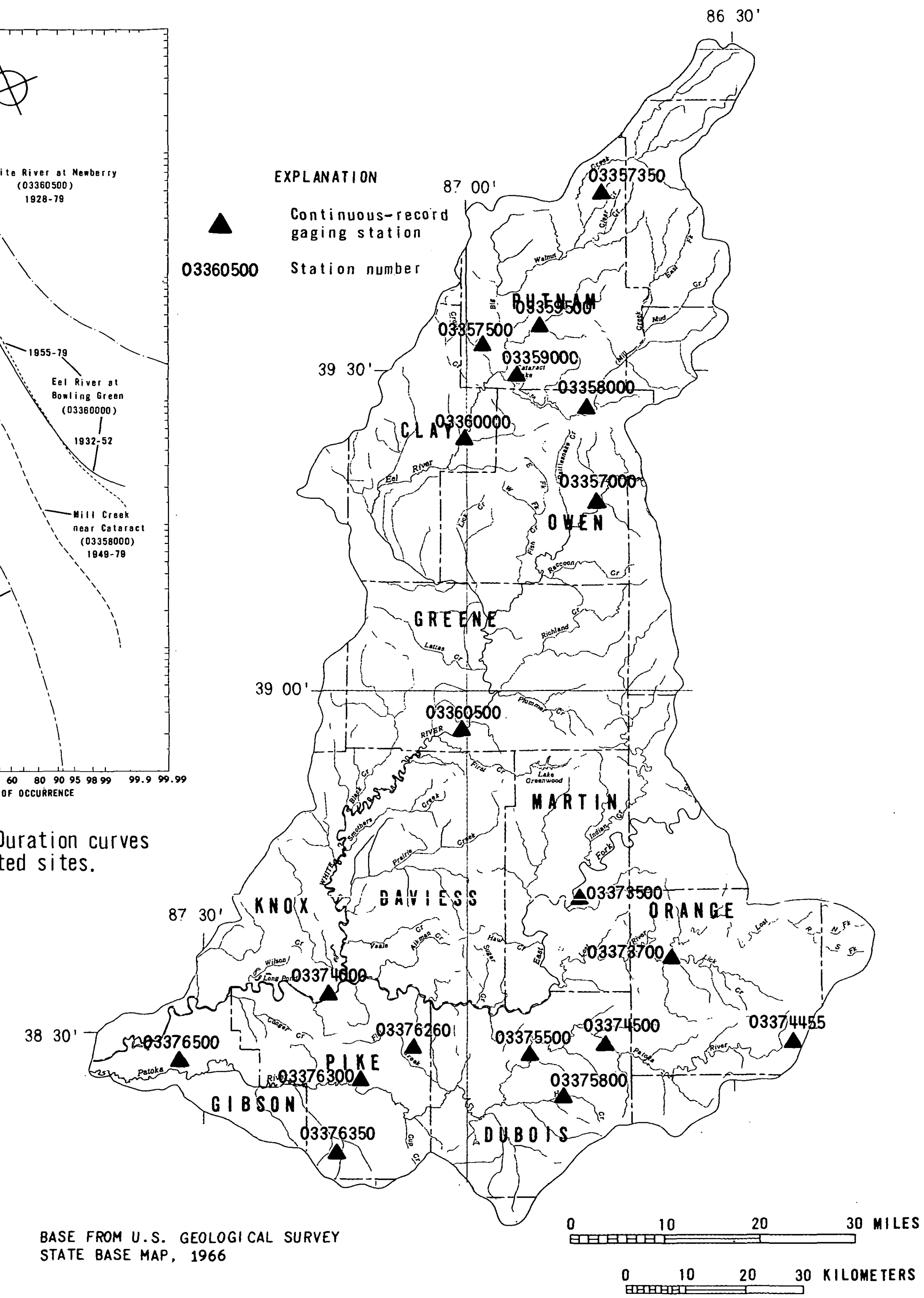


Figure 2.4b.-- Data sites for computation of duration curves

AVERAGE FLOW COMPUTED FOR SELECTED GAGING STATIONS

Records of discharge for streams in Area 32 indicate that average annual flow is proportional to drainage area.

Monthly mean discharges at 19 gaging stations are presented in the accompanying table 2.5. A Geological Survey computer program (Hutchison, 1975) was used to calculate monthly and annual average flows from daily discharges. Locations of the stations are shown in figure 2.5a. Two periods of record were used for the Eel River at Bowling Green and Mill Creek near Manhattan--one for the period of record through 1952, before the construction of Cagles Mill Lake, and the second, for 1955 through 1979, after the reservoir was put into operation.

The curve relating drainage area to mean annual discharge in figure 2.5b indicates that average annual flow is predictable. The small variation around the curve indicates that the dominant factor affecting average annual flow is size of drainage area.

Table 2.5.--Monthly mean discharge at selected gaging stations

Station name	Station number	Monthly mean discharge for period of record (ft³/s) October	November	December	January	February	March	April	May	June	July	August	September
South Fork Patoka River near Spurgeon	03376350	14.6	28.9	55.6	58.8	80.3	97.3	92.6	62.2	45.7	38.7	25.6	160
Patoka River near Princeton	03376500	193	355	765	1,524	1,762	2,346	1,984	1,386	694	393	243	170
White River at Spencer	03357000	931	1,589	2,490	4,497	4,484	5,242	5,584	4,064	2,808	1,865	1,048	1,039
Plum Creek near Bainbridge	03357350	1.41	3.56	5.35	4.29	6.31	8.43	5.23	3.18	2.96	3.52	1.61	.56
Big Walnut Creek at Greencastle	03357420	88.4	79.5	287	235	383	656	294	208	119	261	179	48.6
Big Walnut Creek near Reelsville	03357500	82.6	204	382	507	525	675	597	418	338	227	126	91.6
Deer Creek near Putnamville	03359500	11.1	31.4	59.6	75.4	93.3	120	123	79.5	60.8	29.6	12.5	29.8
Mill Creek near Cataract	03358000	47.1	188	304	383	422	534	398	281	249	196	87.6	61.6
Mill Creek near Manhattan	03359000	47.8	200	254	585	486	518	547	401	333	105	66.7	86.8
Mill Creek near Manhattan[1]	03359000	82.3	177	235	321	493	482	581	389	343	238	86.5	77.3
Eel River at Bowling Green	03360000	228	503	758	1,697	1,305	1,559	1,587	1,255	824	382	214	264
Eel River at Bowling Green[1]	03360000	231	517	905	1,011	1,310	1,598	1,571	1,148	889	639	362	284
White River at Newberry	03360500	1,274	2,446	4,228	7,028	6,917	8,726	8,770	6,467	4,335	3,095	1,846	1,332
East Fork White River at Shoals	03373500	1,546	2,530	5,118	9,096	8,563	11,590	9,897	6,829	4,102	2,884	1,869	1,350
Lost River near West Baden Springs	03373700	70.2	221	478	456	555	751	738	428	243	207	190	96.7
White River at Petersburg	03374000	2,891	5,534	10,140	17,980	18,040	23,330	21,560	15,930	10,300	7,187	4,579	3,089
Patoka River near Hardinsburg	03374455	2.72	16.6	35.8	37.3	39.3	57.7	56.8	28.7	17.6	15.6	7.26	3.60
Patoka River near Ellsworth	03374500	22.9	104	237	323	384	618	455	247	125	54.6	45.3	29.6
Patoka River at Jasper	03375500	44.2	188	389	635	688	897	653	434	196	99.5	62.1	39.2
Hall Creek near St. Anthony	03375800	8.62	31.4	46.1	40.1	63.8	73.6	61.6	20.4	19.0	33.4	20.8	7.92
Flat Creek near Otwell	03376260	4.16	13.1	31.4	33.2	38.5	50.2	40.5	24.7	12.3	15.7	8.52	3.13

[1]Record reflects regulated condition.

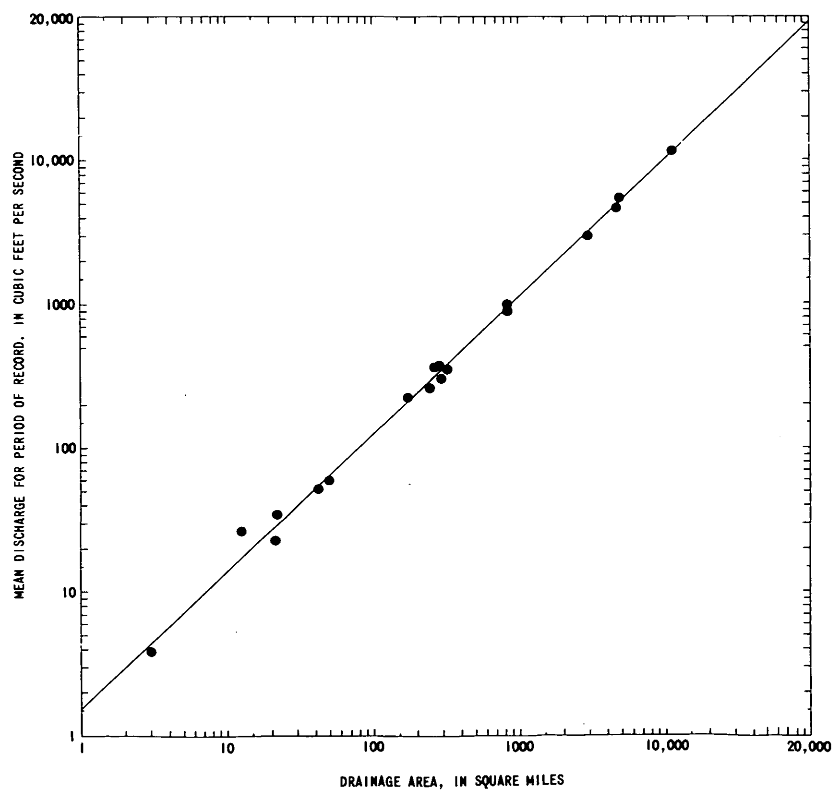
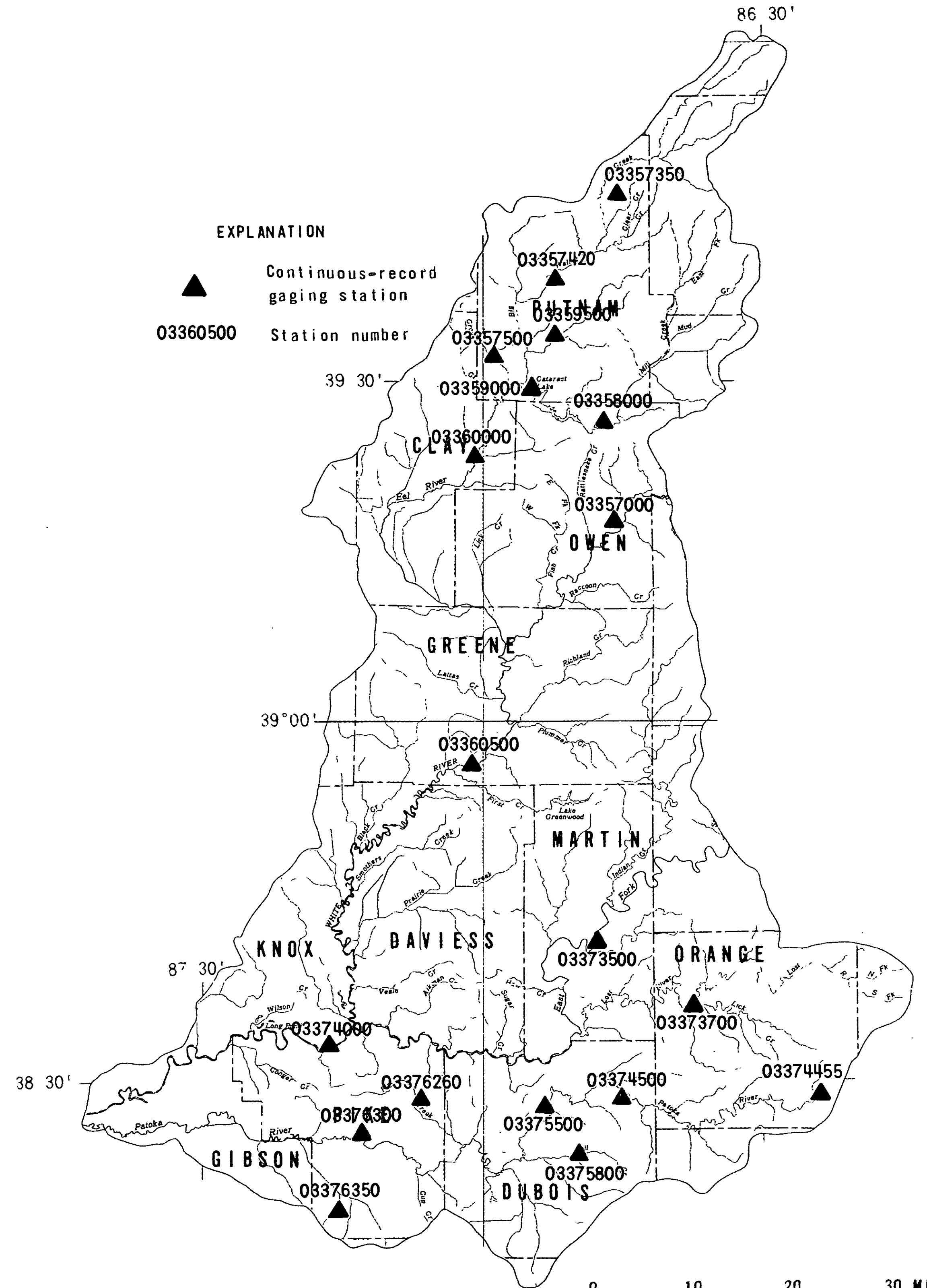


Figure 2.5b.-- Relation of drainage area to mean discharge.



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

0 10 20 30 MILES

0 10 20 30 KILOMETERS

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

GLACIAL DEPOSITS AND BEDROCK ARE SOURCES OF GROUND WATER

Glacial sand and gravel deposits along streams and in buried valleys and lenses of sand and gravel in till or lake deposits may yield large supplies of water. Sandstone and coal of Pennsylvanian age and limestone and sandstone of Mississippian age are sources of small supplies of ground water.

Ground water is available from glacial sand and gravel deposits and from bedrock of Pennsylvanian and Mississippian ages. Glacial deposits yield the most water, but bedrock aquifers must be used in some areas.

Glacial sand and gravel deposits are classified in two groups: (1) valley train or outwash and (2) lenses in till or lake sediments. Valley train and outwash, which were deposited by glacial melt water, are found along modern streams or over buried bedrock valleys. Older outwash deposits can also be found in these buried valleys under till or lake deposits. These types of aquifers range in thickness from 10 to 80 feet and can yield large quantities of water. Isolated lenses of sand and gravel in till and lake sediments are usually found by trial and error drilling. Wells in the thicker and more widely distributed lenses can yield as much as a few hundred gallons per minute. Wells in the thinner and less widely distributed sand and gravel lenses yield only a few gallons per minute. Sand and gravel lenses within the lake sediments are as thick as 25 feet (Nyman and Pettijohn 1971, p. 4). The locations of major valley train and outwash aquifers and of till and lake deposits, where isolated sand and gravel aquifers can be found, are shown on the adjacent map of glacial geology (fig. 3.1a).

In the glaciated area, bedrock aquifers are used where till is too thin to contain adequate sand and gravel lenses or where outwash aquifers are not present. Although the unglaciated area contains some outwash and lake deposits, the bedrock is generally the only ground-water source. The areal extent and the stratigraphic relationships of bedrock in Area 32 are shown in the bedrock-outcrops map (fig. 3.1b) and in the geologic column (fig. 3.1c), respectively.

Limestone and sandstone of Mississippian age are sources of small ground-water supplies. The Chesterian Series, especially the Stephensport and West Baden Groups, consist of porous sandstone and limestone interbedded with impermeable shale. These aquifers can maintain small-yield wells. The underlying Blue River and Sanders Groups are dense, fractured limestones. The dense limestone is not an aquifer, but water can be removed from crevices and solution cavities. The fine-grained rocks of the Borden Group transmit little water, and the 1 to 10 feet thick jointed Rockford Limestone lies between impermeable layers of rock. According to Harrell (1935, p. 88-89), the Borden Group and the Rockford Limestone are not aquifers; nor is a small outcrop of New Albany Shale at the northern tip of Area 32.

Small ground-water supplies can generally be developed anywhere in the Pennsylvanian outcrop area. Discontinuous confining layers downdip from the outcrop areas can limit recharge and reduce yield. The Mansfield Formation, Merom Sandstone Member of the Mattoon Formation, and Busseron Sandstone Member of the Shelburn Formation, as well as other sandstones, are generally good aquifers, except under these confining conditions. In coal-seam aquifers, clay layers beneath the coal allow water to collect in the coal joints and crevices (Harrell, 1935, p. 74-76).

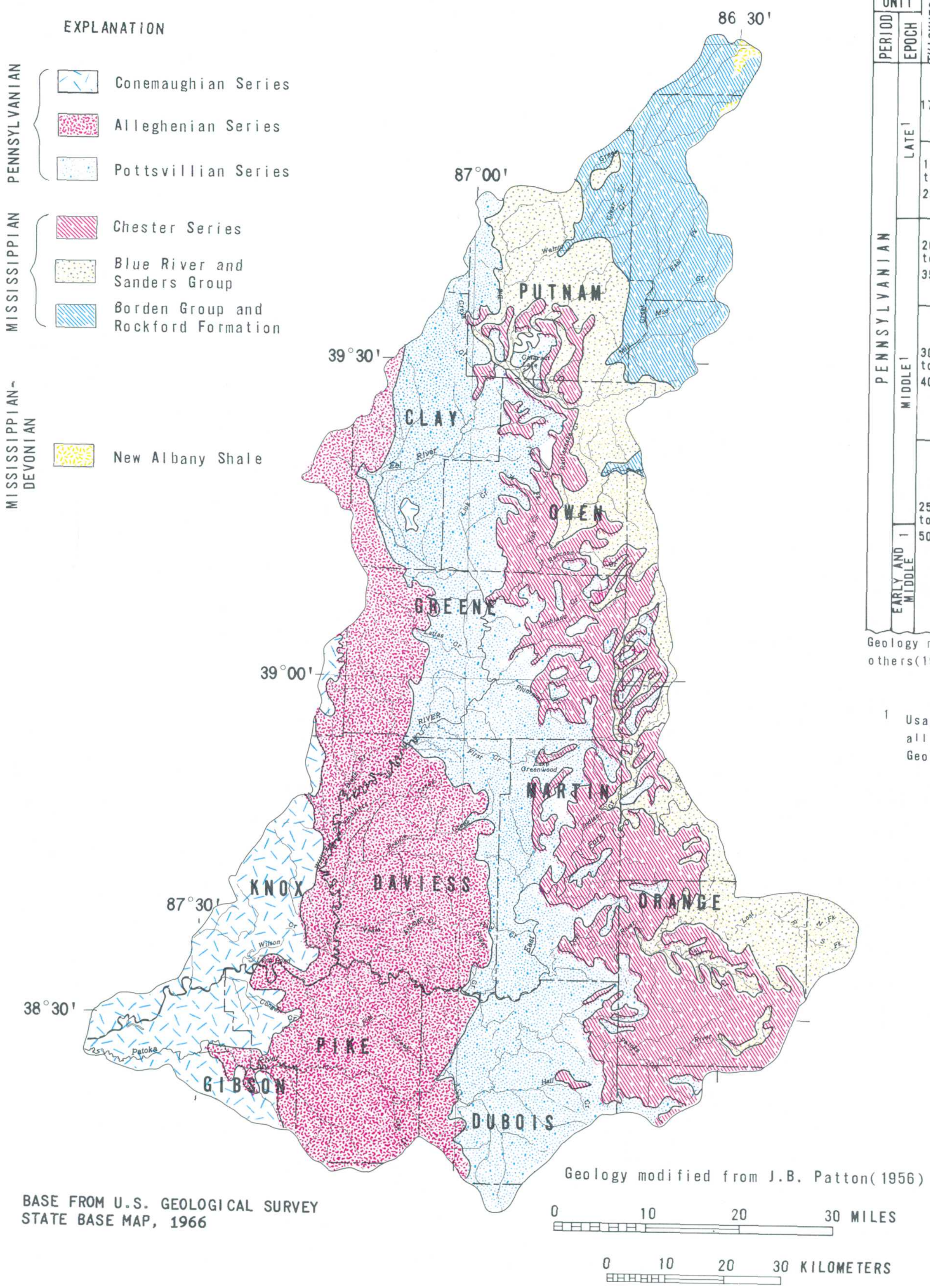


Figure 3.1b.-- Bedrock outcrops.

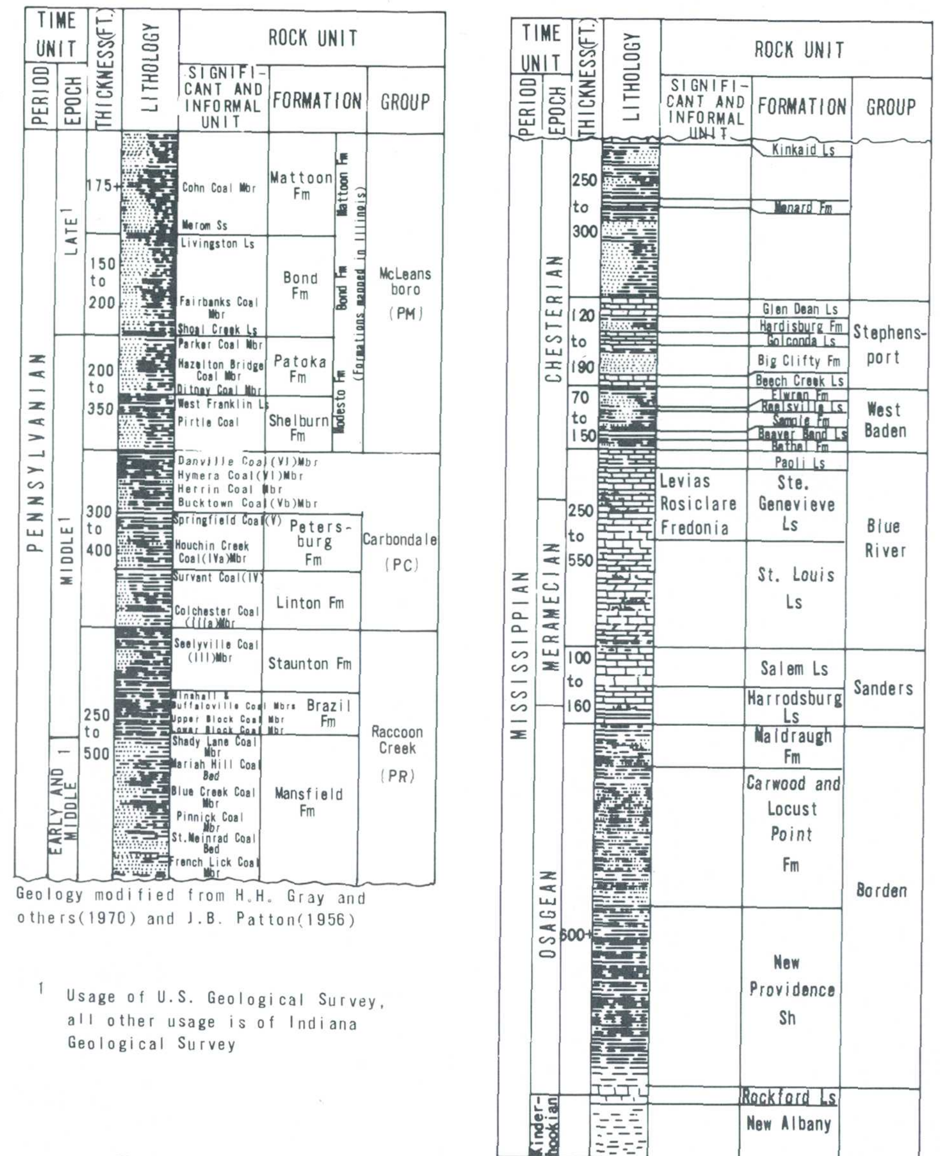


Figure 3.1c.-- Geologic column.

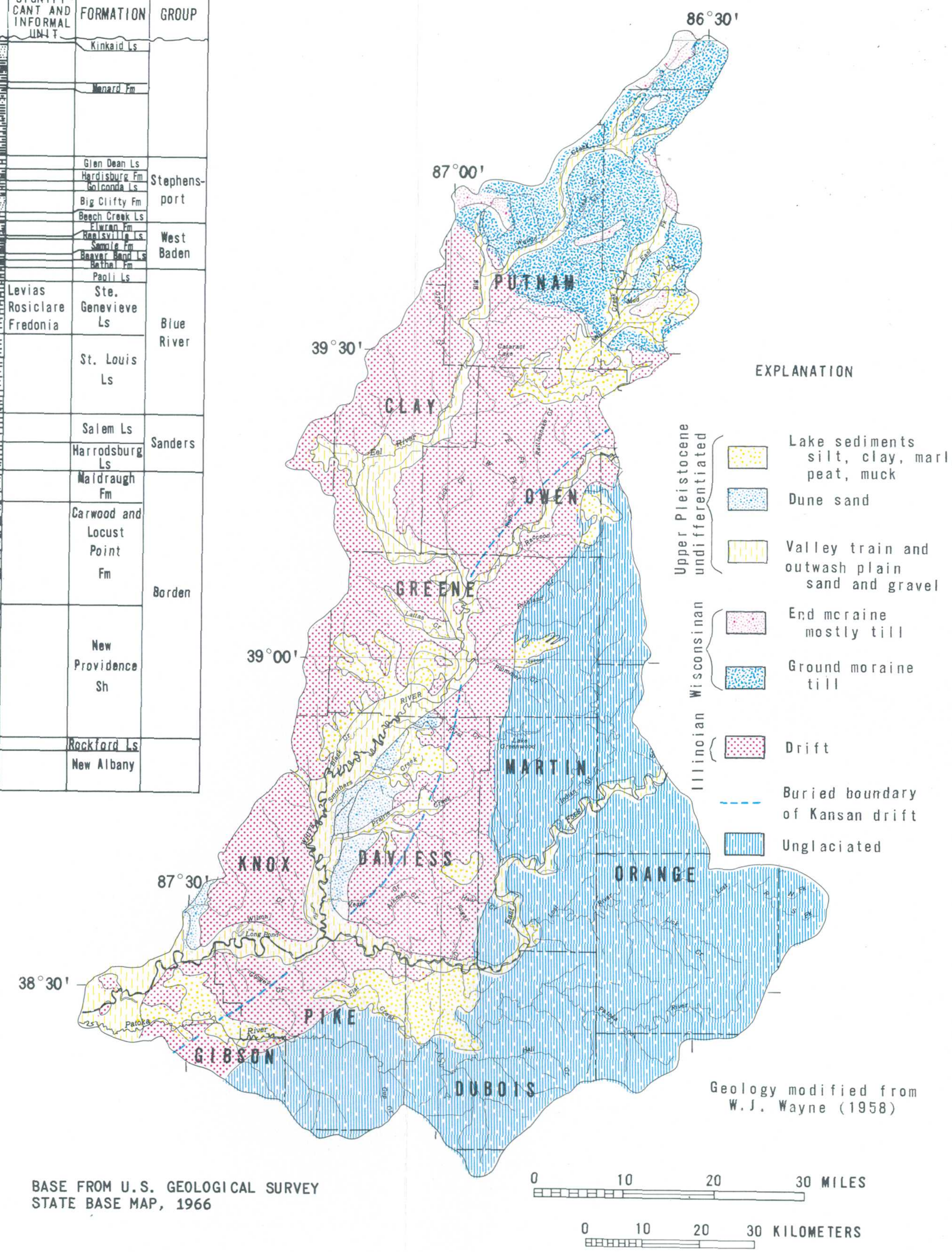


Figure 3.1a.-- Glacial geology.

GROUND-WATER DEVELOPMENT POTENTIAL OF THE GLACIAL AND THE BEDROCK AQUIFERS DEPENDS ON SEVERAL VARIABLES

High-yield water wells can usually be developed in glacial sand and gravel deposits because of their high hydraulic conductivity and recharge rates. Valley train and outwash deposits have greater development potential than aquifer lenses confined in till or lake sediments. Yields from bedrock aquifers are usually small, but the aquifers are areally extensive.

Ground-water development potential of glacial and bedrock aquifers depends on thickness, areal extent, permeability, and recharge. Bedrock aquifers underlie nearly all parts of the study area but have a lower development potential than the more localized glacial sand and gravel aquifers.

Valley train and outwash deposits have the highest potential for ground-water development and can support some industrial and municipal supplies, where wells yield 1,000 gallons per minute or more. These aquifers, as thick as 100 feet, are the most areally extensive sand and gravel deposits. The hydraulic conductivity of these aquifers is typically 2,000 (gal/d)/ft^2. Recharge, directly from precipitation or seepage from valley walls, is estimated to be 350,000 (gal/d)/mi^2 for unconfined aquifers and 125,000 for those confined under till or lake sediments (Nyman and Pettijohn, 1971, p. 4, 5, 10).

Many sand and gravel lenses confined in till or lake deposits have high yields but low development potential. The hydraulic conductivity of these deposits is probably about the same as that of the valley train aquifers [2,000 (gal/d)/ft^2], but their thickness (as much as 25 feet) and areal extent are much less. Recharge is probably even less than for confined valley train or outwash deposits [125,000 (gal/d)/mi^2] because all recharge travels vertically through the confining materials. Wells in these aquifers typically yield from 50 to 500 gallons per minute (Nyman and Pettijohn, 1971, p. 4).

Some wells in sandstone and coal of Pennsylvanian age can produce 20 gallons per minute but generally produce less than 10. The basal sandstone of the Mansfield Formation can produce as much as 100 gallons per minute in localized areas (Clark, 1980, p. 28). Supplies of ground water for domestic use can be developed almost anywhere in the Pennsylvanian outcrop area (Harrell, 1935, p. 75). Hydraulic conductivity of Pennsylvanian aquifers is typically 25 (gal/d)/ft^2. Recharge amounts to about 60,000 (gal/d)/mi^2 (Nyman and Pettijohn, 1971, p. 5, 10). Precipitation recharges the aquifers at their outcrops, either directly or by percolation through glacial deposits (Cable and others, 1971, p. 5).

Limestone and sandstone aquifers of Mississippian age are similar to aquifers of Pennsylvanian age in hydraulic conductivity and recharge. The Upper Mississippian sandstones of the Chesterian Series generally yield less than 5 gallons per minute, and the dense, fractured limestones of the Blue River and Sanders Groups usually yield less than 10 gallons per minute but in small areas yield more than 100 (Clark, 1980, p. 28).

The maximum well yield that can be expected in a particular area is shown on the adjacent map (fig. 3.2). This generalized map is representative of all aquifers, glacial and bedrock.

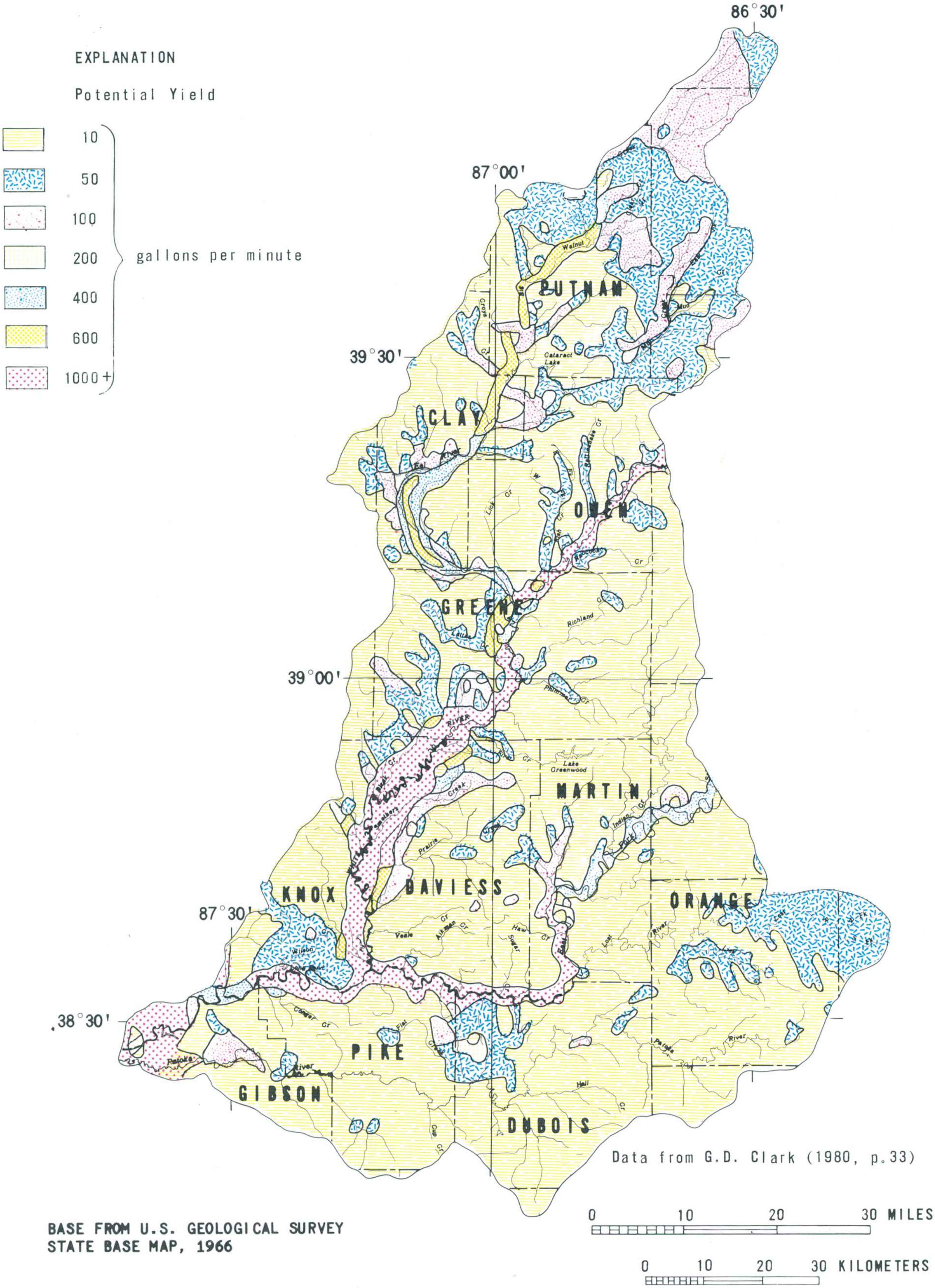


Figure 3.2.-- Ground-water potential.

MAJOR STREAMS INFLUENCE GROUND-WATER FLOW, AND WATER LEVELS FLUCTUATE SEASONALLY

Ground-water flow is part of a regional flow system in the Wabash River basin. The source of ground water is precipitation percolating into the aquifers. Ground water leaves aquifers as seepage into streams, evapotranspiration, and pumpage. Water levels fluctuate seasonally in a regular pattern but can be influenced by prolonged variations from normal precipitation.

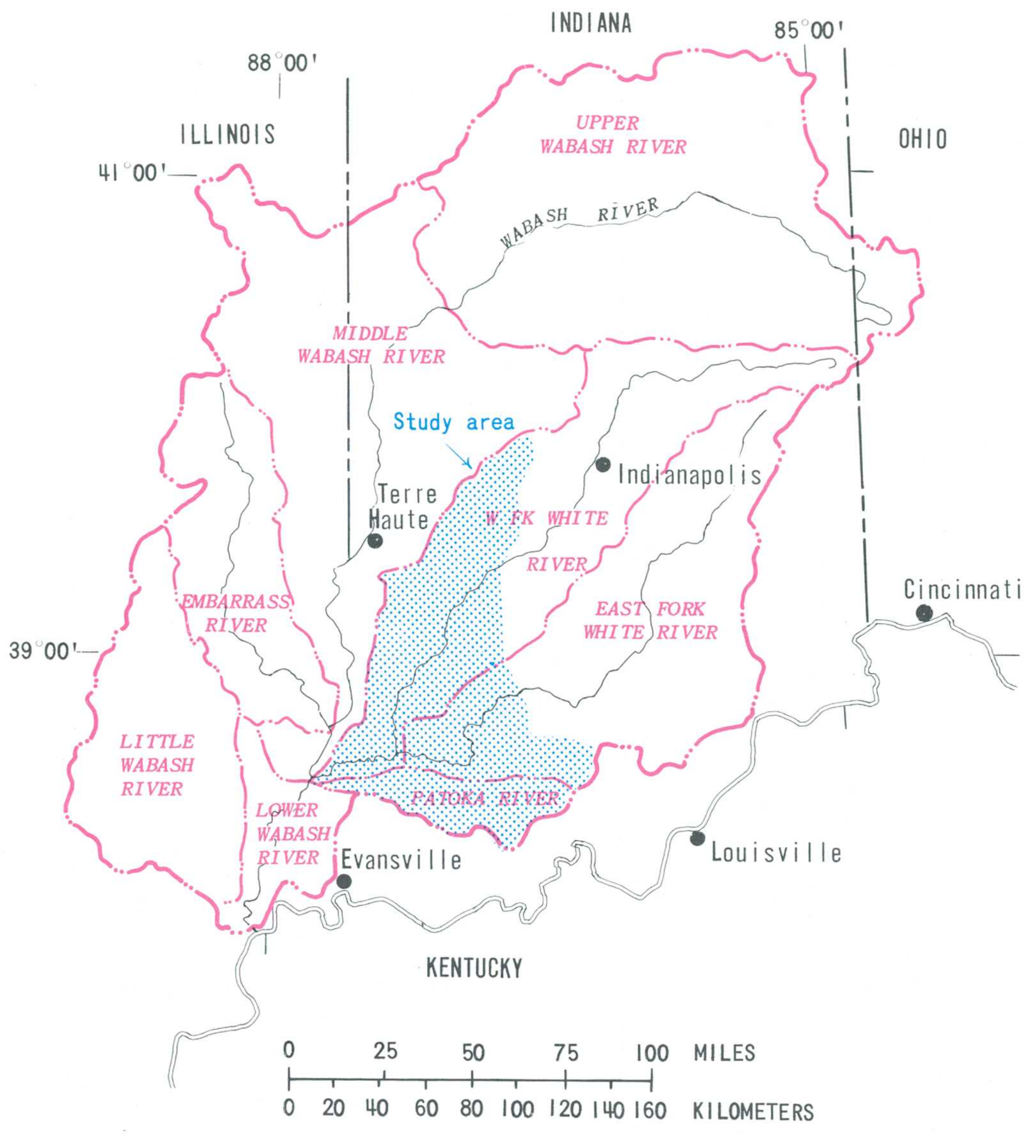
In general terms, the Wabash River basin (fig. 3.3a) is a single hydrologic unit. Precipitation percolates through till, sand, gravel, and bedrock and flows through the aquifers toward streams. Ground water leaves the system as seepage into the streams, evapotranspiration, or pumpage (Nyman and Pettijohn, 1971, p. 12).

Ground-water flow patterns are affected by the major streams in the Wabash River basin. Three drainage subbasins are delineated in figure 3.3b. Glacial aquifers discharge water into these streams by seepage. Bedrock aquifers, where cut by stream valleys, discharge water by seepage or springs. Although flow in the bedrock is locally toward a major stream, there is also a regional component of flow downdip in the Illinois structural basin.

The natural rate of ground-water seepage can be measured in a stream at base flow. This rate of seepage is related to aquifer transmissivity and the head differential between aquifer and stream (Nyman and Pettijohn, 1971, p. 5). Glacial aquifers in Area 32 usually discharge more than the bedrock aquifers. Also, Corbett (1965, p. 2) observed that cast overburden resulting from coal strip mining in the Patoka River basin produces significant discharge compared with little or no discharge in the undisturbed areas.

Water levels in the study area are recorded continuously in four observation wells whose locations are shown on the study area map (fig. 3.3b). Historic data from these wells are available at the Geological Survey office in Indianapolis and are published annually in "Water Resources Data for Indiana" beginning with the 1975 water year (U.S. Geological Survey, 1976-79). Each well is set in a different aquifer, and all the wells except PN4 are artesian. HD4 is 85 feet deep and is cased to 70 feet in Mississippian sandstone. MT5 is 143 feet deep and is cased to 53 feet in Pennsylvanian sandstone. OW7 is 150 feet deep and is cased to 15 feet in Mississippian limestone. PN4 is 60 feet deep and is cased to 20 feet in Holocene sand and gravel deposits (U.S. Geological Survey, 1979, p. 359, 365, 369, 372).

Ground-water levels fluctuate seasonally, high levels in the spring and low levels in the fall. Increased precipitation and decreased evapotranspiration in the fall cause levels to rise again. Hydrographs of four wells (fig. 3.3c) show the general pattern of fluctuation for the 1976 and 1978 water years but an anomalous pattern for the 1977 water year. A drought in late 1976 caused the lowest water levels in 20 years, but increased precipitation in 1977 caused water levels to rise and resume the typical fluctuation pattern (Clark, 1980, p. 34-35).



Modified from D.J. Nyman and R.A. Pettijohn (1971, p.4)

Figure 3.3a.-- Wabash River basin and subbasins.

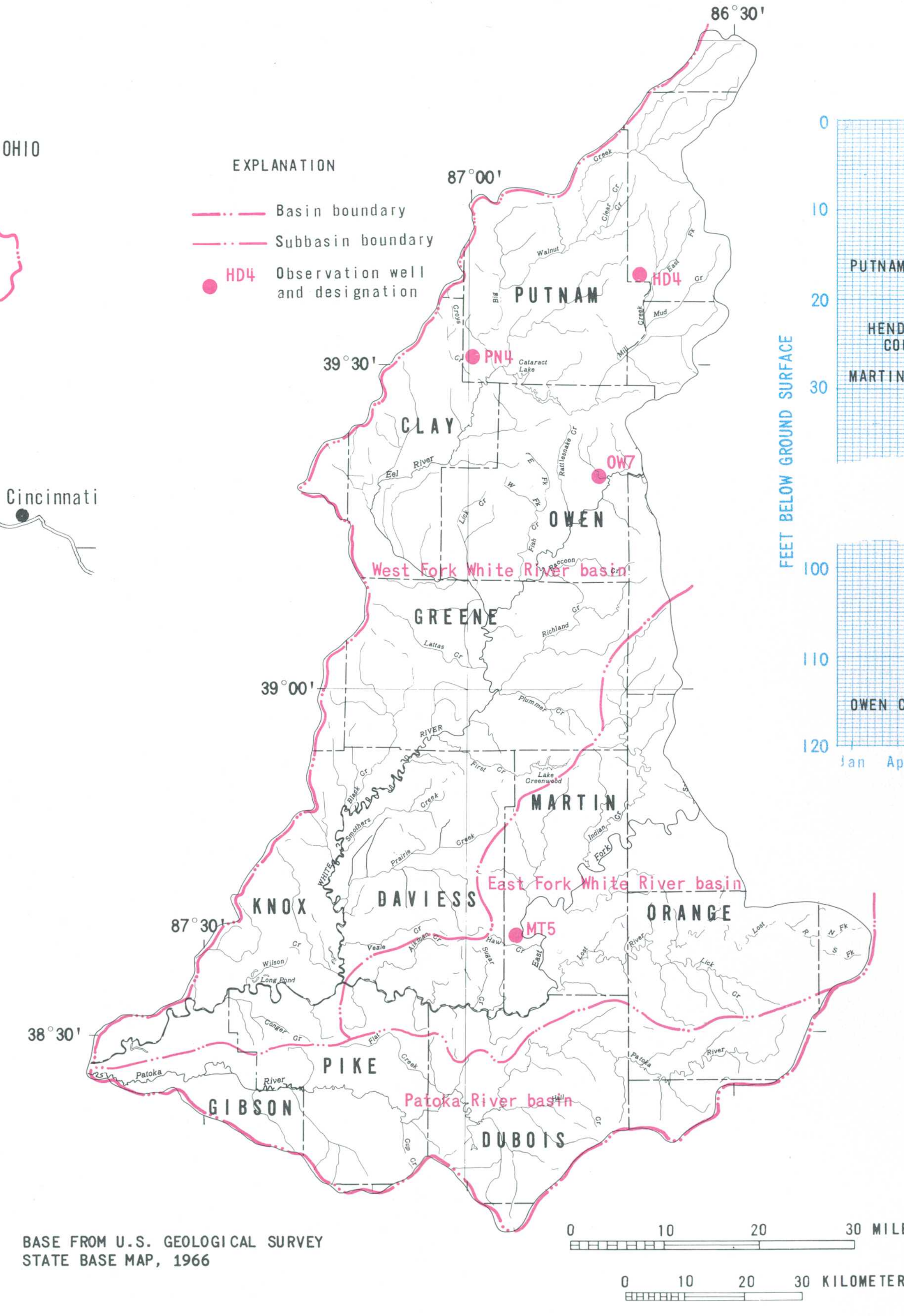


Figure 3.3b.-- Subbasins of the Wabash River basin within the study area.

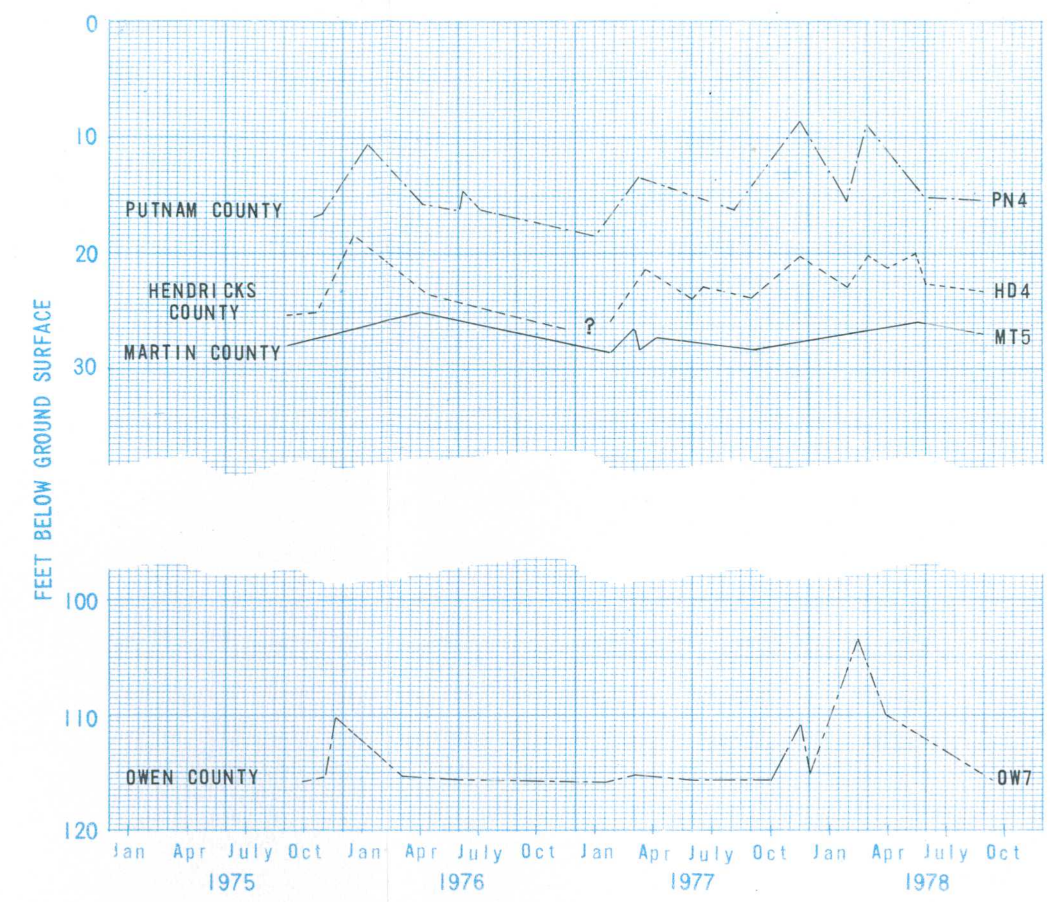


Figure 3.3c.-- Hydrographs of selected wells.

WATER-QUALITY DATA ARE REQUIRED FOR COAL-MINING 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 applications. 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 (Dyer and Curtis, 1977; Hoehn and Sizemore, 1977; King and others, 1974; and Letterman and Mitsch, 1978). Because of the oxidation and the weathering of pyrite and marcasite exposed by mining operations, drainage in many old mining areas has an acidic pH (<7). 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, acidic drainage from the old 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 natural water. Erosion from unreclaimed areas of old mines or unvegetated areas of new mines can substantially increase sediment loads in streams (Dyer and Curtis, 1977).

Few water-quality data are available for the coal-mining region of southwestern Indiana. 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 and properties 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: (1) dissolved solids, (2) suspended solids, (3) acidity, (4) pH, (5) total and dissolved iron, and (6) 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 affect water adversely in several ways: (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 sediment loads in streams can adversely affect the biological communities in streams; and (6) sediment loads deplete the storage capacity of reservoirs, reduce river-channel capacities, and may increase the frequency of flooding and the 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 water 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 the 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 mine drainage.

Uncomplexed iron in equilibrium with atmospheric oxygen is extremely insoluble. Therefore, in most water, soluble iron is a complexed 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 (Hem, 1970, p. 129).

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. The iron and manganese concentration limits recommended for drinking water by the U.S. 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 to water, detectable by some persons at concentrations 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.

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

Water-quality data collected by the Geological Survey, U.S. Army Corps of Engineers, 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 stations in or near the study area 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 analyses. Water-quality constituents and properties for which data were retrieved include total and dissolved iron, total and dissolved manganese, sulfate, alkalinity, specific conductance, and pH. The average value for each constituent and property 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 averages and medians were used for regional comparisons. The median of the station averages were 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 the 10th percentile; values from the 10th through the 25th percentiles, from the 26th through the 50th percentiles, from the 51st through the 75th percentiles, from the 76th through the 90th percentiles; and values 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 analyses are located on the adjoining map (fig. 4.1.2). Latitude and longitude of all stations having data stored in WATSTORE and STORET, the county where each station is located, the agency responsible for sample collection, and the number of observations for each water-quality constituent measured are listed in Appendix 2. The station identification number listed in the table and shown on the map is a numerical 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 table apply only 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.)

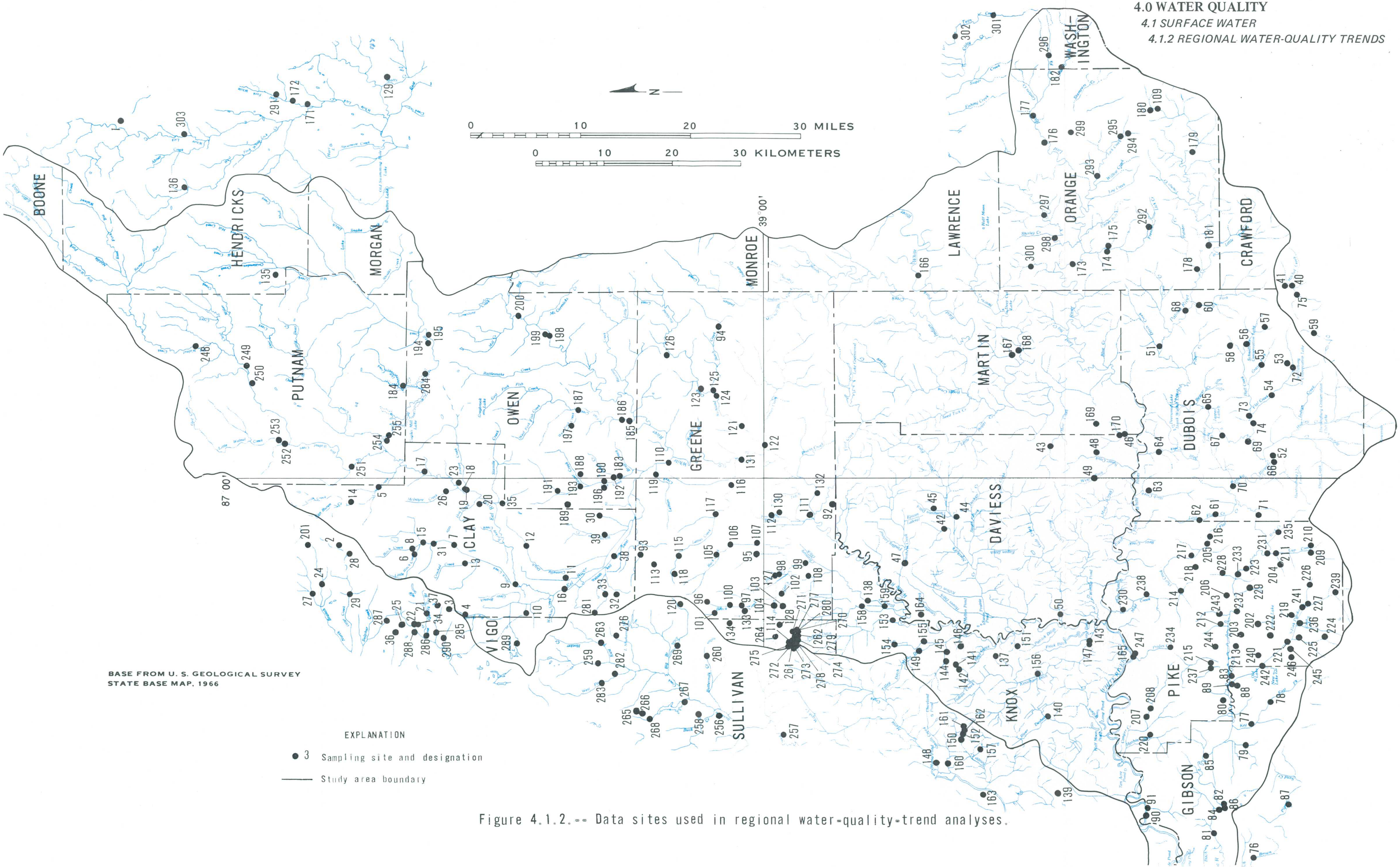


Figure 4.1.2.-- Data sites used in regional water-quality-trend analyses.

REGIONAL WATER-QUALITY TRENDS IN pH

The median pH of the medians at 293 stations in or near Area 32 was 7.4, and the range in median pH was from 2.4 to 8.9.

Values of pH were generally less than 7.4 in the southwest part of the study area, principally in Greene, Knox, and Pike Counties, where mining has been concentrated. No other trends in pH were apparent. Surface waters in the west part of the study area are primarily representative of the glaciated Wabash Lowland physiographic unit. Surface water in the east part of the study area is primarily representative of the unglaciated Crawford Upland physiographic unit. Surface-mining activity in the southwest area, before present-day reclamation techniques were instituted, may be the cause of the pH less than 6. Hydrogen ions formed by exposure and oxidation of pyrite and marcasite may lower the pH of surface water (Hem, 1970, p. 162). The median pH at the 293 sites sampled was grouped into six ranges by percentile and are presented in figure 4.1.2.1.

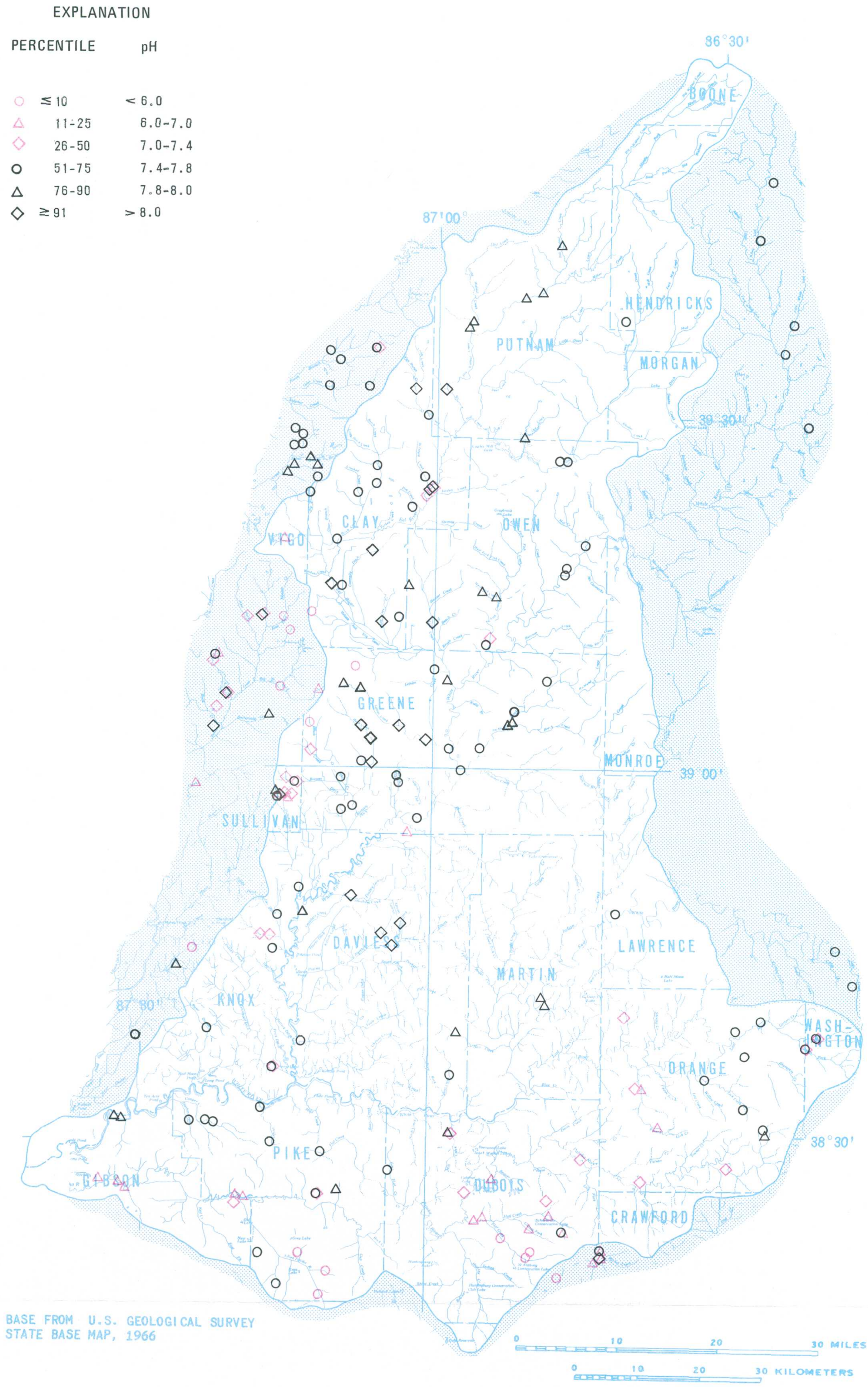


Figure 4.1.2.1.-- Ranges of median pH values.

REGIONAL WATER-QUALITY TRENDS IN ALKALINITY CONCENTRATION

The median of average alkalinity for samples from 153 stations in or near the study Area 32 was 143 mg/L as calcium carbonate. The average alkalinity ranged from 0 to 468 mg/L.

Alkalinity of surface water was generally lower in the west part of the study area than in the east. Like pH, the alkalinity is probably affected by the amount and the extent of surface mining as well as the surficial and bedrock geology of the region. The average alkalinity of water samples was grouped into six ranges by percentile, which are presented in figure 4.1.2.2.

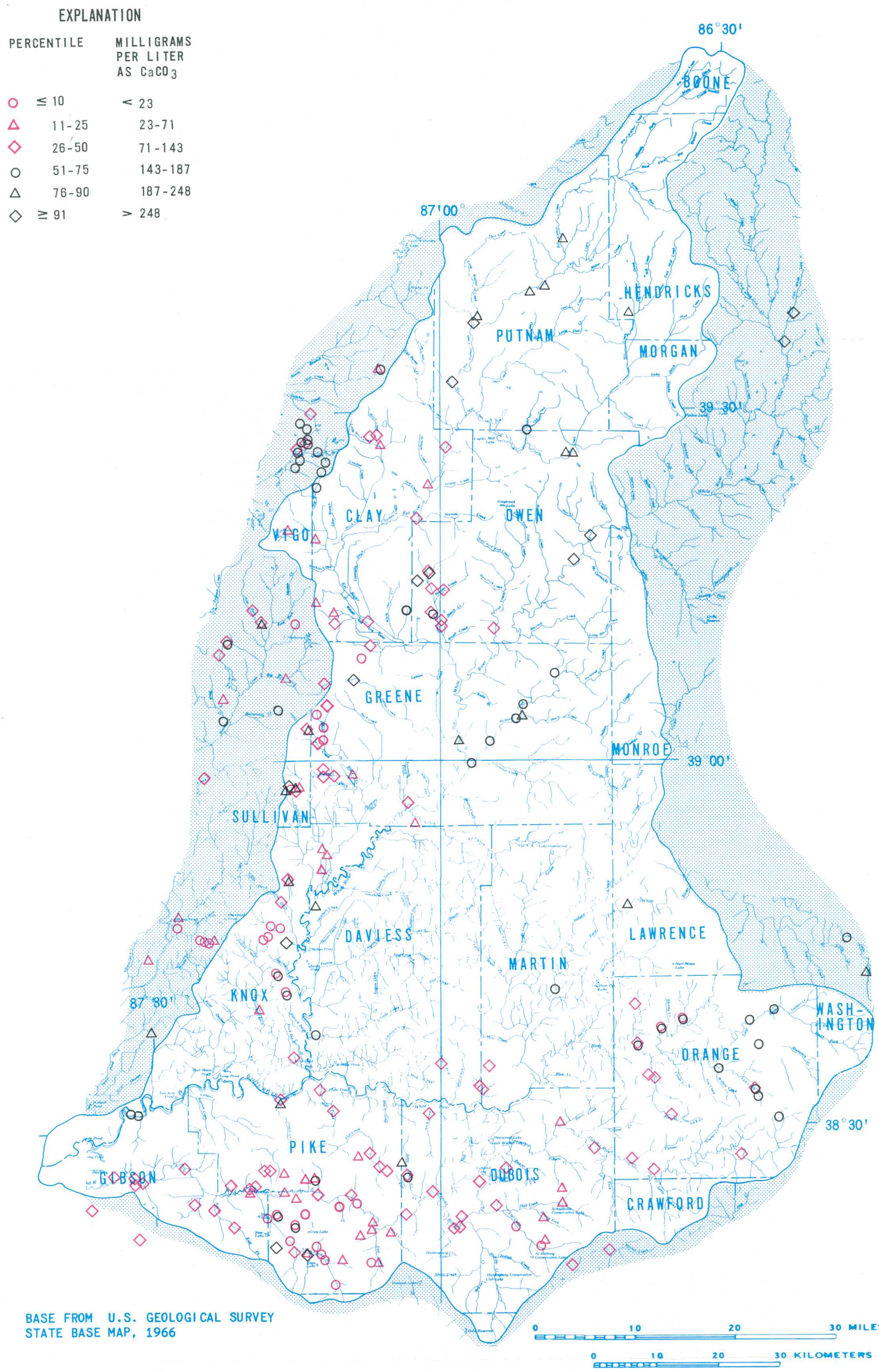


Figure 4.1.2.2.-- Ranges of average alkalinity concentrations.

REGIONAL WATER-QUALITY TRENDS IN SPECIFIC CONDUCTANCE

The median of average specific conductance for samples from 286 stations in or near Area 32 was 615 µmhos/cm at 25° C. Average specific conductance ranged from 39.5 to 8,960 µmhos/cm at 25° C.

More coal has been mined in the west half of Area 32 than in the east half. Surface water in the west half of the study area is representative of the Wabash Lowland physiographic unit. Average specific conductance was generally higher in the west half of the study area than in the east half. Both the amount and the extent of surface mining, as well as the surficial and the bedrock geology of the region, seemed to affect specific conductance. Also, the dissolved-solids concentration is higher in the west half than in the east half, probably because the water in the west half contacts glacial overburden, which has a higher content of carbonate mineral species than the sandstone and the shale of the Crawford Upland in the east half. Concentrations of most major dissolved constituents are higher in both old and new mining areas than in areas unaffected by mining. The higher concentrations 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 surficial deposits, bedrock, and surface mining activity cannot be determined. The average specific conductance for stations within the study area was grouped into six ranges by percentile, which are presented in figure 4.1.2.3.

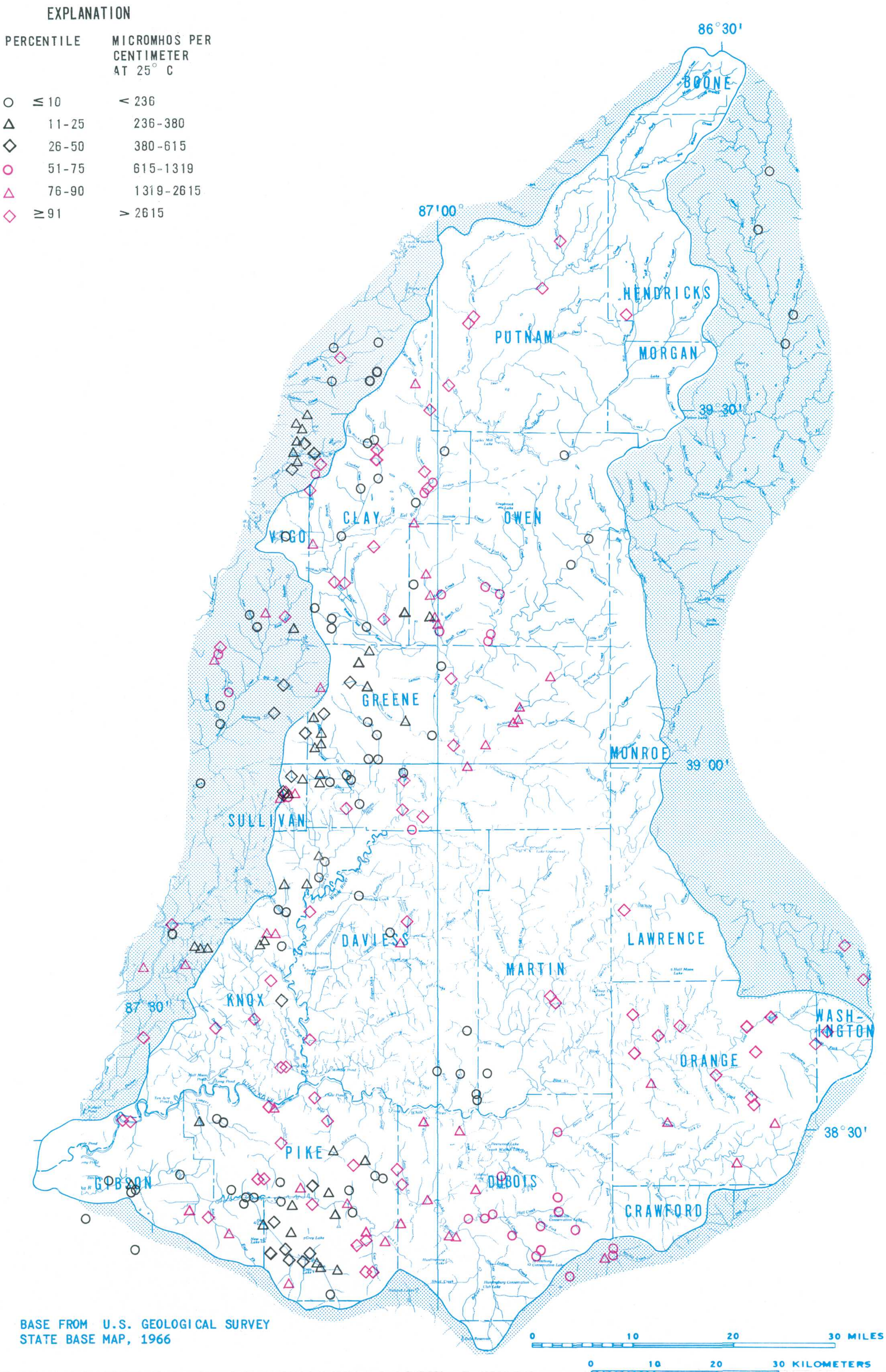


Figure 4.1.2.3.-- Ranges of average specific conductance.

REGIONAL WATER-QUALITY TRENDS IN SULFATE CONCENTRATION

The median of average sulfate concentration for 145 stations sampled in or near Area 32 was 65 mg/L. The average sulfate concentration ranged from 2.4 to 6,230 mg/L.

Average sulfate concentration of surface water was higher in the west half of Area 32 than in the east half. Considerably more coal has been mined in the west half than in the east half. The higher sulfate concentrations in the west half of the study area may be the result of leaching of oxidized pyrite and marcasite as a consequence of mining. During the oxidation, sulfate is produced (Hem, 1970, p. 124 and 162). The average sulfate concentration for stations within the study area was grouped into six ranges by percentile, which are presented in figure. 4.1.2.4.

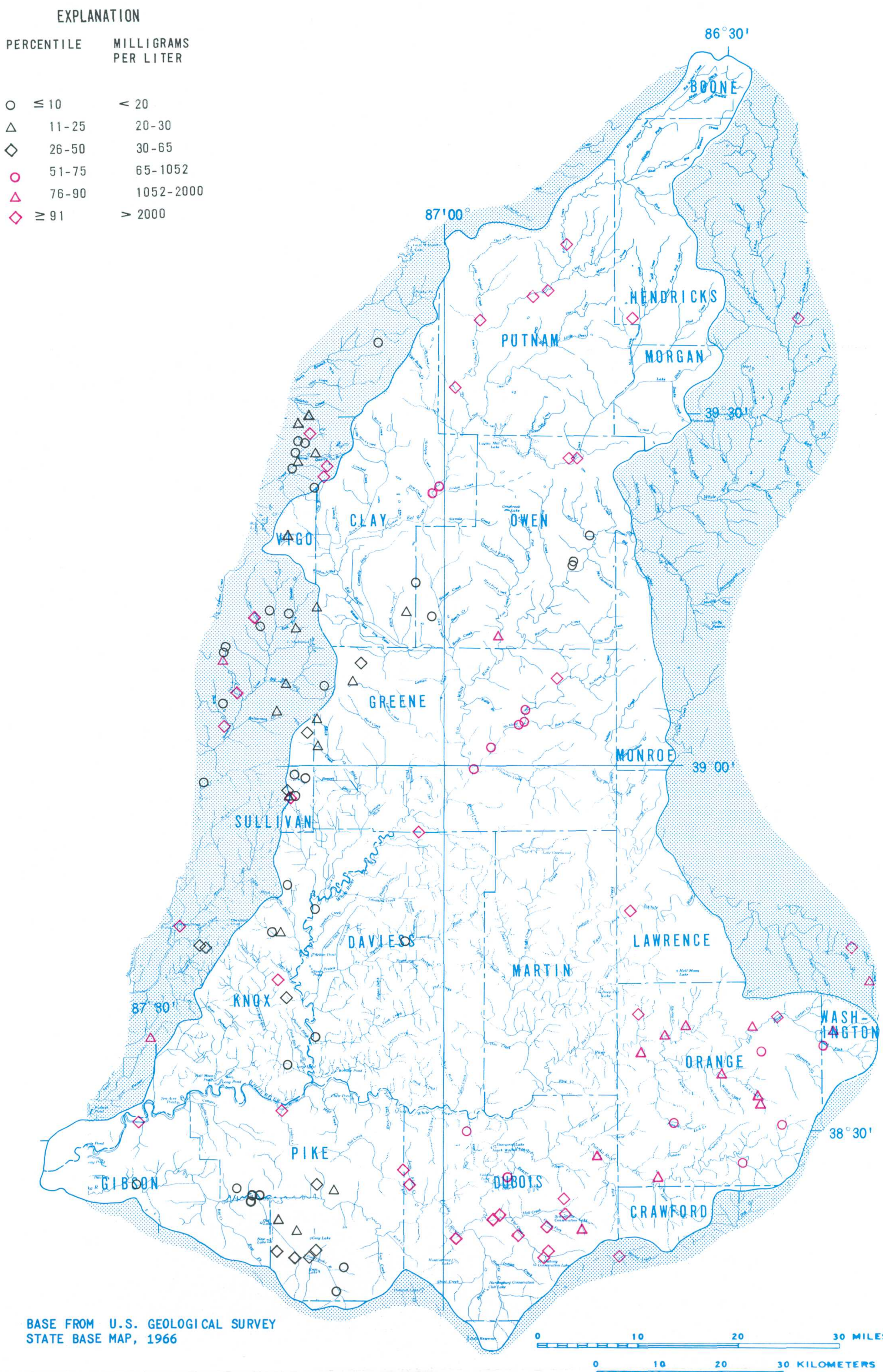


Figure 4.1.2.4.-- Ranges of average sulfate concentrations.

REGIONAL WATER-QUALITY TRENDS IN TOTAL- AND DISSOLVED-IRON CONCENTRATIONS

The median of average total iron concentration for samples from 100 stations in or near Area 32 was 1.3 mg/L. The average total-iron concentration ranged from 0.03 to 2,300 mg/L. The median of average dissolved-iron concentration for samples from 120 stations in or near the study area was 0.07 mg/L. The average dissolved-iron concentration ranged from 0.01 to 255 mg/L.

Concentrations of total and dissolved iron were generally higher in the west half of Area 32 than in the east half, although data for dissolved iron were variable. This variability may be due to greater surface-mining activity in the west half. Concentration of iron in surface water has been increasing in both reclaimed and unreclaimed mining areas, probably because the water has been exposed to increasing amounts of weathered pyritic and marcasitic material. Average total- and dissolved-iron concentrations were grouped into six ranges by percentile, which are presented in figures 4.1.2.5a and b.

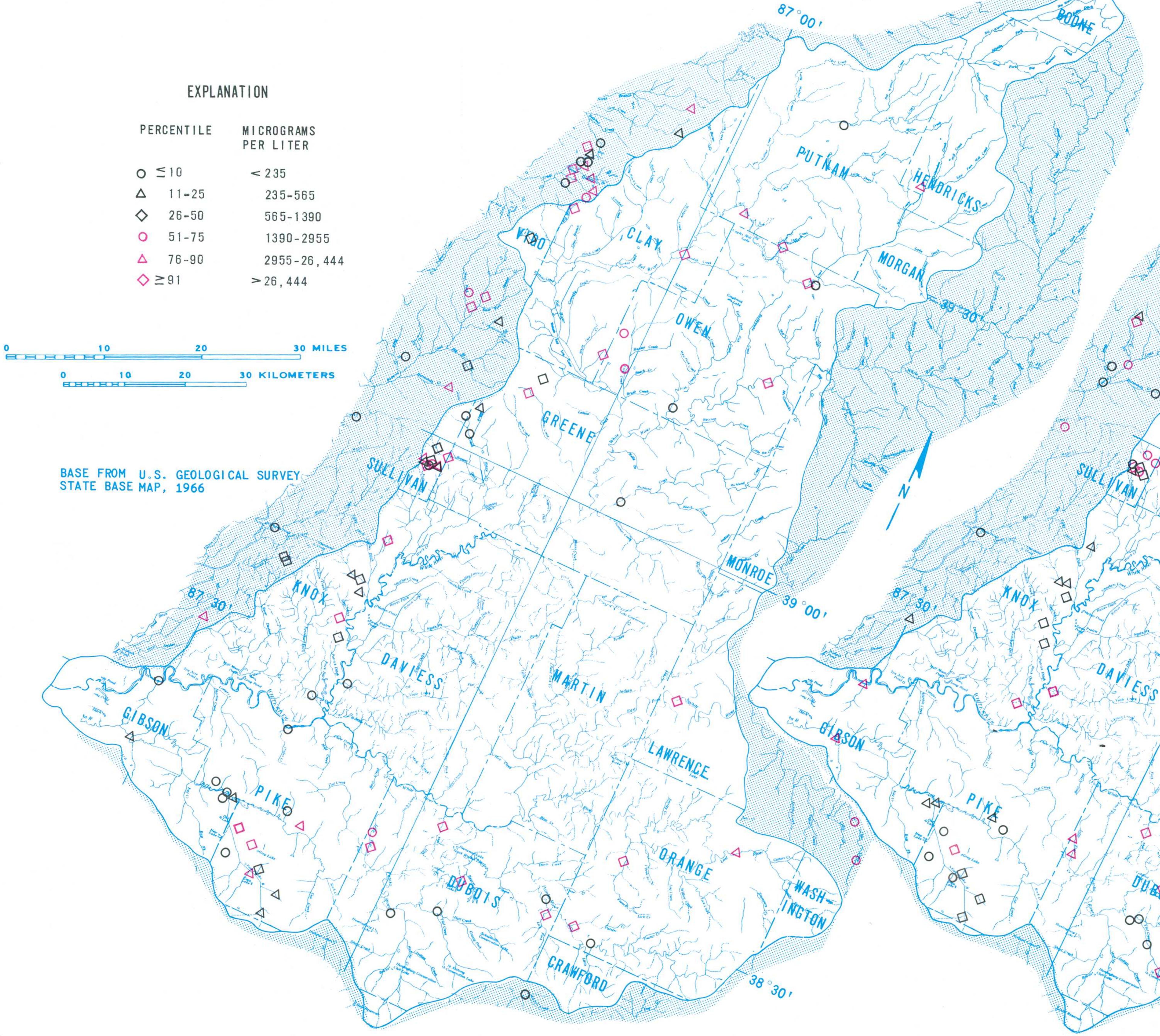


Figure 4.1.2.5a.-- Ranges of average total-iron concentrations.

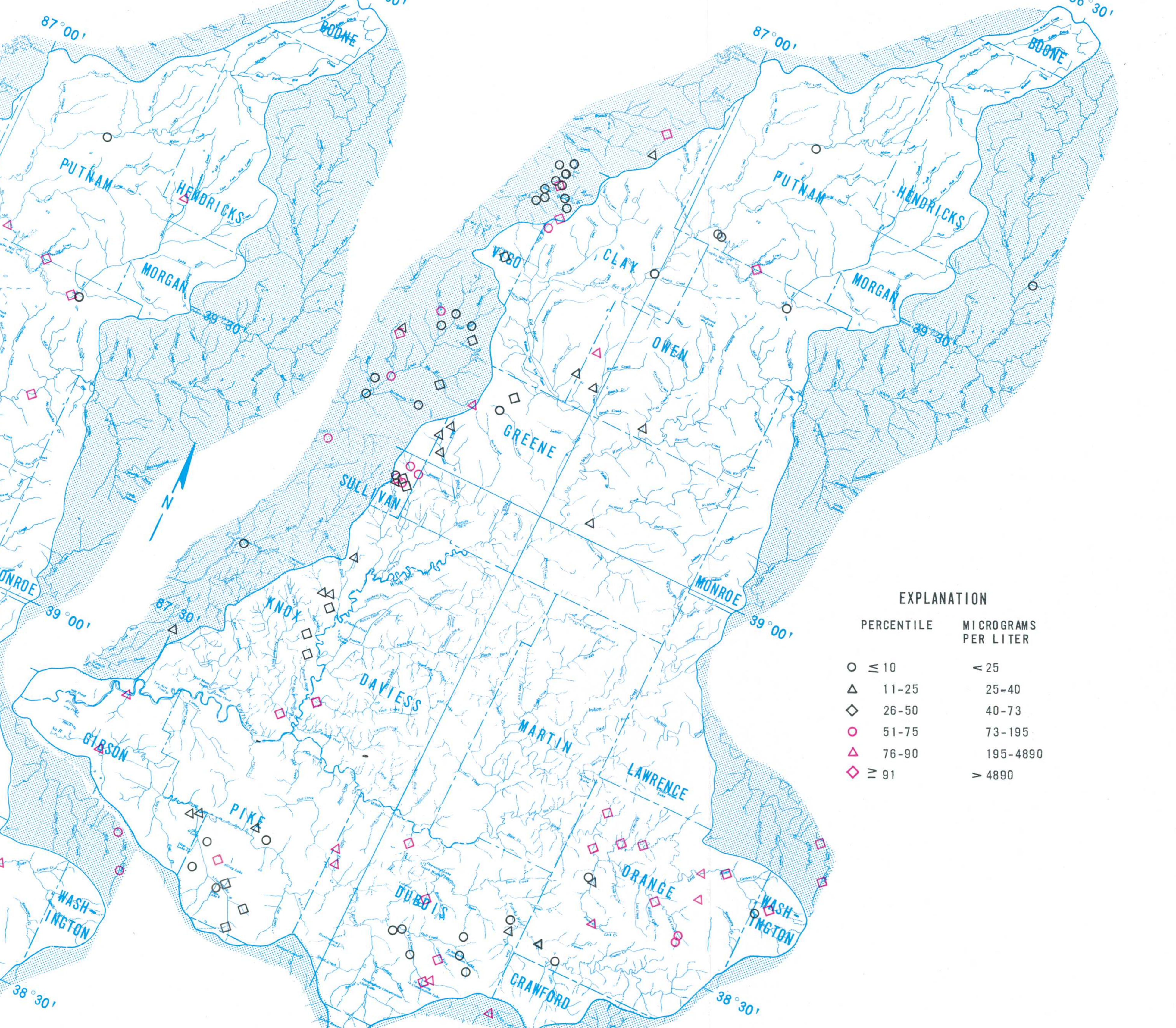


Figure 4.1.2.5b.-- Ranges of average dissolved-iron concentrations.

REGIONAL WATER-QUALITY TRENDS IN TOTAL- AND DISSOLVED-MANGANESE CONCENTRATIONS

The median of average total-manganese concentration for samples from 98 stations in or near Area 32 was 0.62 mg/L. The average total-manganese concentration ranged from 0.01 to 33 mg/L. The median of average dissolved-manganese concentration for 119 stations in or near Area 32 was 0.38 mg/L. The average dissolved-manganese concentration ranged from 0.01 to 34 mg/L.

Concentrations of total and dissolved manganese were generally higher in the west half of Area 32 than in the east half. This variability may be due to greater surface-mining activity in the west half of the study area than in the east half. The average total- and dissolved-manganese concentrations were grouped into six ranges by percentile, which are presented in figures 4.1.2.6a and b.

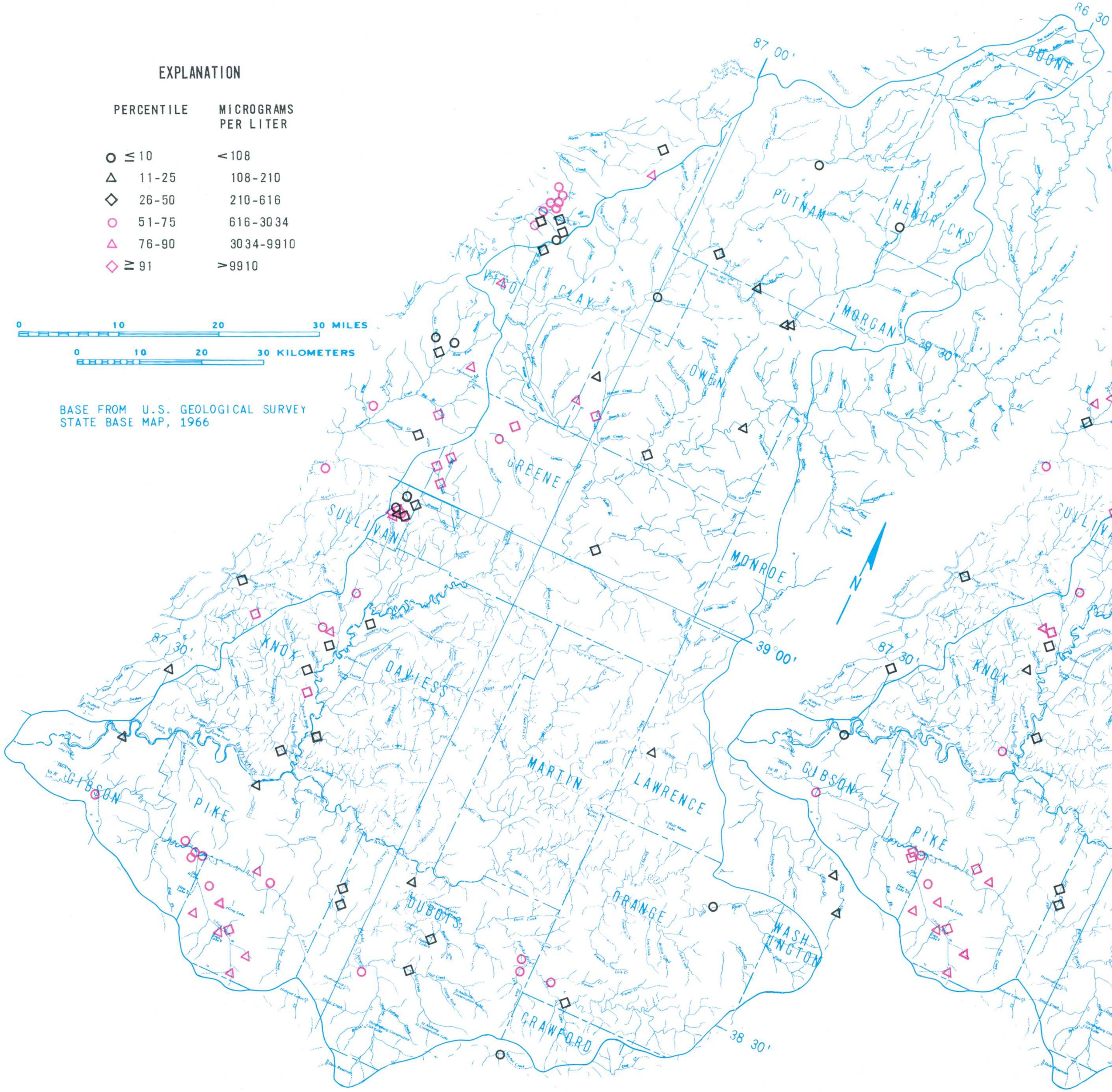


Figure 4.1.2.6a.-- Ranges of average total-manganese concentrations.

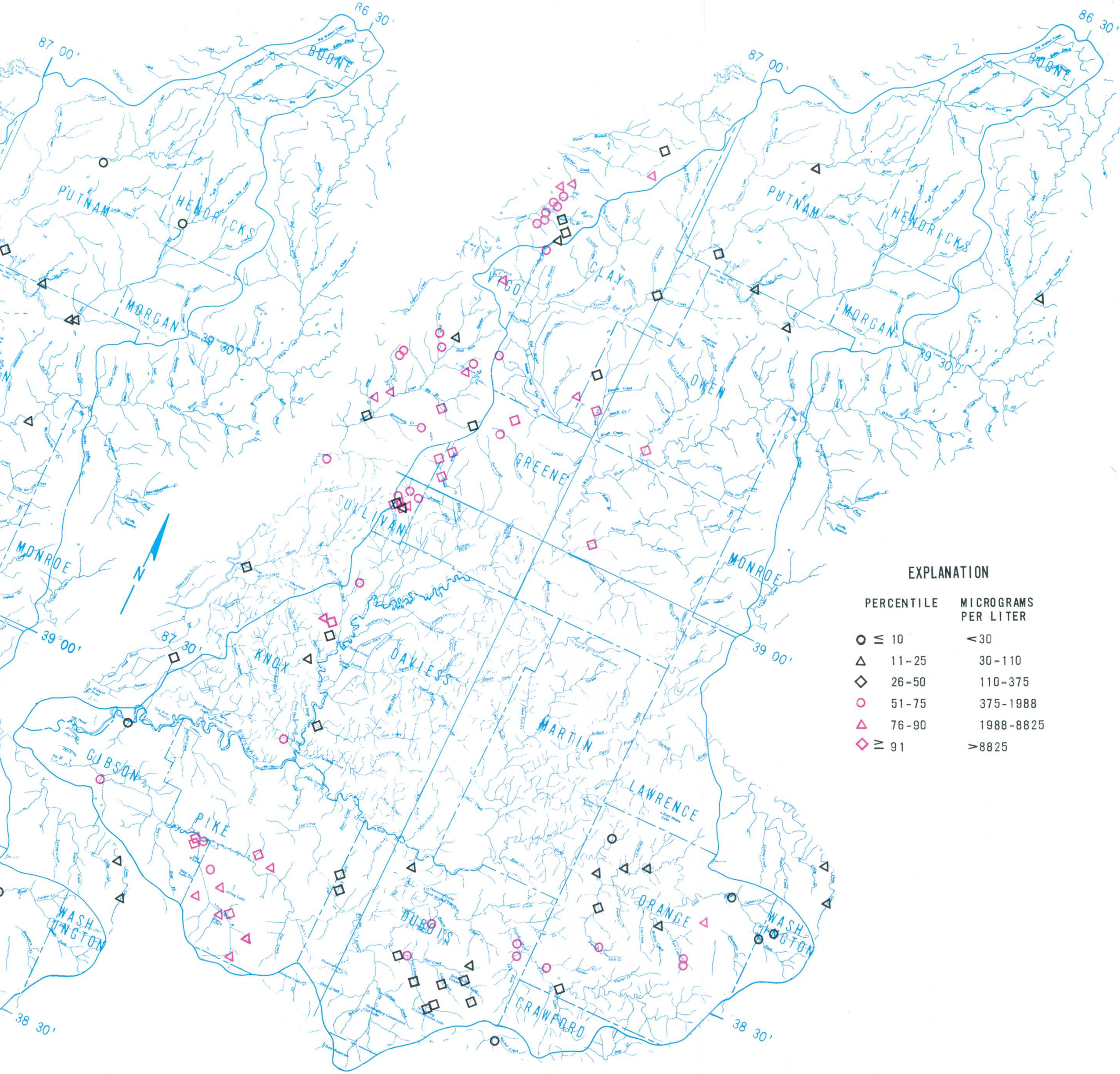


Figure 4.1.2.6b.-- Ranges of average dissolved-manganese concentrations.

SUSPENDED-SEDIMENT DATA FOR SELECTED GAGING STATIONS

Variation in suspended-sediment concentrations is probably due to geology, physiography, land use, precipitation intensities, and sampling time.

Suspended-sediment data available at five sites within Area 32 are listed in table 4.1.3, and their locations are shown on the adjoining map (fig. 4.1.3a). The relation between suspended sediment and discharge at four of the five sites is shown by the curves in the adjoining illustration (fig. 4.1.3b). Although they are not mathematical regressions, the curves show the relation of suspended-sediment concentration to discharge. Suspended-sediment data are available at the Geological Survey office in Indianapolis, Ind.

Table 4.1.3.--Suspended-sediment concentration and discharge information at selected gaging stations

Station name and number	Drainage area (mi^2)	Years of record	No. of samples	Discharge (ft^3/s)			Suspended sediment (mg/L)			Size class of suspended sediment		
				Minimum	Maximum	Median	Minimum	Maximum	Median	Sand size (percent finer than 2 mm)	Silt size (percent finer than 0.062 mm)	Clay size (percent finer than 0.004 mm)
Big Walnut Creek nr Reelsville (03357500)	326	16	58	22	6,850	245	5	1,420	78	100	81	45
Mill Creek nr Cataract (03358000)	245	11	49	6.5	6,860	295	6	1,240	80	100	83	58
Lost River nr West Baden Springs (03373700)	287	2	14	72	7,220	280	14	267	69	100	98	96
White River at Hazleton (03374100)	11,190	7	57	514	68,400	8,800	14	513	110	100	84	52
Patoka River at Princeton (03376500)	822	16	66	3.6	11,800	290	2	570	40	---	--	--

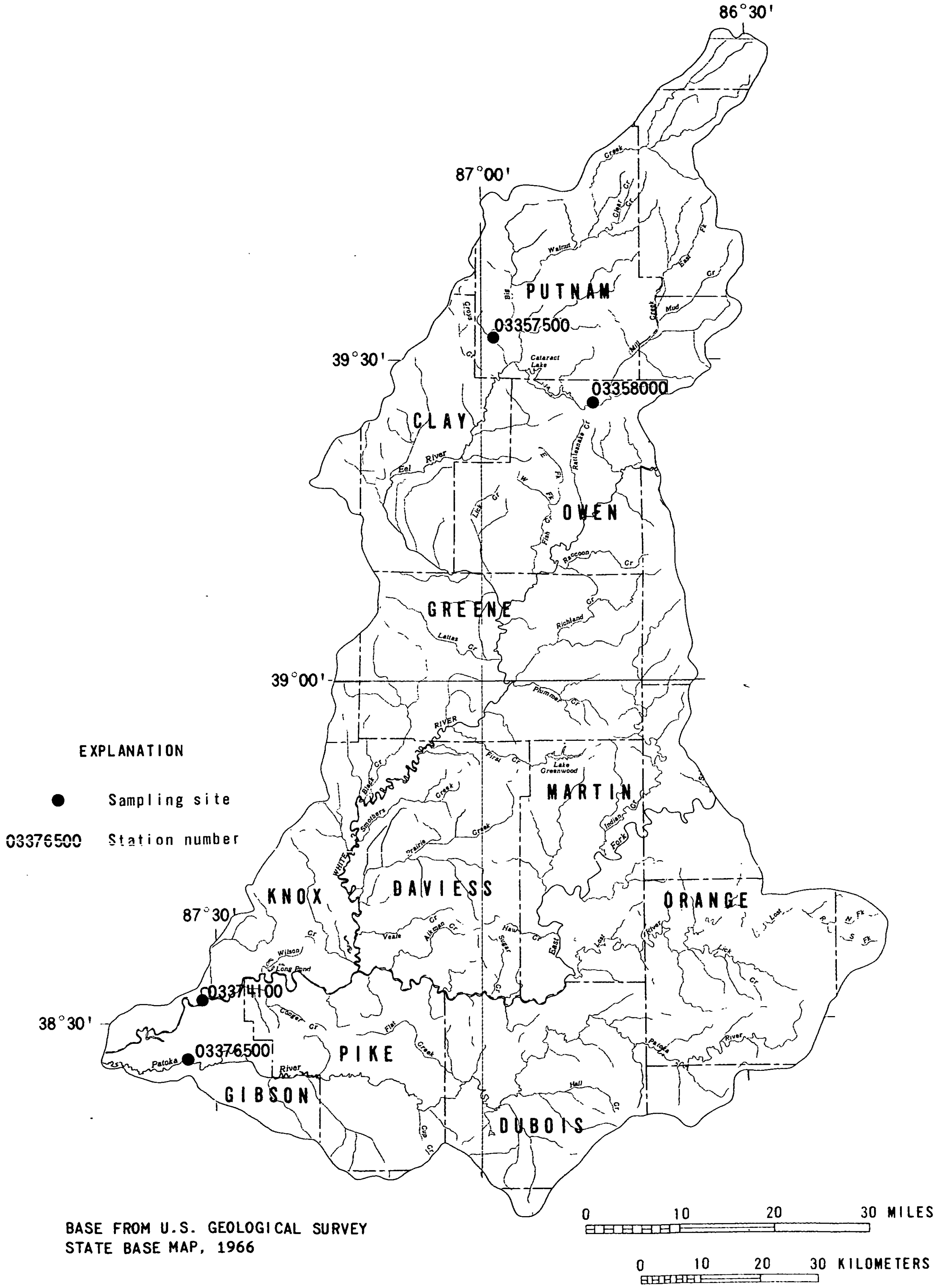


Figure 4.1.3a.-- Suspended-sediment sampling sites.

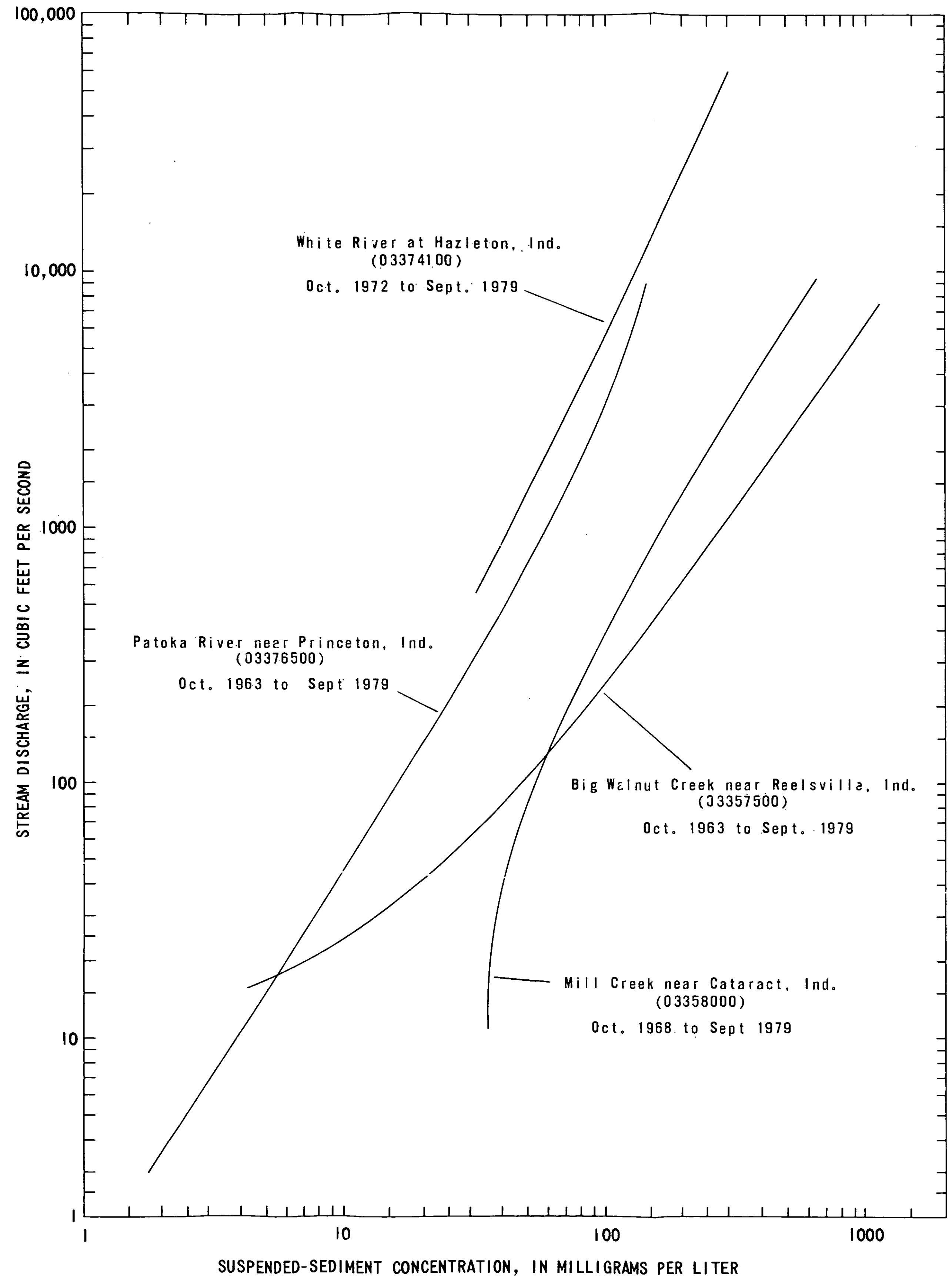


Figure 4.1.3b.-- Relation of suspended-sediment concentration to stream discharge.

GLACIAL AQUIFERS GENERALLY PRODUCE WATER OF BETTER QUALITY THAN BEDROCK AQUIFERS

In general, ground-water quality diminishes with depth in Area 32. Sulfate and manganese concentrations are higher in the bedrock aquifers than in the glacial sand and gravel aquifers, but sulfate concentration can be very high locally. Also, dissolved-solids concentration generally decreases with depth. Iron concentration is generally high throughout Area 32.

Chemical constituents in ground water are from several sources: (1) the surface materials through which water percolates, (2) minerals in the aquifer, and (3) seepage from surrounding formations (Nyman and Pettijohn, 1971, p. 7). Glacial aquifers and bedrock aquifers near their outcrop areas usually produce water of good quality. Deep bedrock aquifers that are confined by impervious layers usually produce poor-quality and sometimes non-potable water (Harrell, 1935, p. 75-76). According to Nyman and Pettijohn (1971, p. 7), "Wells deeper than 300 ft (in the Wabash River basin) generally yield mineralized or saline water."

The ground-water-quality parameters considered in this section are pH and concentrations of dissolved solids, total iron, total manganese, and sulfate. For convenience, the concentrations presented are compared to the National Secondary Drinking Water Standards of the U.S. Environmental Protection Agency (1979) drinking water standards as a point of reference.

A pH of less than 6.5 can contribute to the corrosive potential of the water, and values greater than 8.5 can give the water a bitter taste or cause encrustation of pipes (U.S. Environmental Protection Agency, 1979, p. 42201). The median pH's in the glacial and bedrock aquifers are 7.2 and 7.6, respectively (fig. 4.2a). Dissolved-solids concentrations greater than 500 mg/L may cause excessive hardness, mineral deposition, corrosion, and adverse taste (U.S. Environmental Protection Agency, 1979, p. 42201). The median dissolved-solids concentration in glacial (sand and gravel) aquifers is 316 mg/L and in bedrock aquifers is 391 mg/L (fig. 4.2a). However, the dissolved-solids concentration generally increases with depth as shown in figure 4.2b. Iron and manganese concentrations greater than 0.3 and 0.05 mg/L, respectively, cause taste and staining problems (National Academy of Sciences and the National Academy of Engineering 1972 [1974], p. 69 and 71). The median total-iron concentrations of water in bedrock and glacial aquifers are 0.5 mg/L, and the median total-manganese concentration of water in the bedrock is 0.02 mg/L. Sulfate concentrations greater than 250 mg/L cause adverse taste and laxative effects, but consumers can adjust to these concentrations (U.S. Environmental Protection Agency, 1979). The median-sulfate concentration in glacial aquifers is 22 mg/L and in bedrock aquifers is 20 mg/L.

The adjacent bar graphs (fig. 4.2a) show the medians and ranges of concentrations for constituents and properties of the water from glacial and combined bedrock aquifers. Although the data sources are not equally distributed areally, the generalized graphs are representative of the water-quality range in the study area. Additional water-quality data from wells in the study area have been processed into the National Water Data Storage and Retrieval System by latitude and longitude and are available at the Indiana District Office of the Geological Survey, Indianapolis, Ind. However, for most samples, the aquifer has not been identified, and the information is of limited use.

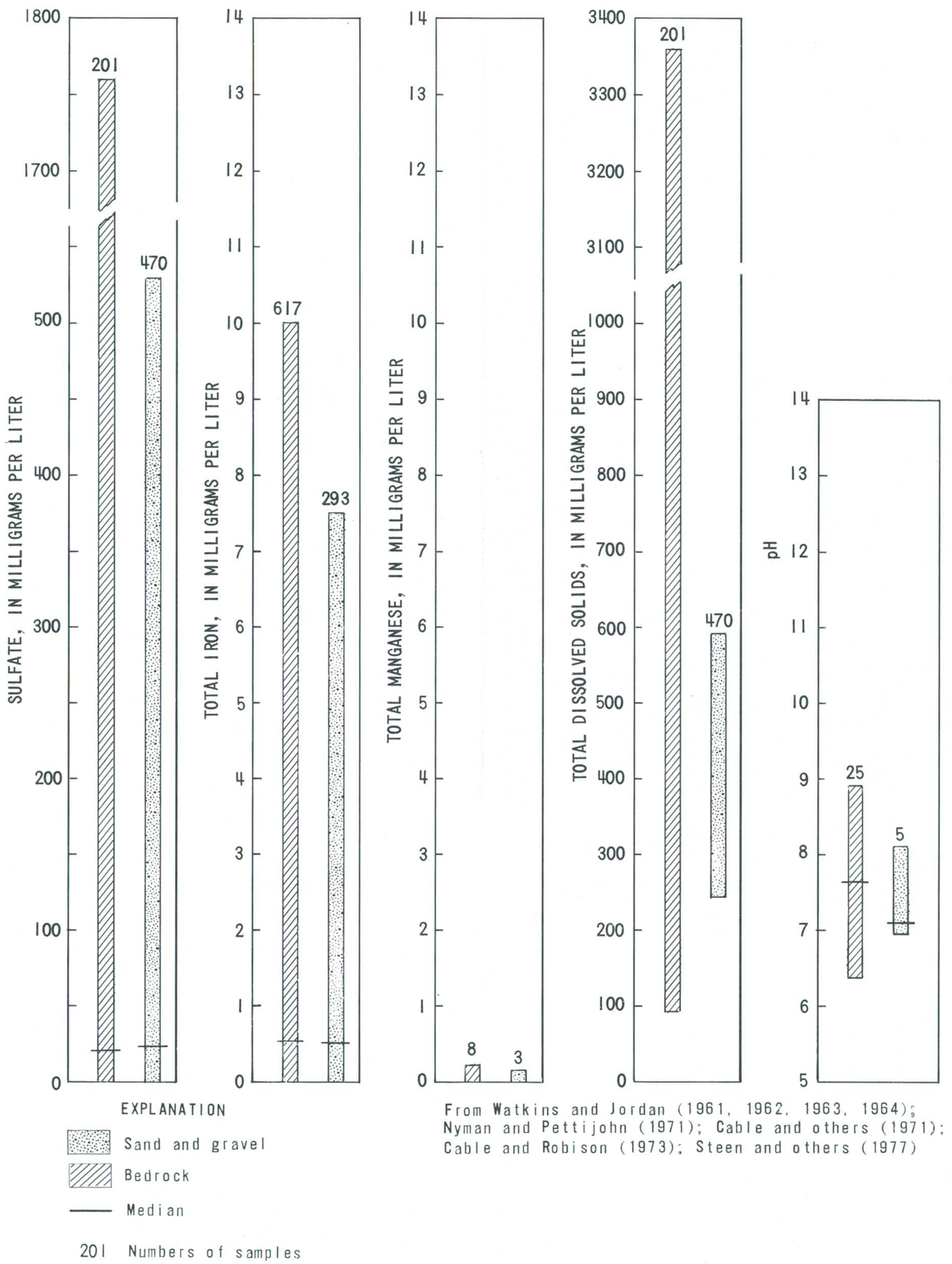


Figure 4.2a.-- Median concentrations and ranges in concentration of selected ground-water-quality parameters.

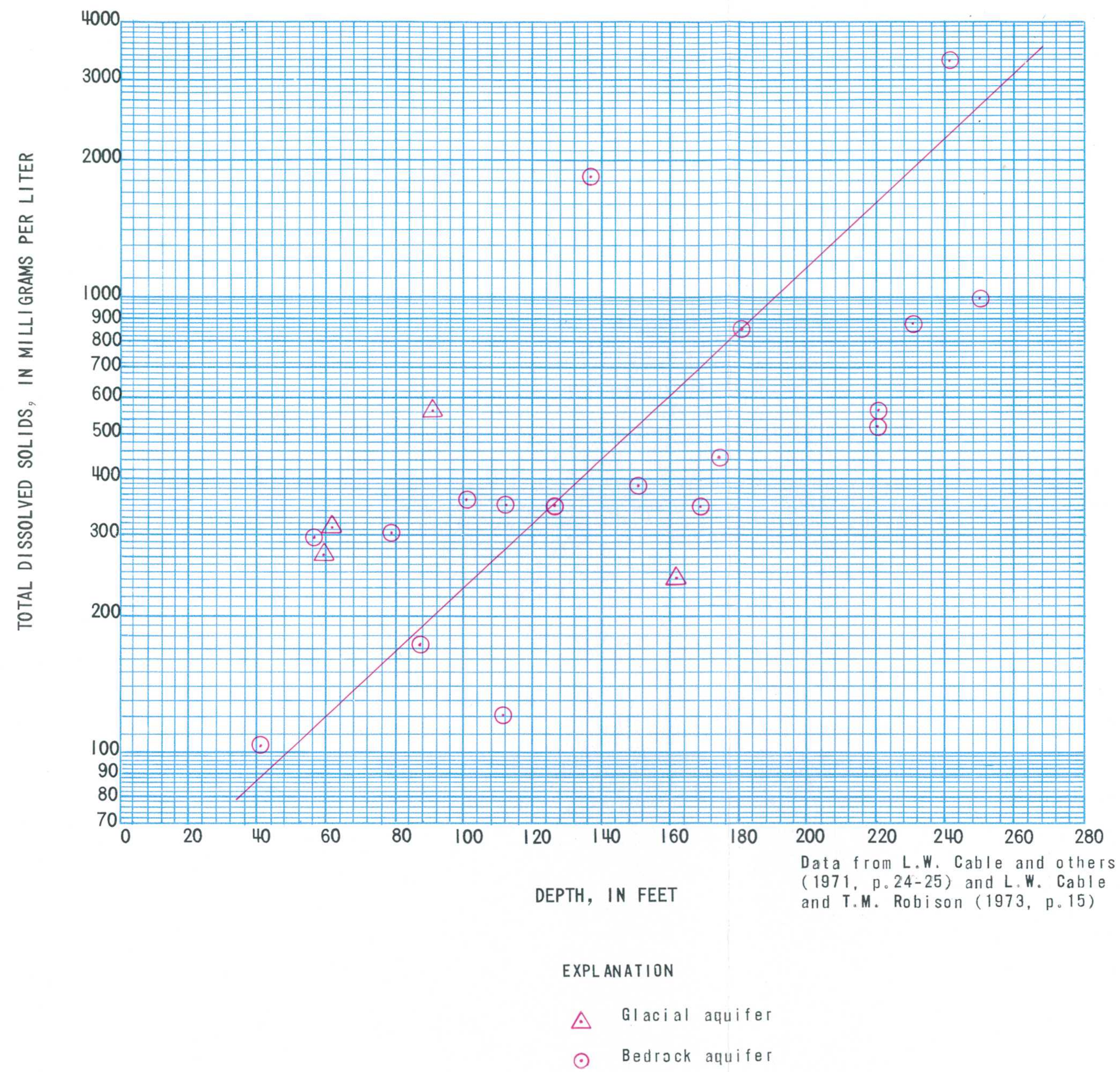


Figure 4.2b.-- Relation of dissolved-solids concentration to depth in Clay and Greene Counties, Ind.

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 Retrie-vaL 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 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 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 readily accessible and to facilitate an 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 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 time, extensive personnel time, duplicating services, or other costs to NAWDEX in 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 on 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

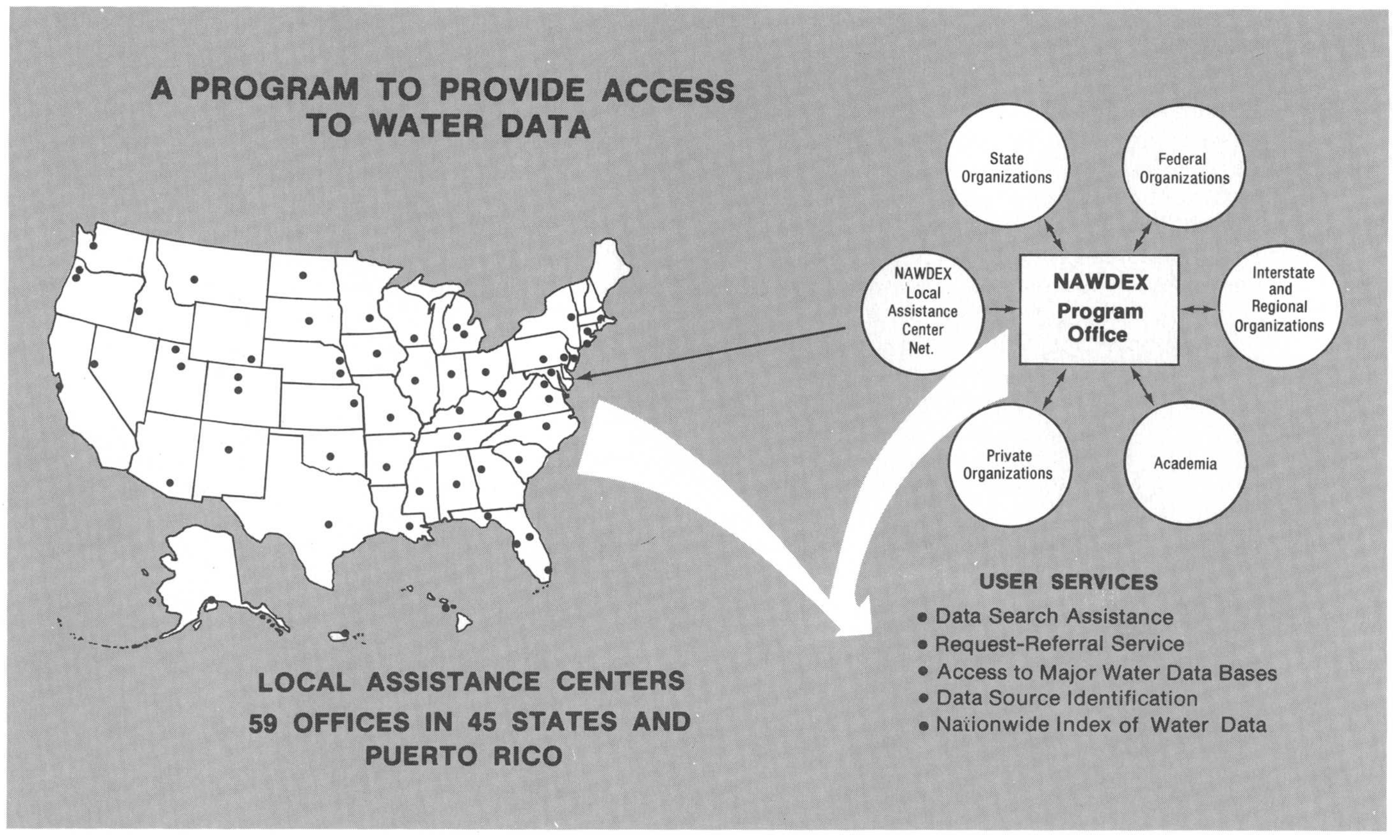


Figure 5.2-1 Access to water data

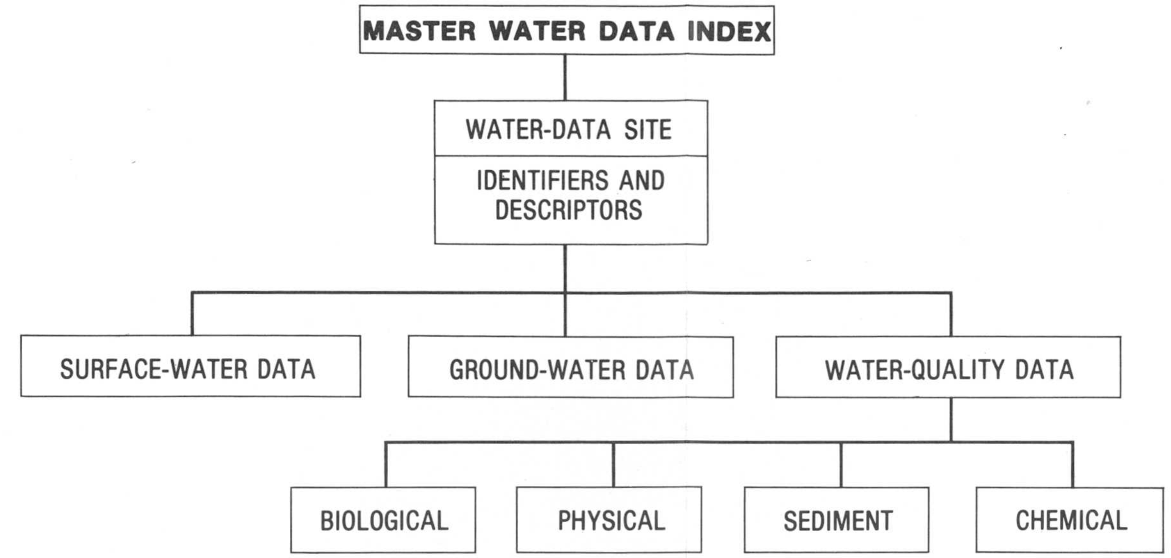


Figure 5.2-2 Master water-data index

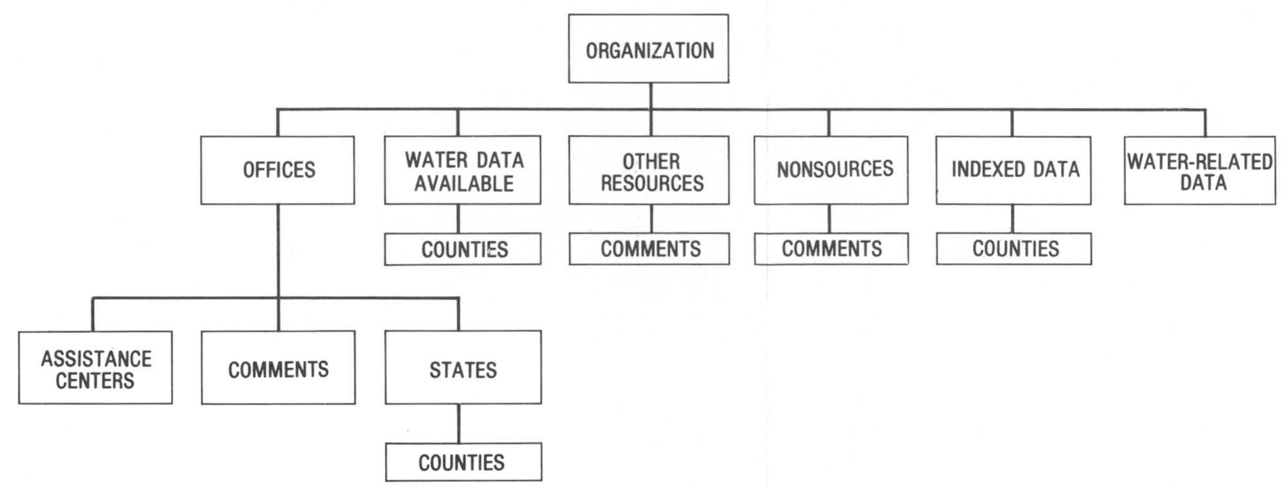


Figure 5.2-3 Water-data sources directory

WATSTORE AUTOMATED DATA SYSTEM

The National Water-Data Storage and Retrieval System (WATSTORE) of the Geological Survey provides computerized procedures and 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 Survey at its National Center in Reston, Va. Data may be obtained from WATSTORE through 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 (1980) collects data at approximately 16,000 stream-gaging stations, 1,000 lakes and reservoirs, 5,200 surface-water-quality stations, 1,020 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 DailyValues, 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 more than 400,000 peak measurements.

Water-Quality File: Analyses of more than 1.4 million water samples in this file indicate 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 File and the Daily-Values File. The file contains inventory data on wells and springs. Examples of data are site location, site identification, geohydrologic characteristics, well-construction history, and one-time 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 real-time 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 (1980).

Central-Laboratory System: The two water-quality laboratories of the Water Resources Division, in Denver, Colo., and Atlanta, Ga., analyze more than 150,000 water samples per year. These laboratories are equipped to determine concentrations of dissolved constituents ranging from simple inorganic compounds, such as chlorides, 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 storing 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 to produce 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 statistical package (SAS) to provide extensive analyses of data such as regression analysis, analysis of variance, transformations, and correlations.

Digital Plotting: WATSTORE also uses 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 points, 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.

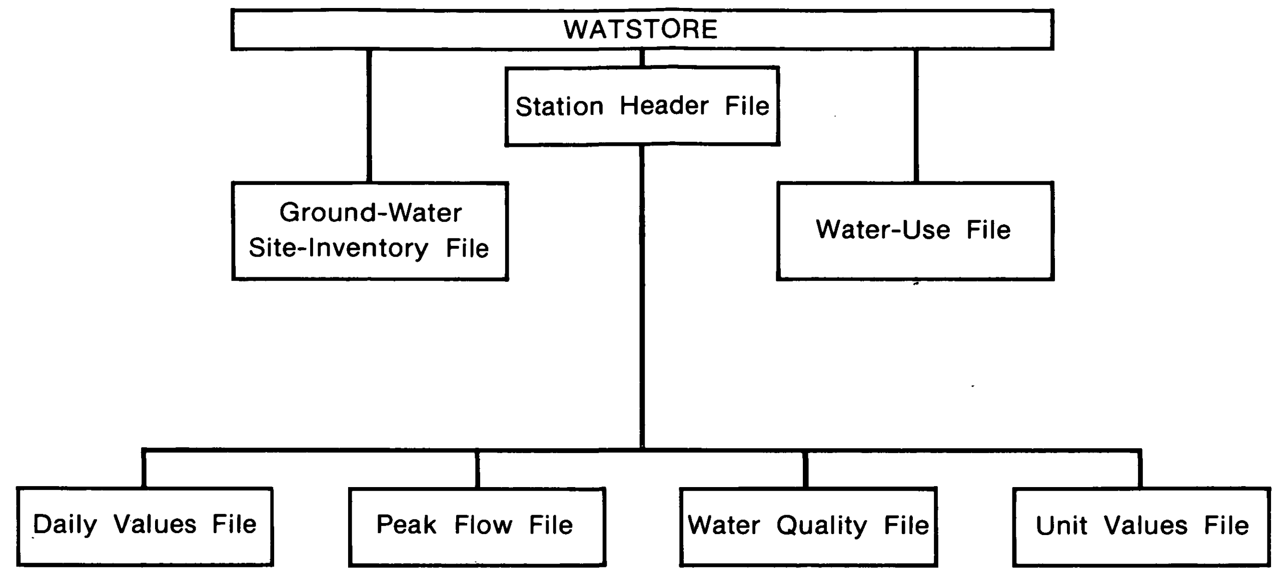


Figure 5.3-1 Files of stored data.

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 does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available. 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. These volumes 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, Stream-flow 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 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

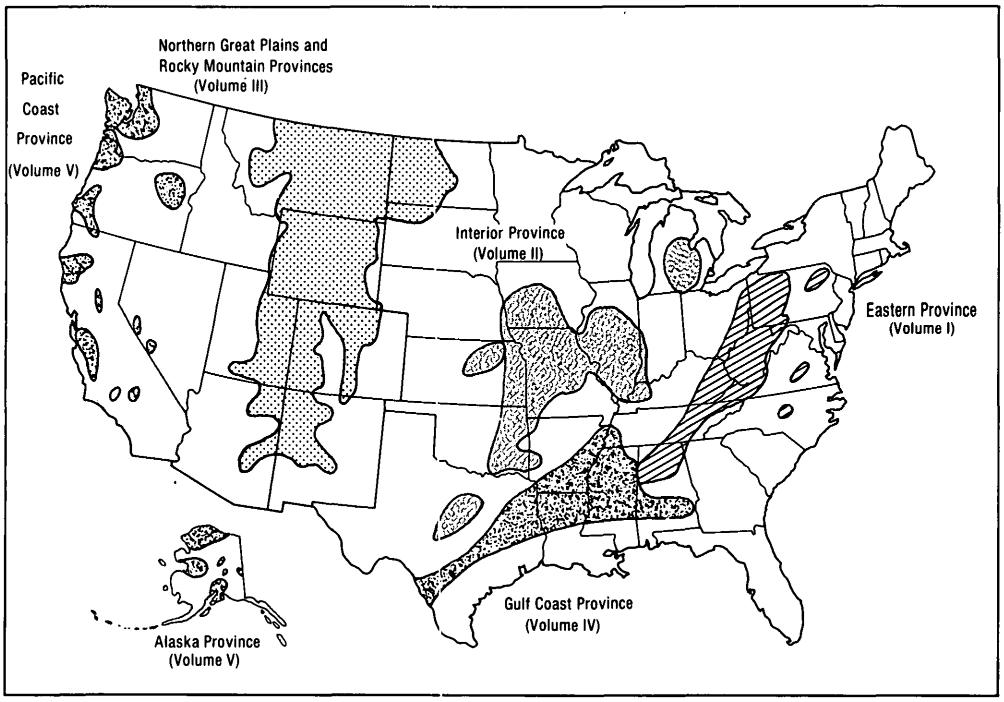


Figure 5.4-1 Index volumes and related provinces

6.0 REFERENCES

6.1 References Cited

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Appendix 1. Description of soil associations.

[Source: U.S. Soil Conservation Service (1977b)]

Soil association		Soil description			Normal slope range (percent)	Remarks
Symbol	Major soil series	Surface horizons	Subsoils	Drainage		
A1	Genesee	Light-colored loam.	Light-colored loam with sand below 40 inches.	Well drained.	0-2	Parent materials are calcareous loamy alluvium, found on wide flood plains of streams originating in glacial deposits of Wisconsin age. Fox soils are associated.
	Eel	do.	do.	Moderately well drained.	0-2	
	Shoals	do.	do.	Poorly drained.	0-2	
A2	Fox	Light-colored, sandy loam, loam, or silt loam.	Clay loam, and sandy, clay loam with sandy and gravelly calcareous lower layers.	Well drained.	0-6	Fox and terraces are formed from loamy outwash over stratified calcareous sand and gravel of Wisconsin age. Genesee and Eel formed from recent loamy alluvial deposits on flood plains. Minor soil types are Mahalasville and Westland.
	Genesee	Light-colored or brownish loam.	Light colored or brownish loam with sand below 40 inches.	do.	0-2	
	Eel	do.	do.	Moderately well drained.	0-2	
A3	Sloan	Dark, silty clay loam.	Silty, clay loam and clay loam.	Poorly drained.	0-2	Parent materials are alluvial and lacustrine deposits. Sloan and Ross on flood plain, Vincennes on low terraces. Minor soil types are Bartle and Fox.
	Ross	Dark loam.	Loam.	Well drained.	0-2	
	Vincennes	Light-colored loam.	Clay loam.	Poorly drained.	0-2	
	Zipp	Light-colored, silty clay or silty, clay loam.	Silty clay or silty, clay loam.	do.	0-2	
A4	Stendal	Light-colored, silty loam.	Silty loam or silty, clay loam.	Poorly drained.	0-2	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.	0-2	
	Wakeland	do.	do.	Poorly drained.	0-2	
	Nolin	do.	do.	Well drained.	0-2	
C3	Lyles	Dark-colored, fine sandy loam.	Sandy, clay loam.	Very poorly drained.	0-2	Parental material is calcareous outwash sand and eolian fine sand deposited in Wisconsin time. Found on level terraces with high water table. Minor soils are Bloomfield, Kings, and Vincennes.
	Ayrshire	Light-colored, fine sandy loam.	do.	Somewhat poorly drained.	0-2	
	Princeton	Fine sandy loam.	do.	Well drained.	0-12	
D2	Patton	Dark-colored, silty clay loam.	Silty, clay loam.	Very poorly drained.	0-2	Parent materials are stratified silty lacustrine deposits and sandy outwash or eolian deposits found on nearly level lacustrine plains. Minor soils are Shoals and Wakeland.
	Lyles	Dark-colored, fine, sandy loam.	Sandy, clay loam.	do.	0-2	
	Henshaw	Light-colored, silt loam.	Silty, clay loam.	Somewhat poorly drained.	0-2	
D3	Zipp	Light-colored, silty clay.	Silty clay.	Very poorly drained.	0-2	Zipp and 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.	do.	Well drained.	2-12	
	McGary	do.	do.	Poorly drained.	0-2	
E5	Parke	Light-colored loess or silt loam.	Silty, clay loam.	Well drained.	2-18	Parent materials are Wisconsin loess over old reddish sandy clay loam soils. Found on remnants of terraces or outwashes of Illinoian age. Minor soil is Pike.
	Negley	Light-colored loam.	Reddish sandy clay loam.	do.	18 to >35	

Appendix 1. Description of soil associations. (Continued)

Soil association		Soil description		Drainage	Normal slope range (percent)	Remarks
Symbol	Major soil series	Surface horizons	Subsoils			
G	Princeton	Light-colored, fine sandy loam.	Sandy, clay loam.	Well drained.	0-12	Parent material is calcareous eolian sand of Wisconsin age. Found on dunes and swales along the Wabash River and its tributaries. Minor soils are Iva and Lyles.
	Bloomfield	Light-colored, loamy fine sand.	Bands of sandy loam.	do.	2-18	
	Ayrshire	Light-colored, fine sandy loam.	Sandy, clay loam.	Somewhat poorly drained.	0-2	
H	Alford	Light-colored, silty loam.	Silty, clay loam.	Well drained.	2-18	Parent material leached loess more than 5 feet thick. Found in loessial hills.
I3	Fincastle	Light-colored, silt loam.	Silty, clay loam, clay loam, and compact till at 40-60 in.	Poorly drained.	0-2	Parent material loess over loam textured glacial till. Minor soils are Russell and Xenia.
	Ragsdale	Dark-colored, silt loam or silty, clay loam.	Silty, clay loam.	Very poorly drained.	0-2	
I4	Reesville	Light-colored, silty loam.	Silty, clay loam.	Somewhat poorly drained.	0-2	Developed entirely in Wisconsin loess. Minor soils are Alford, Fincastle, and Iva.
	Ragsdale	Dark-colored, silty loam or silty, clay loam.	do.	Very poorly drained.	0-2	
I5	Iva	Light-colored, silty loam.	Silty, clay loam.	Somewhat poorly drained.	0-2	Formed on leached loess deposits from 3½ to 5 ft thick. Found on till plains.
	Vigo	do.	do.	do.	0-2	
J3	Crosby	Light-colored, silt loam.	Silty, clay loam and clay loam.	Somewhat poorly drained.	0-2	Formed in loam glacial till and drift and overlying loess. Found on glacial till plains. Minor soils are Celina and Miami.
	Brookston	Dark-colored, silt loam or silty, clay loam.	Silty, clay loam.	Very poorly drained.	0-2	
L4	Miami	Light-colored silt loam.	Clay loam over calcareous loam till.	Well drained.	2-12	Parent materials are calcareous loam glacial till and overlying loess. Found on end moraines and rolling areas near streams that direct glacial till plains. Minor soil is Hennepin.
	Crosby	do.	Silty, clay loam and clay loam.	Somewhat poorly drained.	0-2	
	Brookston	Dark-colored silt loam or silty, clay loam.	do.	Very poorly drained.	0-2	
L5	Miami	Light-colored, silt loam.	Clay loam over calcareous loam till.	Well drained.	2-12	Parent materials glacial till and loess. Found on rolling areas and steep side slopes between nearly level till-plain uplands and terraces. Minor soil is Celina.
	Hennepin	Light-colored loam.	Loam and loam till.	Well drained.	18-735	
	Crosby	Light-colored, silt loam.	Silty, clay loam and clay loam.	Somewhat poorly drained.	0-2	
L6	Miami	Light-colored silt loam.	Clay loam over calcareous loam till.	Well drained.	2-12	Parent materials loess and calcareous loam glacial till. Found on end moraines and rolling areas near streams that disect glacial till plain. Minor soil is Xenia.
	Russell	do.	do.	do.	2-12	
	Fincastle	do.	do.	Somewhat poorly drained.	0-2	
	Ragsdale	Dark-colored silt loam or silty, clay loam.	Silty clay loam.	Very poorly drained.	0-2	

Appendix 1. Description of soil associations. (Continued)

Soil association: Symbol	Soil association: Major soil series	Soil description: Surface horizons	Soil description: Subsoils	Drainage	Normal slope range (percent)	Remarks
L7	Russell	Light-colored silt loam.	Clay loam over calcareous loam till.	Well drained.	2-12	Parent materials are loess and glacial till. Found on rolling areas and steep side slopes between till-plain uplands. Minor soil is Reesville.
	Hennnepin	Light-colored loam.	Loam and loam till.	do.	18->35	
	Fincastle	Light-colored silt loam.	Clay loam over calcareous loam till.	Somewhat poorly drained.	0-2	
N1	Bartle	Light-colored, silty loam.	Silty, clay loam.	Poorly drained.	0-2	Acid, silty parent materials. Found on lacustrine plains and slack-water terraces. Minor soils are Hosmer and Robinson.
	Peoga	do.	do.	do.	0-2	
	Dubois	do.	do.	do.	0-2	
O1	Hosmer	Light-colored, silty loam.	Silty clay with fragipan.	Well drained.	2-12	Leached loess deposits usually 4-6 feet 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. Found on gently sloping unglaciated areas. Minor soil is Muskingum.
	Wellston	do.	Silty clay but lacks fragipans.	do.	12-25	
	Tilsit	do.	Silty clay with fragipans.	Moderately well drained.	2-10	
O3	Cincinnati	Light-colored silt loam.	Silty, clay loam and buried clay.	Well drained.	6-25	Parent materials are Wisconsin loess and Illinoian till or buried soils formed from Illinoian till. Found on slopes of ravines and adjacent rolling areas. Minor soils are Hickory and Iva.
	Vigo	do.	do.	Poorly drained.	0-2	
	Ava	do.	do.	Moderately well drained.	2-6	
P	Wellston	Light-colored, silty loam.	Silty, clay loam.	Well drained.	12-25	Parent materials are weathered acid Mississippian and Pennsylvanian siltstone, sandstone, and shale, which are often covered by a thin layer of loess. Found on steep slopes of unglaciated areas. Minor soils are Gilpin and Muskingum.
	Zanesville	do.	Silty, clay loam with fragipan.	do.	2-18	
	Berks	Loam and silty loam with shale.	Loam and silty loam with shale.	do.	18-35	
Q1	Crider	Light-colored silt loam.	Silty, clay loam and reddish clay.	Well drained.	2-18	Parent materials are red clayey material derived from weathered Mississippian limestone bedrock and overlying thin loess. Found on moderately sloping portions of karst plain. Minor soil is Zanesville.
	Bedford	do.	do.	Moderately well drained.	2-6	
	Lawrence	do.	Similar to above but grayer.	Somewhat poorly drained.	0-2	
Q2	Crider	Light-colored silt loam.	Silty, clay loam and reddish clay.	Well drained.	2-18	Parent materials are weathered Devonian and Mississippian limestone bedrock with thin loess cap. Found on hilly part of karst landscape. Minor soils are Baxter, Corydon, Grayford, and Haywood.
	Hagerstown	do.	Reddish clay.	do.	2-18	
	Bedford	do.	Silty, clay loam and reddish clay.	Moderately well drained.	2-6	
Q3	Crider	Light-colored silt loam.	Silty, clay loam and reddish clay.	Well drained.	2-18	Parent materials are weathered Mississippian limestone with a thin layer of loess on some soils. Found on hilly and steep parts of karst areas. Minor soil is Haymond.
	Baxter	do.	Reddish clay with chert fragments.	do.	2-18	
	Corydon	Dark-colored loam.	Clay with many stones.	do.	18->35	

Appendix 2. Number of determinations of 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	White Lick Cr at Brownsburg[1]	Hendricks	USGS	395039	0862402	1	0	1	0	0	0	0	0
2	Benwood Run nr Brazil[1]	Clay	USGS	393307	0870628	2	2	2	2	2	2	2	2
3	Big Slough nr Staunton[1]	Clay	USGS	392431	0871257	1	1	1	1	1	1	1	1
4	Big Slough nr Riley	Clay	USGS	392332	0871349	1	1	1	1	1	1	1	1
5	Billy Cr nr Clay-Putnam County Line	Clay	USGS	393005	0870051	1	0	1	0	0	0	0	0
6	Birch Cr at SR 59	Clay	USGS	392714	0870734	1	0	1	0	0	0	0	0
7	Birch Cr nr Ashboro (03360050)[2]	Clay	USGS	392413	0870641	1	0	1	0	0	0	0	0
8	Birch Cr nr Hoosierville	Clay	USGS	392737	0870705	1	0	1	0	0	0	0	0
9	Birch Cr at 55 West Road	Clay	USGS	391935	0871046	1	0	1	0	0	0	0	0
10	Birch Cr at 79 South Road	Clay	USGS	391833	0871319	1	0	1	0	0	0	0	0
11	Conneley ditch at SR 246 east of Eel R.	Clay	USGS	391549	0870912	1	0	1	0	0	0	0	0
12	Conneley ditch at SR 59	Clay	USGS	391837	0870636	1	0	1	0	0	0	0	0
13	Crooked Cr nr Cory	Clay	USGS	392314	0870843	1	0	1	0	0	0	0	0
14	Croys Cr nr Harmony	Clay	USGS	393235	0870238	1	0	1	0	0	0	0	0
15	E. Fk Birch Cr nr Prairie City	Clay	USGS	392650	0870628	1	0	1	0	0	0	0	0
16	Eel R. at SR 246	Clay	USGS	391552	0871119	1	0	1	0	0	0	0	0
17	Eel R. nr Poland	Clay	USGS	392639	0865936	1	0	1	0	0	0	0	0
18	Eel R. at Bowling Green (03360000)[2]	Clay	USGS	392302	0870113	1	0	1	0	0	0	0	0
19	Eel R. nr Bowling Green	Clay	USGS	392302	0870112	1	1	1	1	0	0	0	0
20	Hog Cr nr Bowling Green	Clay	USGS	392238	0870222	1	0	1	0	0	0	0	0
21	Trib. to Honey Cr nr Staunton[1]	Clay	USGS	392642	0871308	1	1	1	1	1	1	1	1
22	Honey Cr nr Staunton[1]	Clay	USGS	392744	0871456	9	9	9	9	9	9	8	9
23	Jordon Cr at Bowling Green	Clay	USGS	392316	0870058	2	1	2	1	1	1	1	1
24	Little Cr at ZZ North Road[1]	Clay	USGS	393446	0871049	1	0	1	0	0	0	0	0
25	Lost Cr nr Staunton[1]	Clay	USGS	392933	0871402	2	2	2	2	2	2	2	2
26	McIntyre Cr nr Center Point[1]	Clay	USGS	392453	0870118	1	0	1	0	0	0	0	0
27	N. Br Otter Cr nr Coal Bluff[1]	Clay	USGS	393522	0871156	1	0	1	0	0	0	0	0
28	Otter Cr nr Brazil[1]	Clay	USGS	393255	0870729	1	0	1	0	0	0	0	0
29	Otter Cr nr Bee Ridge[1]	Clay	USGS	393230	0871158	1	0	1	0	0	0	0	0
30	Pond Cr nr Coal City	Clay	USGS	391243	0870340	2	2	2	2	2	2	2	2
31	Prairie Cr nr Prairie City	Clay	USGS	392607	0870649	1	0	1	0	0	0	0	0
32	Runoff old canal at 129 South Road E. Buch. Cor	Clay	USGS	391140	0871104	1	0	1	0	0	0	0	0
33	Do.	Clay	USGS	391223	0871104	1	0	1	0	0	0	0	0
34	N. Br Honey Cr nr Seelyville[1]	Clay	USGS	392744	0871457	2	2	2	2	2	2	2	2
35	Six Mile Cr nr Swalley Chaple	Clay	USGS	392032	0870218	1	0	1	0	0	0	0	0
36	Trib. to Sulphur Cr nr Seelyville[1]	Clay	USGS	392828	0871445	4	4	4	4	4	4	2	4
37	Unnamed trib. nr Staunton[1]	Clay	USGS	392516	0871252	1	1	1	1	1	1	1	1
38	Wabash-Erie Canal nr Clay City	Clay	USGS	391140	0870743	1	0	1	0	0	0	0	0
39	White Oak Cr at 110 East Road, ¼ mi W. of Duncan Cem	Clay	USGS	391217	0870541	1	0	1	0	0	0	0	0
40	Anderson R. nr Birdseye[1]	Crawford	USGS	381756	0864042	1	1	1	1	1	1	1	1
41	Trib. to Anderson R. nr Birdseye[1]	Crawford	USGS	381811	0864042	1	0	1	1	0	0	0	0
42	Bethel ditch, ¼ mi SE of Bethel Church	Daviess	USGS	384542	0870500	1	0	1	0	0	0	0	0
43	Haw Cr nr Whitfield	Daviess	USGS	383720	0865633	1	0	1	0	0	0	0	0
44	Prairie Cr nr Washington (03360800)[2]	Daviess	USGS	384447	0870312	1	1	1	0	0	0	0	0
45	S. Fk Prairie Cr nr Montgomery	Daviess	USGS	384609	0870246	1	0	1	0	0	0	0	0
46	Slate Cr nr Portersville	Daviess	USGS	383103	0865529	1	0	1	0	0	0	0	0
47	Smothers Cr nr Plainville	Daviess	USGS	384848	0870830	1	0	1	0	0	0	0	0
48	Sugar Cr nr Alfordsville	Daviess	USGS	383315	0865733	1	0	1	0	0	0	0	0
49	Do.	Daviess	USGS	383314	0865933	1	0	1	0	0	0	0	0
50	Veale Cr nr Cumback	Daviess	USGS	383623	0871320	2	2	2	2	2	2	2	2
51	Dubois Cr nr Crystal	Dubois	USGS	382839	0864641	1	0	1	0	0	0	0	0
52	Ephemeral stream nr Huntingburg	Dubois	USGS	381934	0865705	1	0	1	0	0	0	0	0
53	Flat Cr nr St. Marks	Dubois	USGS	381803	0864805	2	1	1	1	0	1	0	1
54	Flat Cr nr St. Anthony	Dubois	USGS	381944	0865132	1	1	1	1	0	1	0	1
55	Grassy Fk nr St. Anthony	Dubois	USGS	382034	0864844	1	1	1	1	0	1	0	1
56	Hall Cr at Celestine	Dubois	USGS	382136	0864616	2	1	1	1	0	1	0	1
57	Hall Cr at Schnellville	Dubois	USGS	382021	0864445	1	1	1	1	0	1	0	1
58	Trib. to Hall Cr at Celestine	Dubois	USGS	382212	0864646	1	1	1	1	0	1	0	1
59	Hurricane Cr nr Birdseye[1]	Dubois	USGS	381602	0864517	1	0	1	1	0	0	0	0
60	Lick Fk Cr nr Ellsworth	Dubois	COE	382525	0864215	0	0	0	0	16	16	3	3
61	Little Flat Cr nr Otwell	Dubois	USGS	382400	0870335	2	1	2	1	1	1	1	1
62	Do.	Dubois	USGS	382520	0870406	1	1	1	1	1	1	1	1
63	Mill Cr nr Haysville	Dubois	USGS	382922	0870113	1	0	1	0	0	0	0	0
64	Mill Cr nr Jasper	Dubois	USGS	382852	0865711	2	2	2	2	2	2	2	2
65	Patoka R. at Jasper (03375500)[2]	Dubois	USGS	382449	0865236	3	3	3	3	3	3	3	3
66	Patoka R. nr Jasper	Dubois	ISBH	381945	0865802	108	71	94	0	70	0	51	0
67	Do.	Dubois	ISBH	382345	0865544	187	0	140	187	0	0	0	0
68	Patoka R. nr Ellsworth	Dubois	COE	382635	0864300	0	26	62	32	62	63	44	44
69	Patoka R. at SR 45	Dubois	USGS	382113	0865632	1	0	1	0	0	0	0	0
70	Patoka R. nr Duff	Dubois	USGS	382246	0870059	1	0	1	0	0	0	0	0
71	Patoka R. nr Millersport	Dubois	USGS	382047	0870315	1	0	1	0	0	0	0	0
72	Richland Cr nr St Marks	Dubois	USGS	381759	0864858	1	1	1	1	0	1	0	1
73	Straight R. nr Huntingburg.	Dubois	USGS	382119	0865332	2	2	2	2	2	2	2	2
74	Straight R. at Jasper	Dubois	USGS	382113	0865430	1	1	0	1	0	1	0	1
75	Trib. to Waddle Br nr Birdseye[1]	Dubois	USGS	381745	0864125	1	0	1	1	0	0	0	0
76	Brown ditch nr Owensville[1]	Gibson	USGS	382100	0873827	1	0	1	0	0	0	0	0
77	E. Fk Keg Cr nr Oatsville	Gibson	USGS	382110	0872428	1	0	1	0	0	0	0	0
78	E. Fk Keg Cr nr Oakland City	Gibson	USGS	381942	0872207	1	0	1	0	0	0	0	0
79	Lost Cr nr Francisco	Gibson	USGS	382148	0872628	1	0	1	0	0	0	0	0
80	Patoka R. nr Oakland City	Gibson	ISBH	382344	0872220	68	64	68	0	47	0	47	0
81	Patoka R. nr Princeton	Gibson	ISBH	382420	0873542	24	0	17	1	0	0	0	0
82	Do.	Gibson	ISBH	382320	0873257	340	0	271	345	0	0	0	0
83	Patoka R. nr Glezen	Gibson	USGS	382258	0871959	3	2	3	3	2	2	2	2
84	Patoka R. nr Princeton (03376500)[2]	Gibson	USGS	382330	0873255	2	2	2	2	2	2	2	2
85	Patoka R. at Wheeling	Gibson	USGS	382443	0872725	1	0	1	0	0	0	0	0
86	Patoka R. nr Princeton	Gibson	USGS	382330	0873256	1	0	1	0	0	0	0	0
87	Pigeon Cr nr Princeton	Gibson	USGS	381802	0873206	1	0	1	0	0	0	0	0
88	S. Fk Patoka R. nr Glezen	Gibson	USGS	382241	0872012	1	1	1	1	1	1	1	1
89	Do.	Gibson	USGS	382244	0872012	2	1	2	1	1	1	1	1
90	White R. nr Hazelton	Gibson	ISBH	382927	0873355	344	0	282	352	0	0	0	0
91	White R. at Hazleton (03374100)[2]	Gibson	USGS	382923	0873300	13	14	13	14	5	6	5	6
92	Addison-Ohio R.	Gibson	USGS	385449	0870239	1	1	1	1	0	0	0	0
93	Howesville ditch nr Howesville	Greene	USGS	390931	0870744	1	0	1	0	0	0	0	0
94	Beech Cr nr Solsberry	Greene	USGS	390331	0864447	0	0	0	0	0	0	0	0
95	Beehunter ditch nr Linton	Greene	USGS	390031	0870731	1	0	1	0	0	0	0	0
96	Black Cr nr Linton	Greene	USGS	390401	0871229	1	0	1	0	0	0	0	0
97	Black Cr nr Whiterose	Greene	USGS	390151	0871250	1	0	1	0	0	0	0	0
98	Black Cr nr Sponsler	Greene	USGS	385855	0870951	1	0	1	0	0	0	0	0
99	Black Cr nr Marco	Greene	USGS	385622	0870819	1	0	1	0	0	0	0	0
100	Black Cr nr Victoria	Greene	USGS	390243	0871246	1	0	1	0	0	0	0	0
101	Trib. to Black Cr nr Ellis	Greene	USGS	390348	0871336	2	2	2	2	2	2	2	2
102	Brewer ditch nr Sandborn	Greene	USGS	385803	0871110	1	0	1	0	0	0	0	0
103	Brewer ditch nr SR 59	Greene	USGS	385844	0871256	1	0	1	0	0	0	0	0
104	Brewer ditch nr Pleasantville	Greene	USGS	385902	0871348	1	0	1	0	0	0	0	0
105	Buck Cr nr Linton	Greene	USGS	390320	0870744	1	0	1	0	0	0	0	0
106	Buck Cr nr Switz City	Greene	USGS	390217	0870631	1	0	1	0	0	0	0	0

Appendix 2. Number of determinations of water-quality parameters. (Continued)

ID	Station name	County	Agency	Lat	Long	Spec. cond.	Sulfate	pH	Alkalinity	Total Fe	Diss. Fe	Total Mn	Diss. Mn
107	Do.	Greene	USGS	390033	0870632	1	0	1	0	0	0	0	0
108	Calico Slash nr Marco	Greene	USGS	385614	0870946	1	0	1	0	0	0	0	0
109	Clear Cr nr Exchange	Greene	USGS	392827	0862210	0	0	1	0	0	0	0	0
110	Eel R. nr Worthington	Greene	USGS	390726	0865811	1	0	1	0	0	0	0	0
111	Fourmile Cr nr Ilene	Greene	USGS	385622	0870353	1	0	1	0	0	0	0	0
112	Fourmile ditch nr Lyons	Greene	USGS	385919	0870347	1	0	1	0	0	0	0	0
113	Trib. to Howesville ditch nr Jasonville	Greene	USGS	390826	0870837	2	2	2	2	2	2	2	2
114	Inlet to South Lake at Pleasantville	Greene	USGS	385745	0871522	8	8	7	8	8	8	8	8
115	Lattas Cr nr Linton	Greene	USGS	390632	0870745	1	0	1	0	0	0	0	0
116	Lattas Cr at Switz City (03360200)[2]	Greene	USGS	390211	0870040	1	0	1	0	0	0	0	0
117	Lattas Cr nr Switz City	Greene	USGS	390337	0870311	1	0	1	0	0	0	0	0
118	Lattas Cr nr Midland	Greene	USGS	390654	0870902	2	2	2	2	2	2	2	2
119	Lemon Cr nr Worthington	Greene	USGS	390814	0865936	1	0	1	0	0	0	0	0
120	Mud Cr nr Vicksburg	Greene	USGS	390631	0871211	3	3	3	3	0	3	0	3
121	Richland Cr nr Bloomfield (03360300)[2]	Greene	USGS	390138	0865425	1	1	1	1	1	1	1	1
122	Richland Cr nr Bloomfield	Greene	USGS	385950	0865605	1	1	1	1	0	0	0	0
123	Richland Cr nr Solsberry	Greene	USGS	390458	0865043	1	1	1	1	0	0	0	0
124	Do.	Greene	USGS	390330	0865129	1	1	1	1	0	0	0	0
125	Trib. to Richland Cr nr Solsberry	Greene	USGS	390345	0865107	1	1	1	1	0	0	0	0
126	Richland Cr nr Solsberry	Greene	USGS	390702	0864756	1	1	1	1	0	0	0	0
127	Sloan ditch nr US 231	Greene	USGS	385855	0870952	1	0	1	0	0	0	0	0
128	Spencer Cr nr Pleasantville	Greene	USGS	385846	0871404	3	2	3	3	2	2	2	2
129	Stotts Cr nr Exchange	Greene	USGS	392958	0861953	1	0	1	0	0	0	0	0
130	Timmons ditch nr Lyons	Greene	USGS	385854	0870313	1	0	1	0	0	0	0	0
131	White R. nr Bloomfield	Greene	ISBH	390139	0865800	325	0	254	334	0	0	0	0
132	White R. at Newberry (03360500)[2]	Greene	USGS	385541	0870108	1	0	1	0	0	0	0	0
133	White Rose Cr nr White Rose	Greene	USGS	390123	0871320	2	2	2	2	2	2	2	2
134	Trib. to White Rose Cr. nr Victoria	Greene	USGS	390236	0871427	2	2	2	2	2	2	2	2
135	Mill Cr nr Stilesville	Hendricks	ISBH	393836	0863906	74	82	83	33	83	0	48	0
136	W. Fk White Lick Cr nr Danville	Hendricks	USGS	394536	0863047	0	0	0	0	0	0	0	0
137	Ben's Cr nr Wheatland	Knox	USGS	384149	0871754	2	2	2	2	2	2	2	2
138	Black Cr nr Westphalia	Knox	USGS	385154	0871209	1	0	1	0	0	0	0	0
139	Deshee R. nr Decker	Knox	USGS	383641	0873103	2	2	2	2	2	2	2	2
140	Deshee R. at SR 61	Knox	USGS	383716	0872353	1	0	1	0	0	0	0	0
141	Ephemeral stream nr Ragsdale	Knox	USGS	384447	0871810	1	0	1	0	0	0	0	0
142	Ephemeral stream nr Bicknell	Knox	USGS	384455	0871805	1	0	1	0	0	0	0	0
143	Frick ditch 1 mi E. of Walnut Grove Church	Knox	USGS	383431	0871605	1	0	1	0	0	0	0	0
144	Indian Cr nr Johnstown	Knox	USGS	384530	0871819	3	2	3	2	2	2	2	2
145	Trib. to Indian Cr nr Blackwell	Knox	USGS	384528	0871722	3	2	3	2	2	2	2	2
146	Trib. to Indian Cr nr Ragsdale	Knox	USGS	384414	0871654	3	2	3	2	2	2	2	2
147	Kessinger ditch nr Petersburg	Knox	USGS	383413	0871635	2	2	2	2	2	2	2	2
148	Maria Cr nr Bruceville	Knox	USGS	384624	0872803	3	2	3	2	2	2	2	2
149	Miller ditch nr Edwardsport	Knox	USGS	384703	0871704	1	0	1	0	0	0	0	0
150	NE Drainage ditch at mine nr Bruceville	Knox	USGS	384400	0872500	1	1	1	0	1	0	0	0
151	Nimnicht Cr nr Wheatland	Knox	USGS	384000	0871647	3	2	3	2	2	2	2	2
152	Outlet of dam nr Bruceville	Knox	USGS	384421	0872523	56	56	56	52	56	0	52	0
153	Pollard ditch nr Westphalia	Knox	USGS	384959	0871406	1	0	1	0	0	0	0	0
154	Purdy Marsh ditch nr Edwards	Knox	USGS	384935	0871643	2	2	2	2	2	2	2	2
155	Purdy Marsh ditch nr Edwardsport	Knox	USGS	384723	0871626	1	0	1	0	0	0	0	0
156	Reel Cr nr Wheatland	Knox	USGS	383809	0871944	1	0	1	0	0	0	0	0
157	Scott Cr nr Bruceville	Knox	USGS	384242	0872721	1	0	1	0	0	0	0	0
158	Singer ditch nr Westphalia	Knox	USGS	385226	0871249	1	0	1	0	0	0	0	0
159	Singer ditch nr Black Cr	Knox	USGS	385023	0871256	1	0	1	0	0	0	0	0
160	Smalls Cr at US 41	Knox	USGS	384517	0872828	1	0	1	0	0	0	0	0
161	Smalls Cr nr Bruceville	Knox	USGS	384440	0872454	1	0	1	0	0	0	0	0
162	Do.	Knox	USGS	384434	0872540	1	0	1	0	0	0	0	0
163	Wabash R. nr Vincennes	Knox	USGS	384225	0873108	1	0	1	0	0	0	0	0
164	White R. nr Edwardsport	Knox	ISBH	384741	0871348	423	68	347	338	0	0	33	0
165	White R. at Petersburg (03374000)[2]	Knox	USGS	383041	0871717	1	0	1	0	0	0	0	0
166	E. Fk White R. nr Williams	Lawrence	ISBH	384747	0863953	93	68	86	1	45	0	34	0
167	E. Fk White R. nr Shoals	Martin	ISBH	384003	0864738	366	0	278	354	0	0	0	0
168	E. Fk White R. at Shoals (03373500)[2]	Martin	USGS	384002	0864733	1	0	1	0	0	0	0	0
169	Ephemeral stream at SR 45	Martin	USGS	383330	0865410	1	0	1	0	0	0	0	0
170	Slate Cr on Daviess-Martin County line	Martin	USGS	383102	0865528	1	0	1	0	0	0	0	0
171	White Lick Cr nr Mooresville	Morgan	USGS	393555	0862232	1	1	1	1	0	0	0	0
172	White Lick Cr nr Mooresville	Morgan	USGS	393628	0862256	0	0	0	0	0	0	0	0
173	Lost R. nr West Baden Springs (03373700)[2]	Orange	USGS	383510	0863803	1	1	1	1	0	12	0	1
174	Fleming Cr nr French Lick	Orange	COE	383244	0863700	0	0	15	1	15	15	0	0
175	French Lick Cr nr French Lick	Orange	USGS	383246	0863634	1	1	1	1	0	1	0	1
176	Lick Cr nr Paoli (03373600)[2]	Orange	USGS	383742	0862636	1	1	1	1	1	1	1	1
177	Lost R. nr Orleans (03373530)[2]	Orange	USGS	383745	0862345	2	2	1	2	0	2	0	2
178	Painter Cr nr Newton Stewart	Orange	COE	382531	0863900	0	0	16	0	15	15	3	3
179	Patoka R. nr Valeene	Orange	USGS	382559	0862709	1	1	1	1	0	0	0	0
180	Do.	Orange	USGS	382908	0862230	1	1	1	1	0	0	0	0
181	Patoka R. nr Newton Stewart	Orange	COE	382421	0863601	0	27	52	35	51	51	37	37
182	S. Fk Lost R nr Livonia	Orange	USGS	383629	0861918	1	1	1	1	0	1	0	1
183	Beech Cr nr Arney	Owen	USGS	391102	0865931	1	0	1	0	0	0	0	0
184	Doe Cr nr Cunot	Owen	COE	392820	0865029	0	0	20	3	20	20	5	5
185	Fish Cr nr Farmers	Owen	USGS	391036	0865401	1	0	1	0	0	0	0	0
186	Do.	Owen	USGS	391038	0865404	2	2	2	2	2	2	2	2
187	W. Fk Fish Cr nr Arney	Owen	USGS	391449	0865315	1	0	1	0	0	0	0	0
188	Hauser Cr nr Stockton	Owen	USGS	391425	0865946	1	0	1	0	0	0	0	0
189	Lenning Br nr Clay City	Owen	USGS	391524	0870243	2	2	2	2	2	2	2	2
190	Lick Cr nr Coal City	Owen	USGS	391204	0870013	1	0	1	0	0	0	0	0
191	Lick Cr nr Denmark	Owen	USGS	391611	0870109	1	0	1	0	0	0	0	0
192	Lick Cr nr New Hope	Owen	USGS	391102	0865946	1	0	1	0	0	0	0	0
193	Lick Cr nr Coal City	Owen	USGS	391425	0870049	1	0	1	0	0	0	0	0
194	Mill Cr nr Devore	Owen	ISBH	392640	0864620	74	81	81	33	79	0	48	0
195	Do.	Owen	COE	392605	0864546	0	23	62	31	65	65	40	41
196	Turkey Cr nr Coal City	Owen	USGS	391203	0870228	2	2	2	2	2	2	2	2
197	W. Fk Fish Cr nr Arney	Owen	USGS	391506	0865421	1	0	1	0	0	0	0	0
198	White R. nr Spencer	Owen	ISBH	391648	0864542	384	72	293	353	11	0	35	0
199	White R. at Spencer (03357000)[2]	Owen	USGS	391649	0864542	1	1	1	1	0	0	0	0
200	White R. nr Ramona	Owen	USGS	391933	0864335	1	1	1	1	0	0	0	0
201	N. Br Otter Cr nr Carbon	Parke	USGS	393652	0870625	2	2	2	2	2	2	2	2
202	Barren ditch at Authur	Pike	USGS	382116	0871412	0	0	1	0	0	0	0	0
203	Barren ditch nr Muren	Pike	USGS	382200	0871521	1	0	1	0	0	0	0	0
204	Beadens Cr nr SR 257	Pike	USGS	381902	0870756	1	0	1	0	0	0	0	0
205	Bone Cr at Flat Cr Road	Pike	USGS	382452	0870638	1	0	1	0	0	0	0	0
206	Bruster Br nr Winslow	Pike	USGS	382328	0871110	3	2	3	2	2	2	2	2
207	Conger Cr nr Union	Pike	USGS	382915	0872426	1	0	1	0	0	0	0	0
208	Conger Cr nr Petersburg	Pike	USGS	382915	0872313	1	0	1	0	0	0	0	0
209	Cup Cr nr Stendal	Pike	USGS	381609	0870707	1	0	1	0	0	0	0	0
210	Do.	Pike	USGS	381610	0870639	1	0	1	0	0	0	0	0
211	Cup Cr at SR 257	Pike	USGS	381859	0870715	1	0	1	0	0	0	0	0
212	Ephemeral stream at Sugar Road	Pike	USGS	382358	0871433	1	0	1	0	0	0	0	0

Appendix 2. Number of determinations of 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
213	Ephemeral stream nr Pike County State Forest	Pike	USGS	382239	0871641	1	0	1	0	0	0	0	0
214	Flat Cr at Cato	Pike	USGS	382656	0871100	1	0	1	0	0	0	0	0
215	Flat Cr nr Glezen	Pike	USGS	382409	0871803	1	0	1	0	0	0	0	0
216	Flat Cr nr White Sulphur Springs	Pike	USGS	382433	0870531	1	0	1	0	0	0	0	0
217	Flat Cr at Cato	Pike	USGS	382611	0870752	1	0	1	0	0	0	0	0
218	Do.	Pike	USGS	382558	0870830	1	0	1	0	0	0	0	0
219	Trib. to S. Fk Patoka R. nr Scottsburg	Pike	USGS	381814	0871320	3	2	3	2	2	2	2	2
220	Hardin Cr at SR 56	Pike	USGS	382903	0872552	1	0	1	0	0	0	0	0
221	Hat Cr nr Coe	Pike	USGS	381842	0871611	1	0	1	0	0	0	0	0
222	Hat Cr nr Oakland	Pike	USGS	381908	0871545	2	2	2	2	2	2	2	2
223	Hog Br at SR 364 nr Augusta	Pike	USGS	382121	0871000	1	0	1	0	0	0	0	0
224	Honey Cr nr Spurgeon	Pike	USGS	381510	0871552	1	0	1	0	0	0	0	0
225	Honey Cr nr Enos Corner	Pike	USGS	381722	0871556	1	0	1	0	0	0	0	0
226	Trib. to Houchin ditch nr Stendal	Pike	USGS	381632	0871029	3	3	3	3	3	3	3	3
227	Houchin ditch nr Scottsburg	Pike	USGS	381643	0871209	1	0	1	0	0	0	0	0
228	Lick Cr at Iron Bridge Road	Pike	USGS	382333	0870930	1	0	1	0	0	0	0	0
229	Mill Cr at SR 364	Pike	USGS	382120	0871050	1	0	1	0	0	0	0	0
230	Mud Cr nr SR 57	Pike	USGS	383138	0871310	1	0	1	0	0	0	0	0
231	Patoka R. at Velpen	Pike	USGS	381941	0870701	1	0	1	0	0	0	0	0
232	Patoka R. at Winslow	Pike	USGS	382248	0871301	1	0	1	0	0	0	0	0
233	Patoka R. nr Southern Railroad Bridge	Pike	USGS	382222	0870918	1	0	1	0	0	0	0	0
234	Prides Cr nr Petersburg	Pike	USGS	382755	0871658	1	0	1	0	0	0	0	0
235	Rock Coe nr SR 64	Pike	USGS	381858	0870509	1	0	1	0	0	0	0	0
236	Rough Cr nr Scottsburg	Pike	USGS	381708	0871432	3	2	3	2	2	2	2	2
237	Trib. to Flat Cr nr Glezen	Pike	USGS	382410	0871854	1	0	1	0	0	0	0	0
238	Trib. to Mud Cr nr Algiers	Pike	USGS	382911	0871142	1	0	1	0	0	0	0	0
239	S. Fk Patoka R. nr Stendal	Pike	USGS	381444	0871123	3	2	3	2	2	2	2	2
240	Trib. to S. Fk Patoka R. nr Oakland City	Pike	USGS	382028	0871722	2	2	2	2	2	2	2	2
241	S. Fk Patoka R. at Scottsburg Road	Pike	USGS	381713	0871309	1	0	1	0	0	0	0	0
242	S. Fk Patoka R. at SR 64	Pike	USGS	382032	0871847	1	0	1	0	0	0	0	0
243	Stone Coe Cr nr Winslow	Pike	USGS	382340	0871312	3	2	3	2	2	2	2	2
244	Sugar Cr at Sugar Ridge Road nr Littles	Pike	USGS	382357	0871638	1	0	1	0	0	0	0	0
245	Wheeler Cr nr Coe	Pike	USGS	381828	0871655	0	1	0	0	0	0	0	0
246	Wheeler Cr nr Enos	Pike	USGS	381740	0871715	2	2	2	3	2	2	2	2
247	White R. nr Petersburg	Pike	ISBH	383041	0871717	95	69	84	1	52	0	34	0
248	Big Walnut Cr nr Bainbridge	Putnam	USGS	394455	0864631	1	1	1	1	0	0	0	0
249	Big Walnut Cr at Greencastle (03357420)[2]	Putnam	USGS	394047	0864839	1	1	1	1	0	0	0	0
250	Big Walnut Cr nr Greencastle	Putnam	COE	394023	0865037	0	31	52	39	53	53	47	47
251	Big Walnut Cr nr Reelsville (03357500)[2]	Putnam	USGS	393211	0865835	1	1	1	1	0	0	0	0
252	Big Walnut Cr nr Reelsville	Putnam	USGS	393724	0865632	1	1	1	1	0	0	0	0
253	Little Walnut Cr nr Reelsville	Putnam	USGS	393730	0865630	1	1	1	1	0	0	0	0
254	Mill Cr nr Manhattan	Putnam	COE	392915	0865538	0	0	0	0	68	69	39	41
255	Mill Cr nr Manhattan (03359000)[2]	Putnam	USGS	392922	0865550	0	0	0	0	0	0	0	0
256	Buck Cr nr Sullivan	Sullivan	USGS	390314	0872355	4	4	6	4	0	4	0	4
257	Busseron Cr nr Carlisle	Sullivan	USGS	385826	0872533	1	1	1	2	1	1	1	1
258	Busseron Cr nr Sullivan	Sullivan	USGS	390433	0872311	2	2	2	2	2	2	2	2
259	Busseron Cr nr Hymera	Sullivan	USGS	391254	0871841	1	1	1	1	2	7	1	1
260	Buttermilk Cr nr Dugger	Sullivan	USGS	390413	0871749	2	2	2	2	2	2	2	2
261	Drainage ditch to trib. no 4 at Pleasantville	Sullivan	USGS	385728	0871610	4	3	4	4	3	3	3	3
262	Drainage ditch to trib. no 7 at Pleasantville	Sullivan	USGS	385728	0871549	1	1	1	1	1	1	1	1
263	E. Fk Cr nr Farmersburg	Sullivan	USGS	391242	0871651	1	1	0	1	0	1	0	1
264	Inlet to S. Lake at Pleasantville	Sullivan	USGS	385745	0871528	1	1	1	1	1	1	1	1
265	Kettle Cr nr Shelburn	Sullivan	USGS	390922	0872333	6	4	6	4	0	4	0	4
266	Kettle Cr at Shelburn	Sullivan	USGS	391033	0872307	5	4	6	4	0	4	0	4
267	Morrison Cr at Sullivan	Sullivan	USGS	390553	0872238	2	1	2	1	0	1	0	1
268	Morrison Cr nr Sullivan	Sullivan	USGS	390834	0872418	2	2	2	1	0	0	0	0
269	Mud Cr nr Dugger	Sullivan	USGS	390628	0871642	1	1	1	1	2	7	1	1
270	Pipe, head of drainage ditch, Pleasantville	Sullivan	USGS	385728	0871536	1	1	1	1	1	1	1	1
271	S. Lake outlet at Pleasantville	Sullivan	USGS	385800	0871537	9	8	9	8	8	8	8	8
272	Trib. to Spencer Cr at Pleasantville	Sullivan	USGS	385748	0871627	1	1	1	1	1	1	1	1
273	Do.	Sullivan	USGS	385758	0871640	4	4	4	4	4	4	4	4
274	Do.	Sullivan	USGS	385752	0871555	12	12	12	12	12	12	12	12
275	Do.	Sullivan	USGS	385802	0871554	33	33	33	33	32	33	32	33
276	Sulphur Cr nr Hymera	Sullivan	USGS	391136	0871555	2	2	2	2	2	2	2	2
277	Trib. no 1 to Spencer Cr trib. at Pleasantville	Sullivan	USGS	385801	0871536	4	3	4	3	3	3	3	3
278	Trib. no 2 to Spencer Cr trib at Pleasantville	Sullivan	USGS	385803	0871554	1	1	1	1	1	1	1	1
279	Trib. no 3 to Spencer Cr trib at Pleasantville	Sullivan	USGS	385752	0871554	4	4	4	4	4	4	4	4
280	Trib. no 7 to Spencer Cr trib at Pleasantville	Sullivan	USGS	385727	0871547	1	1	1	1	1	1	1	1
281	W. Fk Busseron Cr nr Shelburn	Sullivan	USGS	391331	0872133	1	1	1	1	0	1	0	1
282	W. Fk Busseron Cr nr Hymera	Sullivan	USGS	391110	0871944	2	2	2	2	2	2	2	2
283	Trib. to W. Fk Busseron Cr nr Hymera	Sullivan	USGS	391256	0872036	2	2	2	2	2	2	2	2
284	Wildcat Cr nr Lafayette	Tippecanoe	USGS	392627	0864945	0	0	0	0	0	0	0	0
285	Honey Cr trib. nr Riley	Vigo	USGS	392538	0871527	2	2	2	2	2	2	2	2
286	Honey Cr nr Staunton	Vigo	USGS	392632	0871509	9	9	9	9	9	9	7	9
287	Lost Cr nr Seelyville	Vigo	USGS	392840	0871525	1	1	1	1	1	1	0	1
288	N. Br Honey Cr nr Staunton	Vigo	USGS	392711	0871531	10	10	10	10	10	10	8	10
289	Splunge Cr nr Blackhawk	Vigo	USGS	391908	0871637	2	2	2	2	2	2	2	2
290	Stone Quarry Br nr Staunton	Vigo	USGS	392450	0871531	11	11	11	11	11	11	9	11
291	Carters Cr nr Orleans	Washington	USGS	383822	0862118	1	1	1	1	0	1	0	1
292	French Lick Cr below reservoir	Washington	USGS	382902	0863416	1	1	1	1	0	1	0	1
293	Lick Cr nr Paoli	Washington	USGS	383326	0862939	1	1	1	1	0	1	0	1
294	Lick Cr nr Spring Mill	Washington	USGS	383048	0862539	1	1	1	1	0	1	0	1
295	Lick Cr trib below Half Moon Spring	Washington	USGS	383129	0862511	1	1	1	1	0	1	0	1
296	Lost River at Claysville	Washington	USGS	383720	0861720	1	1	1	1	0	1	0	1
297	Lost River at Orangeville Rise	Washington	USGS	383752	0863326	2	1	2	1	0	1	0	1
298	Lost River nr Orangeville	Washington	USGS	383628	0863512	2	1	2	1	0	1	0	1
299	Stampers Cr at Pumpkin Center	Washington	USGS	383518	0862153	2	1	1	1	0	1	0	1
300	Sulphur Cr Spring nr West Baden	Washington	USGS	383811	0863809	1	1	1	1	0	1	0	1
301	Twin Cr nr Salem	Washington	USGS	384142	0861314	1	1	1	1	1	1	1	1
302	Do.	Washington	USGS	384443	0861535	1	1	1	1	1	1	1	1
303	White Lick Cr nr Avon	Washington	USGS	394549	0862503	1	0	1	0	0	0	0	0

[1]Station location outside of Area 32 but data was used in analyses.
[2]For surface-water flow stations see Table 2.1.

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